# Using GPS Technology to Obtain Accurate Facility Location Data for Environmental Programs

## 99-558

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## ABSTRACT

Over the last year, IBM has extensively used survey quality Global Positioning Satellite (GPS) technology to obtain accurate location data for air emission sources, building and property locations, groundwater wells and risk management plan sensitive receptors. In that time period, IBM has made advances in the use of this technology.

The GPS data collected on-site needs to be post processed to remove the effect of the government induced Selective Availability (SA) error. This is accomplished by using a GPS base station at a known location that sees the same GPS satellites over the corresponding time period. Initially, IBM was correcting the data based on remote NOAA CORS GPS base stations located over 60 miles away.

Recently, New York State has upgraded the network of accurately located benchmarks as part of the federal High-Accuracy Reference Network (HARN). As part of the HARN network, these high resolution benchmarks in New York State are separated by no more than 30 miles.

Using the NYHARN station at the Duchess County airport, and two GPS units, IBM was able to set up an accurate benchmarks on-site. With accurate GPS located benchmarks on-site, the time requirements for collecting site GPS information has been significantly reduced. This is due to the fact that the correcting base station is now on-site and only at the worst case within 1 mile of the sampling location. The time a sample must be taken to obtain survey quality data accurate to the centimeter level depends on how close the sampling GPS unit is to the correcting base station. Using the CORS base stations, samples needed to be taken over 1-2 hours to obtain the required amount of satellite data to correct to the sub-meter level. With the correcting base station now located on-site, survey quality samples can be obtained in 15-20 minutes, thus allowing more samples to be taken in the time it took for one sample in the past. Using the on-site GPS benchmark, one GPS unit is set up as a base station and the second survey quality GPS unit is used to collect sample data. The results provide accurate measurements that rival surveyor obtained coordinates.

## INTRODUCTION

Over the last year, IBM has extensively used survey quality Global Positioning Satellite (GPS) technology to obtain accurate location data for air emission sources, building and property locations, groundwater wells and risk management plan sensitive receptors. In that time period, IBM has made advances in the use of this technology.

## GPS TECHNOLOLOGY

The Global Positioning System consists of 24 US Defense Department satellites positioned in an orbiting “constellation”. Each satellite carries an atomic clock and broadcasts low-power radio waves containing this satellite’s identity code and exact time to the nanosecond that the signal was sent. A GPS receiver on earth picks up a satellite’s signal and compares the satellite time with the receiver’s time. This time difference for signals that travel at the speed of light is used to calculate the distance from the satellite to the receiver. When the receiver knows the distance to this satellite, it creates a sphere of possible locations. If the receiver receives data from three satellites these spheres intersect at two points, one in space and another on the surface. This surface point is the location of the receiver. If the receiver acquires signals from additional satellites (up to 7- 8 is not uncommon) the receiver is able to not only determine position but use this information to calculate elevation.

The accuracy of the GPS data received is affected by many factors. Weather, condition of the ionosphere and any buildings or natural structures may obstruct the receiver’s view of the sky affecting the accuracy of the readings.

But the most significant cause of positioning error in GPS is deliberate. For concerns of national security the Defense Department does not allow accurate determination of position for civilians in real time.

The Defense Department makes two radio signals available from GPS satellites, the Standard Positioning Service (SPS) for civilians 1575.42 MHZ and the Precise Positioning Service (PPS) for the government and military. The civilian SPS is degraded in real time to decrease the accuracy by Selective Availability (SA). When SA is active the SPS is accurate to within at least 100 meters horizontally and 156 meters vertically 95 percent of the time.

On January 25, 1999 Vice President Gore announced a $400 million new initiative in the President's budget that will modernize the Global Positioning System (GPS) and will add two new civil signals to future GPS satellites. The second civil signal will be located at 1227.60 MHZ along with the current military signal, and will be available for general use in non-safety-critical applications. The time table for implementing this new signal is for satellites scheduled for launch beginning in 2003. The third civil signal that can meet the needs of critical safety-of-life applications such as civil aviation will be located at 1176.45 MHZ, and will be implemented beginning with a satellite scheduled for launch in 2005. [1]

These new GPS channels will give the public access to accurate GPS data, but until that time using GPS in the civil sector, the effect of SA must be taken into account and corrected.

Figure 1 shows the error due to SA for one minute GPS readings taken over 24 hours at a known location. In order to currently use the GPS data for centimeter accuracy, the effects of Selective Availability degradation needs to be eliminated. This is done by post processing the data using a method of differential correction. Differential correction involves using location and elevation data from a known base station. The receiver and the control point (base station) need to be close enough to see the same satellites. By using the known location and elevation of the base station and looking at the individual GPS readings at the base station, the delta due to SA for each satellite can be determined. By obtaining this information for the same time period as the data period from the receiver, the effect of SA can be removed from the data in post processing to improve the accuracy. By differentially correcting GPS data over a sufficient time period, results can be obtained with better accuracy. Figure 2 show the results of one minute readings taken at the same site as Figure 1 but differentially corrected from a base station 26 kilometers away.

One source of base station data that IBM used for correction in this study is from the NOAA Continuously Operating Reference Station (CORS) network. The objective of CORS is to provide data from base sites which are determined to centimeter accuracy. The CORS sites used in this study were Montauk Point, NY and Sandy Hook, NJ. This data was downloaded from the NOAA CORS website on the Internet.

The closest two CORS sites used at East Fishkill were still a considerable distance away, 80 - 100 kilometers, respectively.

In an effort to create a denser network of GPS sites across the United States that could be used to correct the current North American Datum (NAD) of 1983, all States participated in the Federal Base Network. As part of this network States set up additional GPS benchmark sites as part of the federal High-Accuracy Reference Network (HARN). In the HARN network, these high resolution benchmarks are separated by no more than 30 miles (Figure 3). The closest New York HARN (NYHARN) station to the IBM site is located at the Duchess County airport, which is a HARN station that also has differentially leveled elevation.

IBM used the NYHARN station at Duchess County airport to GPS locate three benchmarks on the IBM site.

The three IBM benchmarks are in NAD83:

| **Benchmark** | **Northing** | **Easting** |
|---|---|---|
| Intersection: | 4599017.312 Meters | 598074.431 Meters |
| Andre: | 4599860.432 Meters | 597650.545 Meters |
| Gerb: | 4600204.598 Meters | 598582.108 Meters |

The three benchmarks form a triangle over the site. These three benchmarks ensure, that when taking a GPS reading anywhere on-site, a correcting station will be within 1-2 kilometers of the where the measurement was taken.

The two GPS systems used in this study were the Magellan ProMARK-CM capable of centimeter accuracy with carrier phase differential processing. The ProMARK-CM consists of a 12 channel GPS Receiver/ Data Logger, external battery pack and multi-path resistant antenna and tripod. (Figures 5 and 6). One GPS unit was used as the base station set up on the on-site benchmarks and the other

GPS unit was used to collect data across the site.

The data collected with the ProMarkCM GPS unit can be collected in various datums. The North American Datum (NAD) 83 is the current standard for USGS maps. It uses the General Reference System of 1980 (GRS-80) ellipsoid which is nearly identical to the World Geodetic System of 1984 (WGS- 84) ellipsoid. The default datum used in the ProMARK-CM is WGS84 which is equivalent to NAD83.

## RESULTS

The GPS units were used to gather location data for air emission sources, building and property locations, groundwater wells and risk management plan sensitive receptors. The results presented in this study will show the levels of accuracy that can be achieved by different methodologies.

GPS readings were taken with one unit and differentially corrected using the two CORS base stations (Montauk Point and Sandy Hook) 80 - 100 kilometers away. To collect a sufficient number of samples to be able to correct to sub-meter accuracy, samples at each location were collected for over and hour.

GPS readings were taken with two GPS units, one on the closest on-site benchmark and the other unit at the sampling location. Since the distance to the correcting base station was very close (1-2 kilometers), the sampling time at each location was 15-30 minutes.

Another resource available to IBM to determine locations, are very detailed maps derived form aerial photography (Figure 6). The site GPS benchmarks were placed on these maps and then the maps were gridded in Universal Transverse Mercator (UTM) meters. These maps are much more detailed than USGS quads or typical site engineering plot plans.

The results presented below show the comparison of determining site location data based on professionally surveyed locations as the control compared to IBM technicians collecting the following:

- One GPS unit to collect site data differentially corrected using remote CORS sites
- Two GPS units - one at an on-site benchmark used to differentially correct the other GPS' data
- Determining location from the highly detailed aerial photography maps.

Measurements were taken at Well 754, Well 423, Well 54, Well 722 and the IBM Recreation Center .

| **Well 754** | **Surveyed** | **Montauk Point, NY** | **Deviation** |
|---|---|---|---|
| Northing: | 4599418.934 Meters | 4599419.183 Meters | 0.249 Meters |
| Easting: | 597747.448 Meters | 597749.532 Meters | 2.084 Meters |

| **Well 754** | **Surveyed** | **Sandy Hook, NJ** | **Deviation** |
|---|---|---|---|
| Northing: | 4599418.934 Meters | 4599419.341 Meters | 0.407 Meters |
| Easting: | 597747.448 Meters | 597749.592 Meters | 2.144 Meters |

| **Well 754** | **Surveyed** | **IBM : GPS** | **Deviation** |
| --- | --- | --- | --- |
| Northing: | 4599418.934 Meters | 4599418.977 Meters | 0.043 Meters |
| Easting: | 597747.448 Meters | 597747.515 Meters | 0.067 Meters |

| **Well 754** | **Surveyed** | **Aerial Map** | **Deviation** |
| --- | --- | --- | --- |
| Northing: | 4599418.934 Meters | 4599419.000 Meters | 0.066 Meters |
| Easting: | 597747.448 Meters | 597747.250 Meters | 0.198 Meters |

The difference using on-site base stations yielded centimeter results and picking the location as best as possible from the aerial maps also yielded centimeter accuracy for Well 754.

| **Well 423** | **Surveyed** | **GPS:CORS** | **Deviation** |
| --- | --- | --- | --- |
| Northing: | 4598662.481 Meters | 4598662.781 Meters | 0.300 Meters |
| Easting: | 597002.972 Meters | 597000.340 Meters | 2.632 Meters |

| **Well 423** | **Surveyed** | **IBM: GPS** | **Deviation** |
| --- | --- | --- | --- |
| Northing: | 4598662.481 Meters | 4598662.640 Meters | 0.159 Meters |
| Easting: | 597002.972 Meters | 597002.817 Meters | 0.155 Meters |

| **Well 423** | **Surveyed** | **Aerial Map** | **Deviation** |
| --- | --- | --- | --- |
| Northing: | 4598662.481 Meters | 4598662.750 Meters | 0.269 Meters |
| Easting: | 597002.972 Meters | 597002.75 Meters | 0.222 Meters |

| **Well 54** | **Surveyed** | **GPS :CORS** | **Deviation** |
| --- | --- | --- | --- |
| Northing: | 4598849.660 Meters | 4598849.587 Meters | 0.073 Meters |
| Easting: | 598602.832 Meters | 598600.960 Meters | 1.872 Meters |

| **Well 54** | **Surveyed** | **IBM: GPS** | **Deviation** |
| --- | --- | --- | --- |
| Northing: | 4598849.660 Meters | 4598849.743 Meters | 0.083 Meters |
| Easting: | 598602.832 Meters | 598602.639 Meters | 0.019 Meters |

| Well 54 | Surveyed | Aerial Map | Deviation |
|---|---|---|---|
| Northing: | 4598849.660 Meters | 4598850.250 Meters | 0.590 Meters |
| Easting: | 598602.832 Meters | 598602.500 Meters | 0.332 Meters |

| Rec Center | Surveyed | GPS: CORS | Deviation |
|---|---|---|---|
| Northing: | 4599209.345 Meters | 4599208.500 Meters | 0.845 Meters |
| Easting: | 599401.604 Meters | 599398.020 Meters | 3.584 Meters |

| Rec Center | Surveyed | IBM: GPS | Deviation |
|---|---|---|---|
| Northing: | 4599209.345 Meters | 4599209.213 Meters | 0.132 Meters |
| Easting: | 599401.604 Meters | 599401.403 Meters | 0.201 Meters |

| Rec Center | Surveyed | Aerial Map | Deviation |
|---|---|---|---|
| Northing: | 4599209.345 Meters | 4599209.500 Meters | 0.155 Meters |
| Easting: | 599401.604 Meters | 599400.750 Meters | 0.854 Meters |

| Well 722 | Surveyed | GPS:CORS | Deviation |
|---|---|---|---|
| Northing: | 4599945.127 Meters | 4599947.570 Meters | 2.443 Meters |
| Easting: | 598396.970 Meters | 598399.841 Meters | 2.871 Meters |

| Well 722 | Surveyed | IBM: GPS | Deviation |
|---|---|---|---|
| Northing: | 4599945.127 Meters | 4599946.086 Meters | 0.959 Meters |
| Easting: | 598396.970 Meters | 598399.178 Meters | 2.208 Meters |

| Well 722 | Surveyed | Aerial Map | Deviation |
|---|---|---|---|
| Northing: | 4599945.127 Meters | 4599946.000 Meters | 0.873 Meters |
| Easting: | 598396.970 Meters | 598399.000 Meters | 2.030 Meters |

The GPS technology used in this study shows that centimeter accuracy to obtain an absolute location can easily be achieved by a technician using the two GPS units. Measuring location with this level of accuracy also requires precision in the measurement process. Setting up the tripod and being off by a few inches can be clearly seen with this technology. This leads us to look further at the results from

Well 722. All of the other measured locations gave centimeter accuracy when compared to the surveyed values. Well 722 shows a greater deviation. Typically, one would question the GPS technology over the surveyor's reading, but in this case the GPS reading and aerial map are in excellent agreement.

The surveyed values were given in an IBM coordinate system ( a grid system in feet overlayed on the facility with an arbitrary 0,0 point). Most of the wells in the surveyed database were measured to three decimal places. Well 722 and a few others were only recorded in the well database with values to one decimal place or rounded to the nearest tenth of a foot. This reduced level of accuracy when converted to UTM coordinates and may explain the deviation between the Well 722 and the GPS and aerial map coordinates.

The accuracy obtained by the on-site differential correction of GPS data, also leads to the questioning of how accurate a surveyed value may be to an absolute location.

## CONCLUSIONS

This study shows the results of using GPS technology to obtain absolute coordinate information for locations on-site. This technology provides accurate coordinate information that is not possible from typical engineering plot plans or USGS quad sheets. Furthermore, data can be collected by a field technician with GPS technology at a level equivalent to professionally surveyed location data. The effort involved in obtaining the information is minimal compared to the improvement in accuracy of the location data over engineering drawings.

The comparison between the surveyed and the GPS system correcting with the on-site base stations are more accurate (centimeter level) than correcting from base stations further away. The other improvement, using two GPS units, is that the time required to collect data for centimeter accuracy is shorter when correcting from the on-site base station. This is due to the number of observations required to correct for SA is less due to the shorter baseline to the correcting station (1-2 KM) than the 80 - 100 KM to the CORS stations.

## REFERENCES

1. Press Release, The White House, *Vice President Gore Announces New Global Positioning System Modernization Initiative,* Washington, D.C., January 25, 1999.

Figure 1. One Minute GPS readings Plotted at a Known Location to Show SA Deviation.

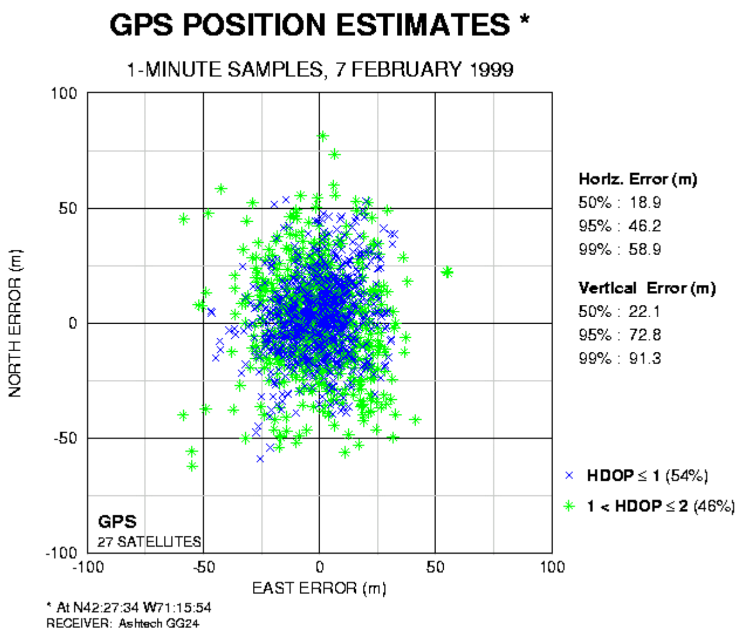


Figure 2. Plot of One Minute Readings at a Known Station after Differential Correction.

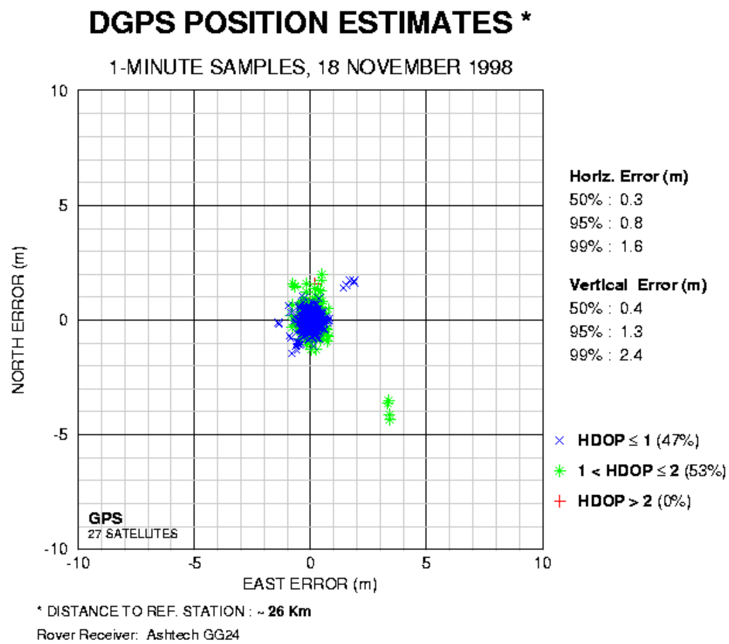



Figure 3. New York High-Accuracy Reference Network.

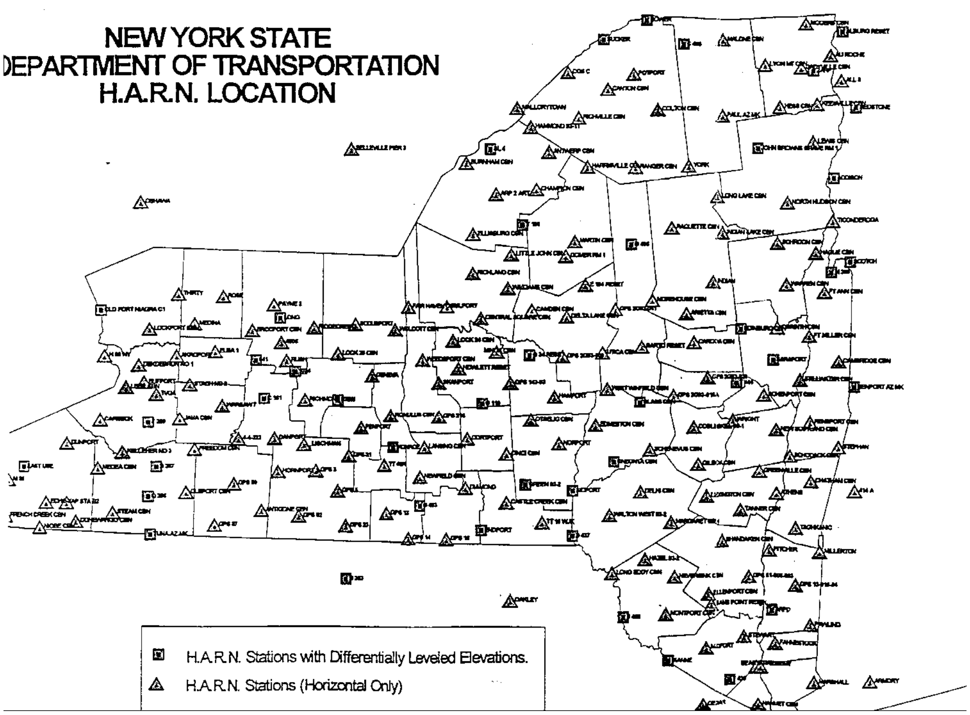
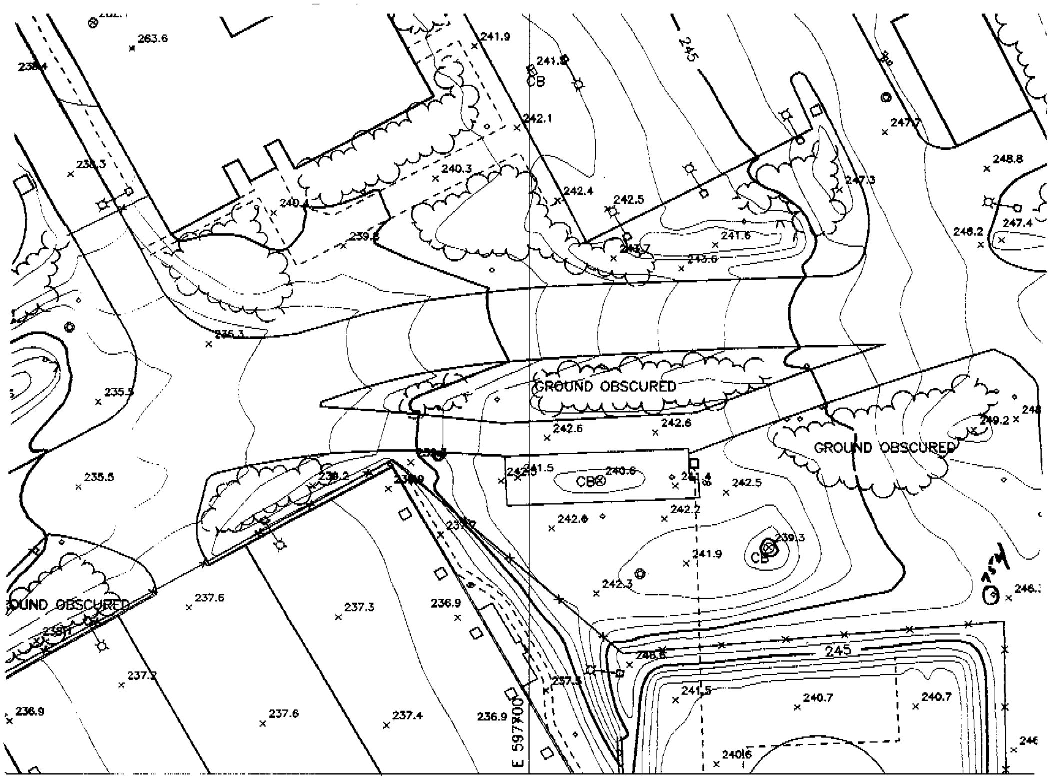


Figure 4.  Magellan ProMARK-CM GPS Unit.

Figure 5.  ProMARK-CM GPS Unit and Tripod.

Figure 6. Example of Aerial Photography Derived Site Map.




TOPOGRAPHIC MAP OF
IBM CORPORATION
EAST FISHKILL FACILITY
HOPEWELL JUNCTION, NEW YORK 12533

10 5 0 10 20 30 40

DATE OF PHOTOGRAPHY MARCH 3, 1997
SCALE 1cm = 5M
CONTOUR INTERVAL 1 FOOT
HORIZONTAL DATUM BASED UPON THE UTM COORDIN
VERTICAL DATUM BASED UPON NATIONAL GEODETIC VERTIC

HORIZONTAL ACCURACY: 90% OF ALL DETAIL, FIELD CHECKED, WILL BE WITHIN +/–
THE REMAINING 10% OF DETAIL, FIELD CHECKED, WILL BE WITHIN +/– .6 METERS OF ITS

VERTICAL ACCURACY: 90% OF ALL CONTOURS, FIELD CHECKED, WILL BE WITHIN +/
THE REMAINING 10% OF CONTOURS, FIELD CHECKED, WILL BE WITHIN +/– 1.0
** TOTAL PAGE.01 **

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