White Paper

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Need for and Benefits of a Modern Spatial Reference Network in Southern New Mexico

Overview:

Economic development in Southern New Mexico (and regions beyond) involves many disciplines and sectors of the economy. Factors common to those efforts include the use of spatial data and the need for reliable maps. Such disciplines/sectors include:

1. Emergency services/dispatch.
2. Planning
3. Administration
4. Engineering
5. Research
6. Surveying & Mapping
7. GIS information managment
8. Construction (Spaceport etc)
9. Fleet management
10. Agriculture
11. NM Board of Licensure for Professional Engineers and Professional Surveyors

A geographic information system (GIS) is a tool used by many to store, organize, and use spatial data for many purposes. Good information management procedures are essential.

Technology has evolved to the point where spatial data are digital and three-dimensional (3-D). That makes a big difference in the way spatial data are now collected, stored, manipulated, and used. Today's user enjoys many options beyond the 2-D flat map.

Using global positioning system (GPS) units and other technology, anyone can know where they are, where they've been, or how to get to where they want to go. GPS units are economical to buy and fascinating to use – even for the novice. GPS is a 3-D tool.

Spatial data accuracy is an issue deserving careful consideration. The value and usefulness of spatial data is directly related to its quality and permanence. Data compatibility (formats and/or coordinate systems) is also an issue.

The goal is for an individual user (with the appropriate equipment) to be able to determine location quickly to an appropriate level of accuracy and for that position to be compatible with information stored/shared/used by others.

Sidebar point – there are separate GIS databases (city/county/state/national/private etc) but underlying data sharing (interoperability) between GIS's is critical to beneficial use.

Not everyone needs or uses the same accuracy (quality) of spatial data. Technology and equipment are available for a wide range of options for collecting and using spatial data. Options range from the simple hand-held GPS unit available at Wal-Mart for ~$100 to an elaborate permanent GPS installation (continuously operating reference station – CORS) that collects, processes, and distributes signals 24/7 but costs tens of thousands of dollars.

An underlying nationwide coordinate network of precisely surveyed points is called the National Spatial Reference System (NSRS) and is established/maintained by the National Geodetic Survey (NGS) in cooperation with state and local users. The NSRS is based on the North American Datum of 1983 (NAD83) horizontal datum and on the North American Vertical Datum of 1988 (NAVD88). The NSRS can also be directly related to the worldwide systems used by the U.S. military and the scientific community; the World Geodetic System of 1984 (WGS84) and the International Terrestrial Reference Frame (ITRF) respectively.

The NSRS (latitude/longitude/height) is made available to local users by:

1. Default in the GPS signal (automatically). Approximate locations are obtained easily, recorded, and/or shown on the display of the GPS unit.
2. Using published coordinate values on permanently monumented points throughout the area. A user goes to a station and collects data referenced to that point. Precise surveys utilize this mode extensively. Cost is a factor.
3. Collecting and using data from a continuously operating reference station (CORS). Various options serve a range of user modes/accuracy requirements.

Purpose

The purpose of this white paper is to promote discussion of options so local users can help develop a shared vision. Compatibility is an important issue – especially at the local level. Various options regarding equipment and implementation need to be considered within a common spatial framework and data management structure. With that goal in mind, various users should be invited to describe how they might contribute to an overall effort and how they can realize benefits of working with a comprehensive shared system that might not be affordable for a single user.

Recommendations

Authors of this white paper recommend that:

1. **Input be solicited from potential participants as to how they could contribute to and benefit from development of a comprehensive spatial reference database for Southern New Mexico (recognizing that the interest could go state-wide).**

2. **A series of timely meetings be conducted for purpose of discussing:**
   - **A. Desirable features of a comprehensive spatial database.**
   - **B. State of technology and what is possible.**
   - **C. Examples of efforts by others.**
   - **D. Possible resources that might be available.**
   - **E. What it is that will be most beneficial to the users.**

Appendix – Expanded Discussion of Various Points

Users/Participants

1. **Emergency services and coordinated dispatch:**
    - A. Police–state, county, and city all need to be on same location system.
    - B. Fire–addresses used primarily, but spatial location needed in outlying areas.
    - C. Search & Rescue – knowing the location of persons in distress is critical.

2. **Planning:**
    - A. Demographics of where people live.
    - B. Knowledge of resource location and inventory.
    - C. Information about where people work and how they get there.
    - D. Transportation studies regarding location/movement of goods/services.
    - E. Economic analysis regarding business location/development.
    - F. Development of the Spaceport.
    - G. Homeland security/Borderland issues – development and Ports of Entry.

3. **Administration:**
    - A. Tax mapping
    - B. Zoning
    - C. Building permits
    - D. Fleet management

4. **Engineering:**
    - A. Spaceport:
        1. Planning documents and site plan
        2. Construction layout and as-built records
        3. Spatial information management and coordination
        4. Quality control regarding standards and specifications
    - B. Transportation - highway/rail/air
        1. Location of infrastructure and compatibility of databases.
        2. Importance of data quality and reference monuments.
        3. Construction including both conventional and machine automation.
    - C. Irrigation, flood plane mapping, and management of resources.
        1. Location and operation of irrigation structures
        2. Easements and assessments
        3. Identification of flood hazard areas
    - D. Water/sewerage (environmental quality)
        1. Location and operation of wells.
        2. Monitoring of ground water levels at specified locations.
        3. Location and operation of water treatment facilities.
        4. Collection and transportation of liquid waste.
        5. Monitoring of water quality – location of samples etc.
    - E. Electric utilities:
        1. Location and inventory of equipment/facilities.
            - A. Overhead – including easements.
            - B. Substation – access, security,

        C. Underground – knowledge of location (avoid digging accidents).
    2. Identifying, predicting, and fulfilling loads by time and place.

F. Development, permitting, & location of infrastructure in livable communities:
    1. Residential – subdivisions
    2. Multi-family - complexes
    3. Commercial/retail
    4. Zoning

5. **Agriculture – Precision farming**
    A. Irrigation
    B. Seed/fertilizer applications
    C. Harvest automation
    D. Records and Inventory

6. **Research**
    A. Universities
    B. National Labs
    C. Military
    D. Agencies
    E. Other

7. **Board of Licensure for Professional Engineers and Professional Surveyors is:**
    A. Charged with protecting the health, safety and welfare of the public with regard to engineering and surveying services performed in New Mexico.
    B. In the process of developing Minimum Standards for spatial data used in surveying practice including, but not limited to:
        1. Topographic surveying.
        2. Boundary/Right-of-Way/Easement surveying.
        3. Spatial data accuracy standards for geodetic surveys.

Evolution of the Geographic Information System (GIS)

In years past, spatial data were considered in terms of maps (2-dimensional). With the digital revolution of the past 50 years, spatial data are now characterized as digital and three-dimensional (3-D). Previously surveyors and engineers were the professionals who generated, maintained, and used maps for a wide variety of applications. Now, with the advent of GPS, computers, wireless communication, and other technology, many persons (as noted previously) need, use, and rely on digital spatial data. Yes, maps and records are still of critical importance but, increasingly, any user can generate a map upon demand from data stored in a GIS database.

With regard to efficient use of data in a GIS, the following issues need to be addressed:

1. Who designs, builds, and physically maintains the GIS:
    A. Organizational/administrative structure.
    B. Is it centralized or distributed? Advantages of each? Should it be both?
    C. Hardware and facilities that house the data.
    D. Software and operational integrity of the system.

2. Various users need to communicate in a common spatial data language – i.e. coordinate system. If designed properly the underlying database will support interoperability while simultaneously permitting users in various areas to continue using existing/traditional systems.

   Note: It is easy to use 2-D or 1-D data as a sub-set of 3-D data but building a 3-D database from 2-D & 1-D data requires careful modeling to preserve geometrical integrity. See for example, http://www.globalcogo.com/setepaper.pdf.

3. The quality of spatial data in a GIS is critical and supervision of that quality is essential. In the interest of protecting the welfare of the public, the New Mexico Board of Licensure for Professional Engineers and Professional Surveyors is in the process of developing Minimum Standards for various categories of surveys and spatial data. Not all categories of spatial data or spatial data uses from a GIS database need to be or will be covered by the Minimum Standards.

   Ensuring the quality of spatial data in a GIS includes policy and procedures for:
   A. Monitoring, identifying, and verifying the quality of spatial data put into the database.
   B. Using data from the database. The danger to be avoided is using approximate data (locations) for applications in which greater accuracy is required.

4. Continuing education and training with regard to how spatial data are developed and used at all levels. An investment in human capital can pay enormous dividends in benefits as various persons learn more about using spatial data tools and develop pride in serving the community using those tools.

Development of Technology

In years past, maps were generated by field survey measurements, later by photogrammetric mapping from aerial photographs, and more recently by addition of various technologies including GPS positioning, LIDAR and terrestrial scanning, and other remote sensing (including space based) measuring systems. The argument is made that users are drowning in spatial data and that the challenge is to identify, find, and use those data needed to support the application at hand. Often the quality of spatial data is an important factor in determining which data are appropriate for a given need.

The global positioning system (GPS) is the technology that makes it possible to determine the location/position of a point or object anywhere, anytime, by anyone. It is possible to determine the position of a point within millimeters using GPS if appropriate equipment and procedures are utilized. Such operations are somewhat costly in terms of equipment, procedures and computations. That means the spatial reference system implemented in Southern New Mexico (or statewide) needs to accommodate the integrity of precise data and/or points as well as supporting the storage, manipulation, and use of data that are not so precise.

Various options and levels of implementation

At the low end of the accuracy spectrum, anyone can purchase an inexpensive GPS unit at Wal-Mart (~$100), turn it on, collect signals from orbiting satellites, and read the latitude/longitude/height position from the display to an accuracy of 10-20 feet. Knowing your position within 20 feet anywhere in the world with respect to the Equator and to the Greenwich Meridian in England is incredibly impressive. But, if you are looking for a fire hydrant buried under a snow bank (bad example for Southern New Mexico) or looking for your property corner so you can tell your neighbor to move his fence, a tolerance of 20 feet isn't so impressive.

At the high end of the spectrum, it is possible to position points very accurately with GPS. For example there is an A-order GPS station named "Reilly" in the middle of the NMSU Horseshoe. You can walk right to it (southeast of the flagpole) and find the brass tablet grouted into the top of a concrete vault that extends 8 feet or more into the ground – the point appears to be very stable. There is a small hole in the middle of the tablet which marks the surveyed location. When collecting the GPS data used to compute that A-order position, the observers were careful to note that the height measurement of the GPS antenna was made to the bottom of the little hole, not to the surface of the brass tablet – a difference of about 1 mm.

Question: Why would anyone in their right mind be so picky? Answer: Because it can make a difference. The accuracy of an A-order station is quoted with 95% confidence as being within 1 part in 10,000,000 with respect to adjacent A-order stations. The nearest A-order station is "Crucesair" located at the Las Cruces International Airport – some 16,000 meters away. Let's see, 1/10,000,000 over a distance of 16,000 m gives a tolerance of 0.0016 meters or 1.6 mm. At the risk of mixing apples and oranges with regard to horizontal and vertical criteria, ignoring the 1 mm depth of the hole in the mark would have consumed more than half of the error budget for the computed position.

Station "Reilly" is part of the High Accuracy Reference Network (HARN) observed in 1999. The HARN evolved from the regional High Precision Geodetic Network (HPGN) and consists of permanently monuments points with one of two classifications – FBN or CBN. The Federal Base Network (FBN) is quite sparse and consist of only a few stations observed and maintained by the federal government. The Cooperative Base Network (CBN) consists of many more stations established and maintained by state/local/private organizations. The data collected at the CBN stations are submitted to the NGS for evaluation. Given that the data collected at a CBN pass the rigorous quality control procedure known as "blue-booking," the coordinates for the point are published as part of the NSRS. Station "Reilly" is a CBN station and Station "Crucesair" is a FBN station. Actually, the difference between a CBN and a FBN is more bureaucratic than technical as CBN's and FBN's of the same accuracy classification can be intermixed in a project.

As incredibly accurate as the HARN stations are, the modern day Continuously Operating Reference Stations (CORS) network is even better. With implementation of the national CORS program administered by the National Geodetic Survey (NGS), those "master" stations form a network that is even more precise than the HARN's. A further advantage of the national CORS is that GPS receivers occupy those stations continuously and the CORS data are made available to the user community. That makes a huge difference in the level of investment needed in the user community (both public and private) for getting access to the data, using the network, and in getting the job done.

GPS receivers collect data continuously at each national CORS station and forward the data to a central repository from whence it is available via the internet (and other modes) to the user community free of charge. The computed/published position of the CORS is related to the global network of GPS points and may be extremely accurate – the accuracy of a CORS is typically within centimeters with respect to the center of mass of the Earth and more precise than that with respect to other CORS stations.

Alternatively, a CORS is established locally and the GPS carrier phase signals are broadcast to local users in support of real-time kinematic (RTK) surveying activities. Generally, such base-station equipment is very similar (if not identical) to the equipment used in the National CORS program.

Here too, there is a range of options available to the user community. Some base stations collect code phase data and/or broadcast differential corrections for "approximate" positioning (example – NMSU base station operated by CAGE Dept). Other base stations collect carrier phase data used in precise positioning and/or broadcast the raw signal to other carrier phase instruments operating within radio range (example – City of Las Cruces base station). The two categories are not exclusive as a single installation can be set up to support both real-time and post-processing applications. Examples include:

1. Statewide CORS networks that are designed, built, and operated in a compatible and seamless mode with the federal programs. Two such examples include:

    A. The State of Ohio – See an article in the December 2004 issue of Professional Surveyor, "RTK Blankets the Buckeye State" which describes a program whereby the Ohio DOT established a network of 52 virtual reference stations (VRS) throughout the state. Bill Clifford, PS, surveying manager for Kokosing Construction Company says, "We now use VRS technology like our regular GPS except we don't have to set up a base station and repeaters. VRS technology is a huge cost savings for us.

    B. The State of Michigan – See a series of two articles in the March and April 2005 issues of Professional Surveyor which describes The Michigan Spatial Reference Network – Setting the Standard for Reference Station Networks Worldwide. Martin Dunn, PS, states in the introductory paragraph, "The Michigan Spatial Reference Network has saved the Department thousands of man hours and has greatly improved the accuracy of the geodetic surveys performed in the state. In September 2004 the Michigan Spatial Reference Network became the first provider of statewide RTK corrections via the wireless Web. Any surveyor with suitable connection and GPS receiver can now gain access to the network and obtain RTK corrections without setting up a local base station. ….Any surveyor or public sector agency with the right equipment and software can obtain precise position coordinates simply by logging on to the wireless network."

2. Community Base Stations have been utilized for 10-15 years and consist of permanently mounted GPS receivers/antennas which collect signals continuously. Two modes of operation include:

    A. The data are recorded and archived on site. The archived files are available for users to access and download. The NMSU civil engineering department hosts a base station that collects and archives **code phase data** used for making differential corrections by users who download those data.

B. The base station receives **carrier phase data** that are re-broadcast in real time to local users in the RTK mode. Although it works well in the immediate area, the range is somewhat limited and “repeater” instruments are needed to provide full coverage over a larger area. The City of Las Cruces operates such a continuously operating base station. Other users in the Las Cruces area are able to tune in to the frequencies broadcast by the city in support of RTK surveying operations.

3. Individual entities routinely use GPS base stations and rover units on a project-specific basis. Set up temporarily ‘as-needed’ (not operating continuously), the base station collects GPS signals, records the data for use in static processing, and broadcasts the data in real-time to rover units operating in a given area. The advantage is that anyone with the equipment can perform GPS and RTK GPS surveys anywhere any time. The disadvantages are:

    A. The security of the base station is an issue – often requiring a person just to stay with the base station to prevent theft or vandalism.

    B. Two GPS units are needed to collect data for a single vector or to run RTK surveys.

    The driving argument for a community (state) supported reference network is that, once operational, only one person using a single receiver can conduct productive GPS surveys, either in the static mode or in the RTK mode. An added bonus is the common reference system and spatial data manipulation procedures available to all spatial data users.

GPS Equipment/Accuracy Options from the User Perspective

The following is a summary of equipment/procedure/accuracy options available to spatial data users.

1. Use an inexpensive GPS unit to find or go to a location quickly within 10-20 feet.
2. Use more expensive equipment (differential GPS) to get within 5-10 feet.
3. Use more elaborate (post-processing) techniques to get within 2-5 feet.
4. Use kinematic GPS equipment (more expensive) to get within 0.5 feet to 2 feet.
5. Use carefully designed system and measurement procedures (RTK GPS surveying) to determine a location in the field within minutes within 0.1 to 0.5 feet.
6. Observe data at a point (monument) for several hours using dual frequency GPS equipment and process that data using the On-line Positioning User Service (OPUS) from the National Geodetic Survey (NGS) to determine the world-wide position of a point within centimeters (.05 to 0.20 feet).
7. Somewhat more expensive but very valuable if the point being surveyed is permanently monumented. That means the position observed/computed position can be used by others: Carrier phase GPS equipment is used to position a point within millimeters (0.01 to 0.05 feet).
8. Points established using vitural GPS networks (still evolving?) can be more accurate than #5 above and less expensive than #7 above. VRS utilizes state-of-the-art technology and CORS data delivered via the internet and/or cell telephones to the receiver in the field.
9. Ultimate – establish a continuously operating reference station (CORS) that collects signals from satellites that are used to determine the location very precisely. From a local user perspective, these points are held “fixed.”

The organizational structure of responsibility/accountability for the GIS database needs to be developed, recognized, and supported by users at all levels**.**

Height Modernization - NGS

"Height Modernization" is a program developed by the National Geodetic Survey (NGS) in cooperation with local (state level) spatial data users in which the expertise of the NGS can be brought to numerous end users outside the normal budget of NGS. Local users develop ideas and support for a plan to implement use of new (GPS) technology in support of local applications with a focus on providing accurate height data. Local users work with NGS professionals (New Mexico already has a Geodetic Advisor on location in Albuquerque) to develop grant proposals that are submitted to and funded as part of the normal congressional budgeting and resource allocation process. The program was started about 8 years ago in one or two states and is currently operating very successfully in 10 different states. The home page for the Height Modernization program is:

www.ngs.noaa.gov/heightmod/

Earl F. Burkholder, PS, PE, teaches in the NMSU Department of Surveying Engineering and is on sabbatical leave during 2005-2006 for the purpose of writing a book titled "The 3-D Global Spatial Data Model." As part of his sabbatical activities, he attended the Fall Convocation of the NGS in Silver Spring, Maryland and learned details about the Height Modernization program – both from professionals within the NGS and from state partners working with the NGS. Since then, he has also learned that there is a lot of interest in developing a Height Modernization Plan for New Mexico.

Such an effort is long-range in nature, but could be very beneficial to Southern New Mexico (and the entire State) with regard to establishing a comprehensive 3-D Spatial Data Reference System in support of local economic development activities.

Dream for New Mexico

Spatial data users throughout Southern New Mexico will work together to develop a comprehensive 3-D Spatial Data Reference System under auspices of the National Geodetic Survey via a Height Modernization program. Potential users include, but are not limited to:

Federal/military
State agencies
Counties/municipalities
Private sector – various professions
Education

What will it take?

The following steps/activities are recommended for the purpose of developing a Height Modernization plan for Southern New Mexico:

Identification of a Vision
Development of Support
Convening a “Height Modernization Forum”
(to be presented by program professionals from the National Geodetic Survey)
Writing grants
Securing funding
Operational organization
Education and training
Realization of benefits

A series of timely meetings should be conducted for purpose of discussing:

A. Desirable features of a comprehensive spatial database:
   1. Organizationally
   2. Politically
   3. Technically
B. State of technology and what is possible:
   1. GPS and measurement technology.
   2. Hardware/software for handling spatial data.
   3. Information management and administration.
C. Examples of efforts by others:
   1. Ohio and Michigan DOT’s
   2. NGS and Southern California GPS network
   3. Other
D. Possible resources that might be available from:
   1. Local participants.
   2. State agencies
   3. Federal agencies:
      a. Civilian
      b. Military
   4. Existing programs – Height Modernization (NGS)
   5. Private sector
E. What it is that will be of most benefit to all users.
   1. Administratively/organizationally
   2. Economically
   3. Technically