Part 1

Cadastral Retracement by Least Squares and RTK GPS

Roger A. Frank, LS

Desperation Leads to New Applications of Technology

November 1994: the four-year economic recession in California appears to be nearly over. The general outlook is brightening, people are shopping for new cars. December 8, 1994: Orange County, California, files bankruptcy! Almost all local cities, water districts, sewer districts, school districts, etc. are involved in this two billion dollar fund loss. Unfortunately, the list of unlucky businesses just happens to very closely match the client list of Johnson-Frank & Associates which has been developed over the past 20 years of business. As a result of this catastrophe, all new projects are frozen and ongoing projects are scaled down as much as possible. Perhaps the recession is not over after all. . .

After much reorganization during the month of December, I decided to take Johnson-Frank & Associates' show on the road to try to market some of our services outside of our normal work area. Our firm added the business of GPS Consulting to our land surveying services in early 1988. This had proven to be a good decision and we had been quite successful in this arena working for other engineering companies, counties, cities, and other agencies for several years. However, during that year many firms and most of the agencies in the southern California area had acquired their own GPS equipment. Although we still used our GPS equipment for our own projects, the consultant portion of the business had dropped considerably.

Mile Marker 7 on the Black Hills Meridian, which is also the SW Corner Section 7, T11S, R1E, BHM and a point on the South Dakota/ Wyoming line.

Star*Net Proves Useful for Many Jobs

One of my other areas of interest was in the Star*Net Least Squares software. I had learned to use and appreciate the capabilities of least squares while working with the Orange County Surveyor's Office in 1969 (see "Starplus Software's Star*Net GPS," *Professional Surveyor*, October 1996). After spending many years watching for a suitable least squares software, I met Ron Sawyer, owner and guiding light of Starplus Software, at a conference at California State University, Fresno in January 1988. He gave me a demo of his software and after testing it, I decided I had finally found a least squares package for the small firm. Within a week I had ordered a full package. I later found out that this was either the first or second Star*Net package Ron and Starplus had ever sold. We have used Star*Net in various functions ever since for almost all of our survey projects. We continue to work with Ron and Starplus Software, testing, evaluating, and suggesting improvements to his package.

In checking the professional conference calendar for 1995, I found that the state land surveyors' conference in my home state of South Dakota (though I moved to California in 1957, I'm still trying to decide if I should stay). January in the Dakotas—what could be better?

Since I was going "on the road" to sell "something," I called Ron Sawyer and asked if I could arrange to be a Starplus dealer. He didn't offer me much encouragement on marketing his product in that area, since he'd had few inquiries from that part of the country. Undaunted, I signed up, he sent some demos, and off we went to make our fortune in retail software sales.

As a first-time "trade show vendor," one of the attractions to the South Dakota Professional Land Surveyors Conference was that we would be so far from our normal area of operations, that there would be little chance of meeting anyone we knew. If we "flopped," none of our acquaintances would ever be the wiser. Unfortunately, the first person I saw as I entered the exhibit hall in Pierre was a Trimble GPS "rep" out of Seattle whom we had known in Orange County, California. Ten minutes later I met the Sokkia "rep" out of Kansas City who used to work with our local instrument company in Anaheim. Next, I met a surveyor I had known in California for more than 20 years, who had recently moved back to his old home in South Dakota. So much for keeping the operation secret! This experience says something about the size of the "survey fraternity" when you can transport yourself to a remote location where you have never practiced and still run into old friends.

During the course of the conference, I learned that only one firm in the state had GPS at that time, and they had only recently taken delivery. It looked like we had found a possible spot to market our GPS services. Surprise—very few firms had any great interest in using GPS in that area. Their reasons centered around land costs being quite low, along with labor, and the fact that most of the surveyors work in an area where you can see about 50 miles in every direction from any particular total station setup point.

However, while "networking" in the bar with my old friend from California, I met Jerry Wendland. Jerry is a surveyor with a small surveying firm in Blackhawk, South Dakota. In addition to his surveying company, he also runs a computer sales and support company. He is quite technologically advanced for the area and expressed some interest in the possibility of using GPS on an upcoming project for which he had a contract. He had been awarded a contract by the U.S. Forest Service to locate and monument the boundary of an area composed of parts of eight sections of private land surrounded by the federally owned National Grasslands area in the southwest corner of South Dakota. We discussed the costs of getting our equipment and people to that area and he seemed to

think that we might be able to make the technology work for him. It appeared that I might have made my first big sale! This salesman stuff wasn't so tough after all! At the time, our GPS equipment consisted of Trimble 4000SSE units which was state-of-the art for "fast static" positioning.

By the next day, Jerry had time to review his thoughts of the previous night. His thought was that he would have to traverse to a point very close to each corner in order to locate the corner. By the time he did that, he would have positions in the neighborhood of each corner which he could use to position any found evidence and to set any final monuments. So what would he do with our GPS to perform the project more efficiently? I didn't have an answer. Maybe this salesman stuff was harder than I first thought!

Real Time Kinematic GPS Base Station setup with "Portable Antelope Guard."

Accepting the Challenge

It took about two days to drive from South Dakota back to Southern California. This gave me a lot of time to review the events of the SDSPLS Conference. I had a project in my hands and it disappeared because I could not add value to what the client could already accomplish. What could I do to change that situation? How could I apply the technologies in my possession to a project such as Jerry's and do it faster, cheaper, or better, to be able to give his client the incentive to hire me as a sub-consultant? A challenge!

Jerry had told me that the area of his survey was almost exclusively open prairie grass on rolling hills. Most of the land had never been fenced. It had been occupied only by cattle, deer, antelope, and buffalo. The original surveys had been performed in the latter part of the 1800s and there were no records of any surveys in the area since that time. The original 1892 section corner monuments were charred stakes in earth mounds. He felt, and I certainly agreed, that locating the corners was going to be a very difficult operation.

In trying to devise a method of making the corner search easier or more productive, I hit upon a scheme which I felt would work. It would combine some of the technology we already possessed, but would require some equipment which had recently become available, yet which we did not own at the time.

Normally on this type of a survey, conventional practice is to find an original corner or two, then traverse from those corners to the next in line, trying to locate additional corners along the way. The further from the existing found corners you go, the less chance you have in finding subsequent corners, since your search radius gets larger and larger as you get farther away from your known positions. In this type of survey, the errors or normal precision, of the original survey can multiply quickly into hundreds of feet. Or, you might compute search coordinates for all of the corners in the area from the original plat. There are some difficulties involved here because the original surveys, notes, and plats are all based on every line being relative to astronomic north, not a "plane" rectangular survey like most surveyors are trained to understand.

I have used Star*Net at length in larger surveys using its "state plane" support. The software computes a mapping angle or convergence factor for each line in the survey. The convergence factor is the difference between a state plane azimuth and a geodetic azimuth. A geodetic azimuth is only a few seconds different from an astronomic azimuth. It occurred to me that the Star*Net software, with a little tweaking, could be used to compute state plane coordinates for search purposes from the original government notes or plats. If the original geometry from the government survey—for example, the entire township—was input into a least squares data file, it could be re-massaged whenever new data, such as found corners, was available and brought in as fixed positions in the adjustment. This system could be used with either conventional survey methods or GPS methods. However, if Real Time Kinematic (RTK) was available, the surveyor could go directly to the corners most likely to be found. This combination of least squares and RTK seemed to be the most efficient method I could devise for this type of project.

After I returned to my office in Anaheim, I toyed with a township plat that I had in my files from another area of South Dakota. The basic idea seemed to have merit. After entering all of the plat data for the township, I could locate the portions of the township in which the geometric data on the plat did not fit together. This alone seemed as it might have some value in planning a survey of this type. I certainly would not start searching corners in the areas where the original data didn't fit. As the software was configured at that time, I had to enter the record plat data as angles and distances, which of course was not the way these surveys were made. I called Ron Sawyer at Starplus to see if he would revise his program to allow entry of geodetic azimuths or bearings, and then apply the convergence angle to them, since he already had the routine to compute the convergence angles at every point in the data file relative to its position on the state plane grid. At first he was not too excited about the idea. He questioned whether there would be a market for this type of routine. I explained to him that since most of the country was subdivided into sections, it certainly seemed there might be a few surveyors who would appreciate a better method of retracing some of them. A few weeks later, the revised program came in the mail.

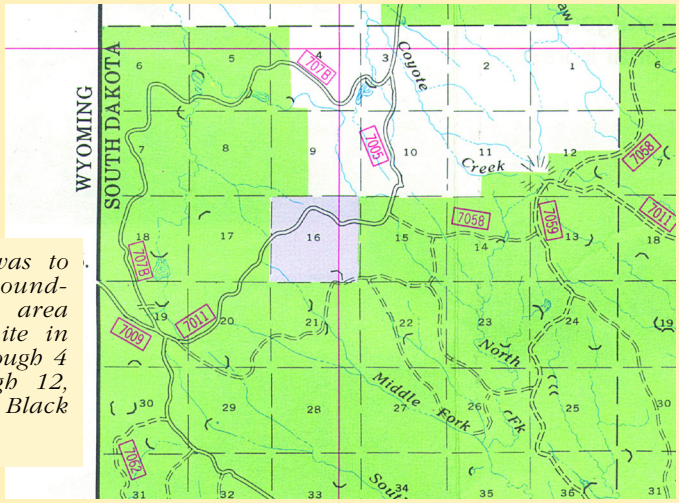
Adding Value to the Job

The program allowed me to enter the data right out of the government notes, in the same order as the survey was performed and using the same units. The bearings were entered as shown in the notes. The software converted each to a state plane bearing using the convergence angle computed at the beginning point of each line. The distances were entered in chains and links as shown on the notes. With a one-line entry, ".MULT 66," all distances were converted to feet by the software. For the really progressive among us, this could be converted to meters just as easily.

About this time, mid-1995, Johnson-Frank & Associates acquired RTK equipment to work with our existing Trimble 4000SSE GPS Receivers. At that time I thought I might have a value to add to Jerry's job. I called to see if he had completed his project. Unfortunately, he had weather problems and the area was about 100 miles from his office. In addition, Jerry had purchased a robotic total station with this job and others in mind. However, he found that the

robotic total station had a difficult time locating him if he was more than about 2,000 feet away. The project was going slowly, was far from being done, and the survey season was evaporating rapidly! I related my ideas on least squares and RTK to Jerry. He thought that this idea might be a possibility. I thought I might have a chance at this job after all.

I asked him to send a copy of his record data that I could work with and review. In the meantime, I called the good folks at the South Dakota State Archives in Pierre and ordered copies of all of the original notes and plats relative to the township in question.



The project was to determine boundaries of the area shown in white in Sections 1 through 4 and 9 through 12, T11S, R1E, Black Hills Meridian.

Entering the Data

Once I received the plat and notes, I entered all of the survey data for the entire township from the notes for the surveys which monumented the township and range lines, along with the section subdivisional surveys. Using appropriate weights for the distances, and azimuths relative to the equipment and period of history in which it was performed, I obtained a very satisfactory adjustment of the original survey data. The west line of the township is also the Black Hills Meridian and the west line of the state. This state line had been resurveyed in 1904 and monumented with 10" x 10" stone monuments, which extend about four feet above the ground. One of these monuments had been positioned by USC&GS at one time. I used this one coordinate to start my state plane system. Again, since all of the GLO bearings were relative to true north, this was all I needed to get the adjustment file started.

As an afterthought, I decided to input the distance calls to all of the topo calls shown in the notes as well. I did so by entering the distance to each topo call, and the distance from the topo call to the next standard corner, replacing the corner-to-corner distance that I had entered earlier. To ensure that during the course of adjustment, there would be no angle points created in the section lines at the topo point, I entered a 180º angle at each point and "fixed" that angle in the adjustment. This forced each topo call to remain on a "straight" section line between the controlling corners.

Having all the available geometric data in a satisfactory adjustment, I exported the resulting diagram using the Star*Net DXF export routine. The DXF file was imported into AutoCad and plotted to USGS quad sheet scale. In accordance with "Murphy's Law, this job fell on the corner of four quad sheets. This particular job also managed to fall on two quads of the normal 1:24000 and two of the metric 1:25000 requiring two separate plots. Taken to the light table for overlay on the quads, I picked out the topo calls, which I could now identify on the quads. Most of the calls were to "drains." The quads showed many small gullies or drainage courses running generally southeasterly at about a 45-degree angle to the section lines. Only a few were called out in the notes. After identifying the appropriate "drains" on the quads, we digitized points along the centers of the drains on both sides of the section lines from the USGS maps. These digitized "drains" were then input into the Star*Net adjustment file as "fixed" positions. An intersection of each drain with its appropriate section line was forced by again "fixing" a 180° angle along the drain centerline at the called point described above from the notes. After adjusting again, I now had the entire township "georeferenced" to the terrain as represented on the USGS quads.

Positioning Mile Marker 7 on the Black Hills Meridian; the SW Corner Section 7, T11S, R1E, Black Hills Meridian; and a point on the South Dakota/Wyoming line using GPS Static Survey.

At this point, I felt fairly confident that I knew the location of every corner in the township within about 20-30 feet, without yet having seen the site! I called Jerry in South Dakota and told him of my successes so far, and that I thought with the data at hand and our new RTK system, we could make some giant strides with his project. He agreed. After some convincing, his client agreed to the strategy. Between them, they came up with enough money, sort of, to cover about four days of my time and equipment on the project. It sounded like plenty of time to locate enough corners to establish half a township!

Luckily, the time period for my part of the survey fell between the deer season in Wyoming (October 1) and the pheasant season in South Dakota (October 15), both of which I had planned to take part in anyway. After completing the Wyoming portion of my wildlife population control responsibilities, I called Jerry to see when he wanted to get started. Jerry was still concerned with the possibility of weather problems keeping us out of the area and winter coming on which would keep him from completing his contract that year. I, along with the equipment I had shipped to Rapid City, was available to begin on October 8, a Sunday. Jerry was eager to get the project under way, so we arranged to meet in Edgemont, South Dakota, early on Sunday morning, October 8.

End of Part One. Stay tuned for Part Two in the November issue.

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Part 2

Cadastral Retracement by Least Squares and RTK GPS

Roger A. Frank, LS

Field Operation, Day One

Jerry previously located some of the "quartzite" monuments along the South Dakota/Wyoming State Line/Black Hills Meridian/west line of our township, along with two stones with the appropriate markings for two of the corners along the north line of the township. He had run a traverse between these corners, which was about a 10-mile loop, but had closure problems, which he could not locate. Our plan of attack was to set the RTK base on one of his traverse points which was on one of the higher hills in the area, tie in the other known corners, then start looking for other evidence using the pre-calced positions.

As company owner, I normally don't operate our field equipment; instead I spend most of my time in the office telling people what we are capable of. Prior to leaving California, I took the RTK system around our office, and using the Trimble manual and some help from our regular GPS field personnel, convinced myself that I could get it up and going. Unfortunately, it didn't go as well in the field. We would get the base unit broadcasting, then travel off about a half mile toward the first point and the unit would quit. We would then go back, pull the plugs, restart, leave the area, and it would quit again. We spent about half of that first day "head- scratching," and since it was Sunday, could get no assistance from anyone at either my office or Trimble. Finally, we decided that the problem might be a low charge on the car battery which we were using to power the base with its radio and amplifier.

Mile Marker 7 on the Black Hills Meridian, which is also the SW Corner Section 7, T11S, R1E, BHM and a point on the South Dakota/ Wyoming line.

In some desperation, after deciding we were not going to get "RTKing" that day, we took off to tie in what we could using "fast-static" procedures. We first went to the west township line and tied in two of the quartzite monumented corners from the 1904 resurvey. These were pretty easy to find in this grassland area since they could be seen about a quarter of a mile away. Following that small success, we decided to go to the south line of the township to look for anything we could find in the way of corners. Jerry had attempted to traverse down this six miles to the south line, but again, he had problems with his total station and ended up with positions in which he had little confidence. I had my handheld Trimble GPS, which I normally use for small plane navigation. We plugged in my computed position for the southeast corner of Section 33, which should have been six miles south of one of Jerry's found stones along the north township line. We then navigated along the ridge tops to what appeared to be the appropriate finger based on the GPS, drove down the finger to the navigated position, got out of the truck and found a rebar with a yellow plastic cap and an old stake right by the right front tire. Jerry was impressed. (I, of course, acted like that is the way it always happened.) We set up a 4000SSE and recorded a fast- static session to position this monument.

It is important to mention that South Dakota has no county surveyors to keep survey records, they have no record of survey law to encourage surveyors to make their surveys public record, and until recently, they had no tagging law to mark their corners with identifying numbers. They do have a corner record law which came into effect about 20 years ago, but it is quite often ignored. In other words, there is nearly no way to know who set this rebar and cap or how they decided to set it at that location. This was a bit of a hard pill for a Southern California-trained surveyor, where we have stringent record of survey and tagging laws (still ignored by many), but over the years have developed a huge repository of public records. So in South Dakota, if it looks like a corner, and seems to be in about the right location, it must be a corner.

Back to the survey--we plugged in the position of the next section corner to the east, the southeast corner of section 34, navigated to it, and found another rebar and plastic cap next to an old fence corner post. Pretty good again for the ±100-meter navigation ability of the Flight-Mate receiver. Again, we tied in this corner with the 4000SSE using static back to our "RTK" base station location.

Prior to closing up for the day, I had Jerry stay with the base unit and I went off about 10 miles to the northeast to occupy the one and only first order NGS station in the area. (This area of the state seemed to have been missed with just about all of the USC&GS/NGS classical triangulation networks.) I located the station near a now abandoned WWII ammunition depot of about 1,000 bunkers, as the sun was going down and the moon was coming up. I occupied that station to get some relatively good control into the survey, and then met Jerry back at the motel in Edgemont.

It is almost exactly 12 hours from sunup to sundown in that latitude at that time of the year, and surveyors in that area know how to use every minute of it to make up for poor surveying conditions during the winter. We used our full 12 hours in the field that first day, then went back to the motel and downloaded and processed the data we had collected that day. We imported the Trimble baselines into a Star*Net data file, and produced usable state plane coordinates for the four corners and the base station point based on the one first order station we occupied. Next, I imported the positions of the found corners into my previous Star*Net file of the cadastral data and updated all of the search positions in the township based on those corners, and still holding the Quad sheet, derived topo calls. The measured positions fit the computed positions very well, just as planned.

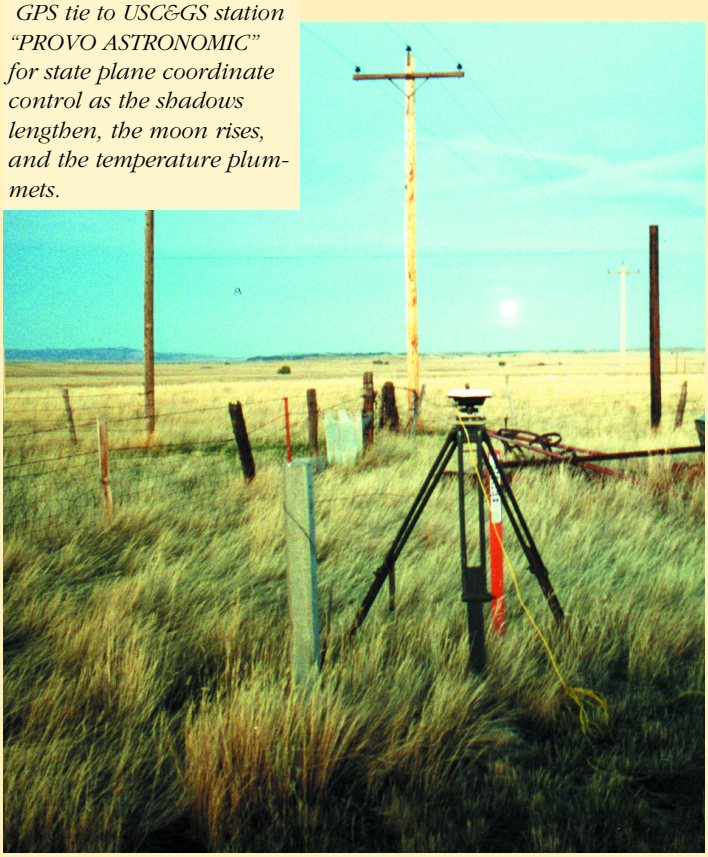
Day Two

Again, we set up the base station, traveled away and it quit. Since it was Monday, we assumed we could contact Trimble for help, however, it was Veterans' Day and nobody was in the office. We did finally contact Sokkia in San Diego, the dealer from whom we bought our equipment. The answer to the problem, unknown to me, was that if you plug the base together as shown in the Trimble manual (Trimble assuming you are using Trimble's Trim-Talk radios), it doesn't work reliably if you actually have the more powerful Pacific Crest radios. Once we plugged the right cable into the "wrong" hole, we were off and "RTKing" just like it says in the book. Just about the time we finally got this thing going, Jerry's client, Ralph Turner of the U.S. Forest Service in Custer, SD, came by to "ride along." Glad he didn't come by the day before!

We used the RTK to tie in the two corners previously located by Jerry along the north line of the township. We set and positioned two additional control points from which we should have been able to transmit our RTK signal to all parts of the township.

Next we started looking at the pre-computed locations for corners. As mentioned earlier, the interior corners of this township were set in 1892 and were charred stakes, with earth mound and pits. The soil in this area is much like that of the South Dakota badlands which "melts" with rain and snow. The 103 years since these corners were set had left nothing much to look for, however we did find and position a fence along the north line of the township and a fence corner at the northeast corner of the township. These fence lines appeared to fit the two found stones along this line fairly well. At some of the pre-calced corners, we found old wooden fence posts lying on the ground in the area. We used the RTK to position the uphill ends of any posts we found (fence posts always fall downhill, right?). We also started to tie in the centers of the "drains" called out in the original survey notes.

GPS tie to USC&GS station "PROVO ASTRONOMIC" for state plane coordinate control as the shadows lengthen, the moon rises, and the temperature plummets.



Again, after 12 fruitful hours in the field, we retired to the motel to download, process, and add the day's data to the previous "measured" Star*Net file in order to produce state plane coordinates. Now we actually had some data which we could compare in order to record and begin to analyze. The office end of the operation got a little longer--another 15-hour day.

Day Three

We set our base station on one of the control points we had positioned the day before, and again looked for corners, but to no avail, and we tied in a lot of old posts and many "drains." During the day, we tied to the other control point we had "rayed" out the previous day. We missed the previous position by about 0.06 foot, in a three-legged traverse of about 12 miles, a closure of about 1/1,000,000. Jerry and Ralph were impressed. (I, of course, told them it was always that way with GPS. You have to appreciate the good stuff when you get a chance!)

My time records only showed 11 hours in the field on October the 10th. However, we now had enough field information to really delve into the analysis of what was good and what was not. After downloading, processing, importing the day's baselines to the Star*Net "measured" file, then bringing our coordinates into the "record" file, we had plenty to sink our teeth into. That night Jerry and I spent eight full hours evaluating every post and drain we had located and determined which could be used as evidence to establish our lines.

Day Four

We continued to locate "drains," fences, and posts. At this point, we had evaluated enough field located data that we were quite confident in our positions. In fact, when we navigated to computed locations where a section line was supposed to cross a drain, we found ourselves standing in the center of the drain. We also located two points that we determined from our survey must be very close to record points based on having good topo in all directions. If a person were to look very close (and possibly use a little imagination), one could see shallow pits 11 feet apart as per the original notes.

By the end of day four, we had:

1) located six identifiable monumented corners;
2) found two possible corners based on knowing a precise location and find ing possible remains of mound and pits;
3) tied in 45 "drain" centerline points;
4) located 45 old wood fence posts;
5) set and controlled 34 temporary points to be used as monumentation kickover points.

But, more importantly, we were confident that we had the entire north half of this township located to the point where Jerry could determine all the corners he needed for his contract. At that point, we determined that my work there was complete.

Ralph Turner of the Forest Service, who had been riding with us during the last three days, was also satisfied that we had the project nailed to the ground with the best evidence available.

Jerry told me as we packed up that fourth and final day, that we had accomplished in those four days of least squares/RTK GPS operation what it would have taken about three months with the conventional cadastral retracement procedures and his robotic total station! Again, sometimes there are rewards that make up for the days when things don't work quite as well as we had planned.

Financial success? Don't ask. We developed a new system, we proved it in the field. That was success enough for this project.

Roger Frank *is the cofounder, current owner, and president of the 26-year-old Land/Geodetic Surveying firm of Johnson-Frank & Associates in Anaheim, California. He has written two previous articles for* Professional Surveyor *including a* Hands On *review of Starplus Software's Star*Net GPS (October 1996) and "Surveyor Droppings" (July/Aug 1999). He can be reached at* roger-frank@Johnson-frank.com

Southwest corner section 34, T11S, R1E, Black Hills Meridian.

Real time kinematic GPS base station at the highest point in the township.