G.P.S. APPLICATIONS IN SUPPORT OF THE GEORGIA ENVIRONMENTAL PROTECTION DIVISION'S DRINKING WATER PROGRAM

Lewis F. Rogers[1], Christopher J. Semerjian[2] and Donald A. Vick[3]

AUTHORS: [1]Chairman, Division of Natural Sciences, Professor of Geology; [2]Research Associate; and [3]Research Assistant, Gainesville College, Gainesville, Georgia 30503.

REFERENCE: Proceedings of the 1995 Georgia Water Resources Conference, held April 11 and 12, 1995, at The University of Georgia, Kathryn J. Hatcher, Editor, Carl Vinson Institute of Government, The University of Georgia, Athens, Georgia.

Abstract. Resource grade GPS receivers are being used to determine the positional indices for wells and associated potential pollution sources for public wells in Georgia. This study was conducted to evaluate the accuracy and precision of the applied technology and techniques. Sixty differentially-corrected GPS positions were calculated at a 1st order monument located 257 miles from the GPS Base Station. The horizontal mean radial error for these tests was 7.8 ft. The RMSE was 9.6 ft. and 98% of all calculated positions fell within 19.2 ft. of the true positions. Elevation errors were about 1.5 times greater than those for horizontal positions. These tests were conducted under ideal conditions. Traditional surveying is used to determine bearing and distances between wells and associated potential pollution sources. A bearing/distance is then shot to a GPS location that is clear of obstruction. The Geographic Calculator is then used to translate distances and bearing from station to station for positional indices. This technique maximizes the accuracy of both horizontal and vertical positional data.

INTRODUCTION

The Georgia Environmental Protection Division's (EPD's) Drinking Water Program has contracted with Gainesville College to update its water source locational data base. The Drinking Water Program's current locational data base consists of positional indices generated from LORAN technology and maps supplied by well owners. The data base update is being conducted using Global Positioning System (GPS) technology. Locational indices are collected for system wells and for the obvious potential pollution sources near each groundwater source.

GPS technology promises to be the most important remote sensing tool for resource management since the aerial photograph (Gerlach, 1992). The GPS has the potential to revolutionize the practice of surveying and to make techniques available to surveyors and professionals from related disciplines that were only available to the best trained and best equipped among us just a few years ago (Leick, 1990). Under ideal conditions, inexpensive, resource grade GPS receivers can provide accurate and reliable position and elevation information. However, in spite of the accolades mentioned above, GPS data collection procedures at this time are not yet turnkey in ease and simplicity (August et al., 1994). In order to achieve accurate GPS position fixes, several errors inherent in GPS technology must be corrected. The United States Department of Defense introduces error, referred to as Selective Availability (SA), into the Standard Positioning Service (SPS) GPS signals to degrade fix accuracy. Other position errors include clock and ephemeris errors which originate with the GPS satellites as well as atmospheric and tropospheric delay errors. The errors mentioned above are all correctable with differential GPS techniques. Other errors, not correctable with GPS differential techniques, include receiver noise and reflection of satellite signals (multipath error). Multipath errors can be reduced with specially designed antennas. Given optimal conditions, GPS can furnish precise and accurate horizontal and vertical position data. Field studies show, however, that users of GPS receivers must be keenly aware of extraneous sources of error that reduce positional accuracy. (August et al., 1994).

The GPS equipment and techniques selected and the precision and accuracy desired for a project such as the one supporting the EPD Drinking Water Program are predicated by the end use of the positional data. The positional indices derived for this project are to be entered into a Geographical Information System (GIS) data base. Bolstad et al., (1992) reported RMSE ranges for spatial data sources based on reports of best "commercial" practice. Data sources pertinent to this study include: traditional survey (0.1-2 ft.), Code-based GPS differential (5-15 ft.), 1:24000 maps before digitization (10-35 ft.), maps manually digitized from 1:24000 maps (20-55 ft.), and maps from digital line graph data (20 ft.). Factory specifications for the Magellan ProMark V GPS receiver used in this project indicate a horizontal accuracy of 3 meters (9.8 ft.) when using Magellan Post-Processing software to calculate a differential position (MSC, 1994). This predicted GPS accuracy is obviously sufficient for the GIS requirements described above. The Magellan Operations Manual (MSC, 1994) recommends that the distance between the remote or field receiver and the base station should not exceed 50 kilometers (31 miles). Well systems included in this study are located throughout the state and movement of the base station in order to stay within 50 kilometers of the field studies is impractical. MSC (1994) reported that some have had success with separations as great as 1000 kilometers (621 miles). Jasumback (1992) tested the Trimble Pathfinder at a remote location 607 kilometers (377 miles) away from the base station and obtained differentially corrected GPS positions with an average horizontal error of 5.6 meters (18.37 ft.). Therefore, the purpose of this study was to evaluate the accuracy and precision of the Magellan ProMark V with separations between the remote and base receivers exceeding the recommended 50 kilometer limit.

METHODS

Hardware and Software

Magellan ProMark V receivers and a Magellan MBS-1, 12-channel base station, located on the Gainesville College campus, are presently being utilized in the project. A Magellan MR Antenna (Model 39009) is used on both remote and control receivers. Data logging for the base station as well as post processing is conducted with a Digital DEC pc LPx 466d2 microcomputer. Magellan CDU software is used for base station data logging and RINEX conversion. Magellan post processing software (version 3.02) is used for pseudo-range differential post processing of field data.

Well systems included in the project are located in a variety of terrains from the mountains to coastal areas. Some have been near or under heavy canopies. From ten to twenty position fixes are required for each well system since many systems include several wells and all systems have multiple potential pollution sources. In order to maximize accuracy and efficiency, a combination of GPS and traditional survey methodology is being used. GPS receivers are operated in areas with minimal obstruction. Distance and bearing from the GPS sites to wells and pollution sources are then determined and translated to position fixes by "waypoint projection". Magnetic bearings derived from the survey are converted to true bearings with current magnetic declination data acquired from the USGS Branch of Global Seismology and Geomagnetism On-line Information System through TELNET. Positional fixes are calculated with distance/bearing data from the GPS position with "The Geographic Calculator" (BMG, 1994).

Data Collection

All data for this test was collected when predicted PDOP values were 4.0 and below. The remote receiver was located at a Department of Transportation 2nd order monument (BV 063 20) at the Jekyll Island Airport near Brunswick, Georgia. The base line distance from the remote site to the Gainesville, Georgia base station was 257 miles. The Gainesville Base Station antenna was surveyed by Rochester and Associates with GPS technology an is 1st order. The exterior antenna was mounted on a range pole/bipod 2.5 meters directly above the monument. The selected mask angles were 0 and 15 degrees respectively for the control and remote receivers. The data sample rate selected was one fix per second for both receivers. All GPS measurements were based on the WGS-84 reference system. Positional data was collected uniformly on two dates, 10/15/94 and 11/4/94. On each day the data was collected in three sample sets each defined by different collection time durations - three, four, and five minutes. Each sample set included 10 GPS sessions for a total of 60 sessions.

DATA ANALYSIS

According to Bolstadt et al., (1992) an individual point may be considered a population with both vertical and horizontal error distributions. If the vertical error (the difference between the "true" and GPS derived elevation) is assumed to follow a random normal distribution, the mean and variance of the distribution characterizes the population of vertical point errors. The vertical root mean-square

$$RMSE_v = [e_r^2/n]^{1/2}$$

where e_r is the residual error for each measured point (the difference between the "true" and derived elevation). Horizontal error may similarly be modeled statistically. However, more distributions and approaches have been proposed because horizontal error may be considered either univariate or bivariate. The horizontal root mean-square error

$$RMSE_h = [(e_x^2 + e_y^2)/n]^{1/2}$$

where e_x is the error in the x direction (longitude) and e_y is the error in the y direction (latitude). The longitude and latitude of all positional fixes were converted to the U.S. State Plane System using the "Geographic Calculator". This conversion allowed easy calculation of the horizontal error for the positional measurements made in this study.

August et al., (1994) defined precision as the variation among repeated measurements of accuracy. Precision is reported as the standard deviation of the mean distance from true. Precision is also reflected in percentile summary statistics. The 50th percentile is the distance from true that includes 50% of all of the fixes in a sample. This is known as the circular error of probability (CEP). Assuming a circular normal distribution, about 63% of all fixes will fall in a circular radius equal to the RMSE and 98% will fall in a circle with a radius of 2RMSE (MSC, 1994).

RESULTS AND DISCUSSION

A summary of the GPS data collected is shown in Tables 1 and 2. Table 1 and 2 contain horizontal and elevation data respectively. Both tables show the cumulative data for the 3, 4, and 5 minute sample sets for each day, cumulative data for

Table 1. Statistical Summary for Differentially Corrected GPS Data - Horizontal Error (feet)

	3	4	5	Daily	3	4	5	Daily	
98th Percentile	16.7	14.8	11.7	14.6	24.4	26.4	19.8	23.6	19.2

PDOP-Position Dilution of Precision, RMSE-Root Mean Square Error, CEP-Circular Error Probable.

Table 2. Statistical Summary for Differentially Corrected GPS Data - Elevation Error (feet)

	3	4	5	Daily	3	4	5	Daily	
98th Percentile	36.4	31.8	28.2	32.4	15.0	32.6	22.0	23.8	28.0

PDOP-Position Dilution of Precision, RMSE-Root Mean Square Error, CEP-Circular Error Probable

each day, and a summary inclusive of both days. The mean Position Dilution of Precision (PDOP) for all collection sessions was from 2.7 to 3.0. The average number of fixes replicated during differential post processing is shown for each session. It should be noted that when collecting data during a timed session, ideally a single fix is taken each second and replicated with base station data during differential post processing. In reality there is a delay incurred while the remote receiver acquires lock on four satellites and the number of replicated fixes will fall short of the theoretical value.

Horizontal Data

The mean radial horizontal error for the first collection day ranged from 4.7 to 6.6 ft. with a mean of 6.0 for the 30 GPS positions calculated that day. The horizontal RMSE for the first day was 7.3 ft. with 98% of all fixes falling within a radius of 14.6 ft. of the true remote position. The mean radial horizontal error for the second day was 9.9 ft., the RMSE was 11.8 ft., and 98% of the calculated positions fell within 23.6 ft. of the true position. Cumulative statistics for both days show a mean radial horizontal error of 7.8 ft., an RMSE of 9.6 ft., and 98% of all calculated positions fell within 19.2 ft. of the true position.

Elevation Data

Statistics for vertical errors show a mean radial error of 13.3 and 8.6 ft., an RMSE of 16.2 and 11.9 ft., and 98% of the calculated position fell within a radius of 32.4 and 23.8 ft. for the first and second days respectively. Cumulative values for both days shared a 10.9 ft. mean radial error, an RMSE of 14.0 ft., and 98% of the calculated positions fell within 28.0 ft. of the true position.

CONCLUSIONS

The results of this study indicate that accurate and precise horizontal GPS locations can be calculated for medium scale maps of 1:24000 resolution. However, there are two potential problems. The elevation error which is about 1.5 times the horizontal error is inadequate for addressing the up/down gradient aspects of wells and associated pollution sources. In addition, the results obtained in this study were accomplished under ideal conditions with little to no obstruction to satellite reception. Both problems are overcome to a great extent by using traditional surveying techniques to network the wells and associated potential pollution sources. A bearing and distance can then be shot to a relatively clear GPS position. A bearing and distance can accurately be converted to longitude and latitude using the technology discussed earlier in this paper. Traditional surveying also provides an accurate and precise method for elevation determinations.

LITERATURE CITED

August, Peter, J. M. Michaud, C. Labash, and C. Smith, 1994. GPS for Environmental Applications: Accuracy and Precision of Locational Data, *Photogrammetric Engineering and Remote Sensing*, Vol. 60, No. 1, pp. 41 - 45.

BMG, 1994. The Geographic Calculator, Blue Marble Graphics, Gardiner, MA.

Bolstad, Paul V. and J. L. Smith, 1992. Errors in GIS: Assessing Spatial Accuracy, *Journal of Forestry*, Vol. 90, No. 11, pp. 21 - 29.

Gerlach, Fred, 1992. Current Conditions and Trends in the Developing Applications of the Global Positioning System, *The Compiler*, Vol. 10, No. 2, pp. 24 - 28.

Jasumback, Tony, 1993. Evaluation of the Trimble Pathfinder Professional GPS Receiver Under a Hardwood Tree Canopy, Timber Tech Tips, Technology and Development Program. U.S. Department of Agriculture and Forest Service, Missoula Technology and Development Center, Missoula, MT, pp. 1 - 6.

Leick, Alfred, 1990. *GPS Satellite Surveying*, John Wiley and Sons, New York.

MSC, 1993. Magellan System Post Processing, Magellan GPS ProMark V User Guide, Magellan Systems Corporation, San Dimas, CA, pp. 5.1 - 5.5.