CHAPTER 11

GPS SURVEYING AND TECHNOLOGY

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11:1 DEFINITIONS

Anti-Spoofing (A-S): For the NAVSTAR system (NAVigation Satellite Timing and Ranging), anti-spoofing (A-S) is the process whereby The P code used for the precise positioning service is encrypted. The resulting encrypted code is called the Y code. The encryption data can only be decoded by GPS receivers with special decryption circuitry, guarding against fake transmissions of satellite data.

DGPS: Differential GPS - A technique for improving GPS solution accuracy. Error is reduced by determining the error at a known location, then subtracting that error from the solution at an unknown location.

Dilution of Precision (DOP): DOP is a function expressing the mathematical quality of solutions based on the geometry of the satellites. Position dilution of precision (PDOP), the most common such value, has a best case value of one, higher numbers being worse. The best PDOP would occur with one satellite directly overhead and three others evenly spaced about the horizon. Higher numbers of PDOP are worse. PDOP could oretically be infinite, if all the satellites were in the same plane. PDOP has a multiplicative effect on the user range error (URE) value. A URE of 32 meters with a PDOP of one would give a user an assumed best accuracy of 32 meters. A PDOP of two would result in an assumed accuracy of 64 meters. Many receivers can be programmed to stop providing position solutions above a specific PDOP level (six is common). There are several other DOP factors such as horizontal and vertical DOP, geometric DOP and time DOP.

Kinematic Surveying: A precision DGPS surveying technique. The roving user does not need to stop to collect precision information. Meter-centimeter level accuracy is available using modern dual-frequency carrier-phase measurement techniques.

L1 Frequency: One of the two radio frequencies (1575.42 MHz) transmitted by the NAVSTAR satellites. All NAVSTAR satellites transmit on the same frequencies. This frequency carries the C/A code used for the standard positioning service (SPS) and the P code used for the precise positioning service (PPS).

L2 Frequency: One of the two radio frequencies (1227.6 MHz) transmitted by the NAVSTAR satellites. This frequency carries only the P code used for the precise positioning service (PPS).

LDGPS: Local area Differential GPS is a real-time DGPS system that is made available over a small area, possibly 150 miles or less.

NANU: Notice Advisory to NAVSTAR Users is a periodic bulletin alerting users to changes in system performance.

Precise Positioning Service (PPS): PPS is the most accurate positioning, velocity, and timing information continuously available worldwide from the basic GPS. This service is limited to authorized U.S. and allied Federal Governments; authorized foreign and military users; and eligible civil users. PPS information is usually (but not always) encrypted to prevent use by unauthorized users. The encryption process is known as *Anti-Spoofing*. GPS receivers that can use the P code provide a predictable positioning accuracy of at least 22 meters (2 drms) horizontally and 27.7 meters (2 sigma) vertically. They can also provide timing/time interval accuracy within 90 nanoseconds (95 percent probability). This improved accuracy is provided in two ways. First, P-code users are not subjected to Selective Availability. Second, access to the L2 channel allows the user to correct for atmospheric propagation errors. Equipment that uses the P code is available for civilian use; however, the capability is useless when Anti-Spoofing is active. Access to GPS receivers that can decrypt the Y code is tightly controlled and is subject to National Security considerations. If you are a civilian user, you will need a really good excuse to get one.

Radionavigation: The determination of position or the obtaining of information relating to position for the purposes of navigation by means of the propagation properties of radio waves.

Selective Availability (SA): Selective availability is the name of a process that allows the DoD to limit the accuracy available to users of Navstar's Standard Positioning Service. It is accomplished by manipulating navigation message orbit data (epsilon) and/or the satellite clock frequency (dither) This process is intended to prevent potential adversaries of the United States from using low-cost GPS receivers for certain military functions.

Spoofing: The deliberate transmission of fake signals to fool a GPS receiver. Spoofer must mimic a GPS satellite, rather like a psuedolite but with disruptive intent.

Standard Positioning Service (SPS): SPS is the standard specified level of positioning and timing accuracy that is available without qualification or restrictions to any user on a continuous worldwide basis. The accuracy of this service is established by the U.S. Department of Defense based on U.S. security interests. Navstar currently provides horizontal positioning accuracy within 100 meters (2 drms) and 300 meters with 99.99 percent probability. The signals providing standard positioning service are inherently capable of greater accuracy than this. The accuracy of the system is limited through the application of a process called *Selective Availability*

Static Surveying: A precision DGPS surveying technique. The roving user is required to sit motionless taking data at a point from fifteen minutes to an hour or more.

Stop-and-Go Surveying: A precision DGPS surveying technique, also called semi-kinematic surveying. The roving user is only required to collect data at a point for a few seconds or minutes.

WAAS: Wide Area Augmentation Service is a service being developed by the FAA to provide wide area DGPS and integrity information to aviation users.

WDGPS: Wide area Differential GPS is a real-time DGPS system that is made available over a large area, possibly global.

11:2 INTRODUCTION

Global Positioning Systems (GPS) are space-based radio positioning systems that provide 24 hour three-dimensional position, velocity and time information to suitably equipped users anywhere on or near the surface of the Earth. The NAVSTAR system, operated by the U.S. Department of Defense, is the first GPS system widely available to civilian users.

GPS systems are being readily used by surveyors to provide accurate survey information throughout the world. GPS systems replace conventional surveying practices under many circumstances. For example, using GPS surveying equipment the horizontal and vertical control for surveying a drain can be established within hours versus days using conventional equipment. Using conventional survey equipment requires a surveyor to sight between setup locations. In many instances there may be buildings, trees or brush in the way requiring several setup points or brush clearing. With GPS equipment a line of site from location to location is not needed. GPS just requires that there are no obstructions from above blocking the satellite signals. Under conventional surveying practices the surveyor may be required to "carry" horizontal and vertical control many miles along the length of a drain project. Using GPS systems the control points can be set independent of each other (maybe at each crossing) without the requirement to site back and forth and "carry" the elevations and location from the previous point.

GPS surveying techniques do not work well under brushy, wooded conditions or in the vicinity of large buildings. The satellite signals are very weak and are easily blocked by objects that are between the receiver and the satellite. It is becoming a standard practice on drainage projects to use the GPS equipment to set up the horizontal and vertical control of a project. The control is set in locations where there is an unobstructed satellite signal. Then conventional survey equipment is used to gather the topographic information.

Survey information that can be provided to the Drain Commissioner using GPS systems include:

a) Route and course of drains – in open areas the route and course of drains can easily be obtained by walking the route with the survey receiver and/or driving the drain with a receiver attached to an ATV.

b) Horizontal and vertical survey control for projects – obtaining the control information on a drain that may be miles long can save many days of survey time.

c) Topographic information - where there are no obstructions along the length of a tile or open drain; the cross section, profile and general topographic information can be obtained very easily.
d) Identifying bridge, culvert and stormwater discharge locations – this can easily be done so that they can be located on the County base map.
e) Assessment district boundary location – many times survey of the drainage district boundary is necessary. Using GPS survey equipment the district boundary can easily be identified.
f) During construction – horizontal and vertical control can easily be established for the contractor during construction.
g) "As-Built" - tie downs can be made for tile, open drain, manhole and catch basin locations after a project has been constructed.
h) Geographic Information Systems (GIS) – the information gathered using GPS equipment can easily be converted to the coordinate system for any GIS system. The information is available in a digital format and can easily be added to computer base maps.

GPS surveying can be a cost effective and time saving tool for the Drain Commissioner, their support staff and consultants. It does not and will not replace conventional surveying practices. However, used in conjunction with conventional survey equipment, GPS systems can provide considerable cost savings. This chapter is designed to provide background information about GPS surveying systems and how they work. Hopefully, as a result of reading this chapter, you will have a better understanding of GPS systems and will be able to discern how they can be used to assist your office.

11:3 SEGMENTS OF A GPS SYSTEM

A global positioning system is composed of three segments, the user segment, the space segment and the control segment.

11:3.1 User Segment

The user segment is the user and a GPS receiver. A GPS receiver is a specialized radio receiver. It is designed to listen to the radio signals being transmitted from the satellites and calculate a position based on that information. GPS receivers come in many different sizes, shapes and price ranges.

The features and costs of GPS receivers are generally dependent on the function that the receiver is intended for. Receivers intended for marine and aviation uses often have the ability to interface with memory cards containing navigation charts. Receivers intended for mapping are capable of very good accuracy and have user interfaces that allow rapid data collection.

11:3.2 Space Segment

The space segment is composed of the GPS satellites that are transmitting time and position to you, the user. The whole set of satellites is called a "constellation".

NAVSTAR constellation is composed of 24 satellites in six orbital planes. The satellites operate in circular 20,200-km (10,900 nm) orbits at an inclination angle of 55 degrees and with a 12-hour period. The spacing of satellites in orbit is arranged so that a minimum of five satellites will be in view to users worldwide, with a position dilution of precision (PDOP) of six or less. Each satellite transmits on two L band frequencies, L1 (1575.42 MHz) and L2 (1227.6 MHz). Each satellite transmits on exactly the same frequency; however, each satellite signal is doppler-shifted by the time it reaches the user. L1 carries a precise (P) code and a coarse/acquisition (C/A) code. L2 carries only the P code. A navigation data message is superimposed on these codes. The same navigation data message is carried on both frequencies. The P code is normally encrypted so that only the C/A code is available to civilian users; however, some information can be derived from the P code. When encrypted, the P code is known as Y code.

There have been three distinct groups of NAVSTAR satellites so far, with one sub-group. The groups are designated as blocks. The block I satellites were intended for system testing. The block II satellites were the first fully functional satellites, including cesium atomic clocks for timing as well as the ability to implement selective availability. They also have radiation hardened electronics, allowing for longer lifetimes in space. In addition, the block II satellite can detect certain error conditions, automatically sending a code indicating that it is out of service. Block II satellites can operate for 3.5 days between corrections from the ground. The block IIa satellites are identical to the standard block II but continue to operate for 180 days between uploads from the ground.

The latest satellites, the block IIR versions, include autonomous navigation. These satellites can operate for 180 days between uploads like the block IIa. Unlike the block IIa, they can generate their own navigation information. Thus, the accuracy of the system can be maintained longer between uploads.

Each satellite has two identifying numbers. First is the NAVSTAR number that identifies the specific satellite hardware. Second is the space vehicle (sv) number. This number is assigned in order of launch. The third is the pseudo-random noise code number. This is a unique integer number that is used to code the signal from that satellite. Some receivers identify the satellites that they are listening to by SV, others by PRN.

11:3:3 Control Segment

The control segment is composed of all the ground-based facilities that are used to monitor and control the satellites. This segment is usually unseen by the user, but is a vital part of the system. The NAVSTAR control segment, called the operational control system (OCS) consists of a monitor station, a master control station (MCS) and uplink antennas.

The passive monitor stations are nothing more than GPS receivers that track all satellites in view and thus accumulate ranging data from the satellite signals. There are five passive monitor stations, located at Colorado Springs, Hawaii, Ascencion Island, Diego Garcia and Kwajalein. The monitor stations send the raw data back to the MCS for processing.

The MCS is located at Falcon Air Force Base, 12 miles east of Colorado Springs, Colorado and is managed by the U.S. Air Force's 2nd Space Operations Squadron (2nd SOPS). The MCS receives data from the monitor stations in real time 24 hours a day and uses that information to determine if the satellites are experiencing clock or ephemeris changes, and to detect equipment malfunctions. New navigation and ephemeris information is calculated from the monitored signals and uploaded to the satellites once or twice per day.

The information calculated by the MCS, along with routine maintenance commands are transmitted to the satellites by ground-based uplink antennas. The ground antennas are located at Ascencion Island, Diego Garcia and Kwajalein. The antenna facilities transmit to the satellites via an S-band radio link.

In addition to its main function, the MCS maintains a 24-hour computer bulletin board system with the latest system news and status. The civilian contact for this is the United States Coast Guard's (USCG) Navigation Center (NAVCEN).

Differential GPS (DGPS) is a method of eliminating errors in a GPS receiver to make the output more accurate. This process is based on the principal that most of the errors seen by GPS receivers in a local area will be common errors. These common errors are caused by factors such as clock deviation, selective availability and changing radio propagation conditions in the ionosphere. If a GPS receiver is placed at location for which the coordinates are known and accepted, the difference between the known coordinates and the GPS-calculated coordinates is the error. This receiver is often called a "base station".

The error, which the base station has determined, can be applied to other GPS receivers (called "rovers"). Since the sources of the error are continuously changing, it is necessary to match the error correction data from the base station very closely in time to the rover data. One way of doing this is to record the data at the base station and at the rover. The data sets can be processed together at a later time. This is called post processing and is very common for surveying applications. The other way is to transmit the data from the base station to the rover. The error calculation is made in the rover in real time. This process is called real-time dgps.

11:4 ACCURACY

Accuracy of GPS depends upon the equipment and techniques that are used for obtaining the information. The following is a summary of the horizontal accuracies expected from different grades of equipment. The vertical accuracy of this equipment is expected to be between 1.5 to 2 times the horizontal accuracy.

(1) 300 meters - 100 meters

This is the accuracy range that the Department of Defense guarantees from the Standard Positioning Service (SPS), the only service commonly available to civilian users.

(2) 25 meters - 10 meters

Cheap handheld receivers in the $300 to $3000 range with basic DGPS can usually achieve accuracies in this range.

(3) 5 meters - 1 meter

Better handheld receivers and mapping grade receivers can get down to this level of accuracy. The cost is from $500 to $5000.

(4) 1 meter - 10 cm

Better quality mapping receivers and low-end surveying equipment can get this accurate. Such receivers will generally use carrier phase measurement techniques instead of code-based solutions and will cost more than $3000 per unit. Users requiring better accuracy can get it by taking long observations (between 20 seconds and 2 hours) and by surveying multiple points as a network and using network adjustment routines. Sub-centimeter accuracies are possible using these techniques.

(5) 10 cm - sub-centimeter

High-end surveying receivers and geodetic receivers are used to reach this level of accuracy. Receivers of this class, costing more than $15,000 per unit, will always use carrier phase measurement techniques and will usually use both of the GPS frequencies. A relatively new technique known as ambiguity resolution on the fly (AROF) allows receivers to start producing high-quality solutions very quickly (within 40 seconds) without complicated initialization procedures.

11:5 POST PROCESSING

In the post processing method, both the base station and the rover must record data simultaneously. How this is done is dependent on the situation. One way is to record the data right in the GPS receiver. This is common in surveying applications where the base and rover are being used to measure a specific baseline.

Sometimes it is physically inconvenient to record the data in the roving GPS receiver. In such cases the roving user may record the data in a laptop PC, a palmtop PC such as an Apple "Newton" or in a specialized data collector. The usual reason for doing this is that the data-collecting device gives the user more flexibility in tagging the GPS data with desired information.

In a situation where the base station will be permanently fixed in one spot and will be used for several rovers, a community base station may be installed. A community base station is nothing more than a GPS receiver permanently connected to a PC. The GPS data is stored in the PC. It is possible to install a BBS system on the base station PC so that roving users can download data sets for remote processing. The PC collects base station GPS data and saves it to files in time-block increments.

Having collected GPS data for post processing, it remains to get the two data sets together. This is not always a straightforward process. Data formats are often proprietary or dependent on the technology used. Users will usually have the same brand of equipment for base stations and rovers so this is not a problem. Sometimes manufacturers will have conversions for different data formats. However, this is not always the case. A data format called RINEX (Receiver INdependent EXchange) may sometimes be used as an alternative.

11:6 REAL TIME PROCESSING

If the user desires improved accuracy at the time the equipment is being used, real-time processing must be used. For real-time processing, special formats are used. There are two predominant formats currently being used.

NMEA-0183 is a data format commonly employed for communications between ship-borne navigation electronics. This format is a voluntary industry standard originated by the National Marine Electronics Association. The second format, **RTCM-104** is an attempt by the Radio Technical Commission for Maritime Services to standardize DGPS operation. The standard is the result of a request by the Institute of Navigation to the RTCM to develop recommendations for DGPS transmission. The RTCM formed Special Committee 104 (SC-104, get it?) titled "Differential NAVSTAR GPS Service". Version 2 of this service is used by many beacon systems (including the US Coast Guard system). Version 2.1 includes additional information for the transfer of real-time kinematic data. Copies of the RTCM SC-104 Standards document may be purchased from the RTCM or from Navtech Seminars.

11:7 SOURCES OF DIFFERENTIAL INFORMATION

(1) Do-it-yourself

Sometimes the only way to get the differentiation that is required is to provide it yourself. This option is not necessarily all that expensive, depending on what you are trying to accomplish. It just requires the use of a base station along with the roving equipment. This is the option that is most often used by surveyors.

(2) Community Base Stations

Some organizations maintain base stations for post-processing and are willing to share the data. Check around state department of transportation offices and civil engineering and surveying departments at universities.

(3) Government Radio Beacons

The U.S. Coast Guard has tested a system of high frequency DGPS radio beacons positioned around the coast and along certain waterways. Starlink Incorporated maintains a list of sites and system status for the Coast Guard system and for systems for other countries on the Internet.

The FAA is considering three types of differential GPS service for aviation use: (1) local area DGPS (LADGPS), which would be located at each airport or closely grouped airports to support instrument approaches to current CAT I weather minimums; (2) wide area DGPS (WADGPS), which would provide GPS integrity broadcast (GIB) and accuracy improvements for all of North America; and (3) use of kinematic carrier phase positioning for instrument approach and landing.

All three types of DGPS service are still under development; however, WADGPS/GIB is in the FAA budget for procurement and installation. The basic concept for WADGPS/GIB is to have several GPS ground monitoring stations (about 20 for North America) with two master control stations where differential corrections and integrity for each satellite are determined. This information will be sent to two communications satellite earth stations and relayed to the aircraft via a satellite signal that is similar to a GPS signal with unique codes. This signal may also be suitable for ranging providing improved navigation availability.

(4) Commercial Services:

There are commercial services for getting real time differential data. Commercial services are great where you cannot afford the expense of maintaining or operating your own base stations. If you are a business person trying to map the location of your clients, for example, commercial service is probably the way to go. They are listed in the DGPS Services web page. For the most part, they all require you to purchase a radio receiver of some sort and sign a service contract. All the receivers produce RTCM-104 output. However, GPS receivers do not have a standard connector and you may have to make your own.

11:8 LINKS FOR REAL TIME DGPS

The technology you pick for a real-time dgps data link depends on what you are trying to accomplish and how much money you have.

11:8.1 HF/VHF/UHF/Microwave Radio

HF radios are best for transmitting over long distances. This is the technology used by the U.S. Coast Guard's DGPS system. The drawback to using HF is that the receive antennas are relatively large (rather like a CB antenna) which can be a hassle if you are trying to survey with it. Transmit antennas can be even larger, a problem if you have space limitations.

VHF and UHF Radios are very light weight and use small, convenient antennas. The drawback is that VHF radio signals are largely limited to line-of-sight. UHF is even worse. If you are mapping or surveying with two units you will probably only get a couple of miles range maximum. To go further you will have to get the transmit antenna up higher, using a mast or tower. Hilly terrain and dense trees can limit where you can hear the signal.

11:9 CONCLUSION

There are many different types of GPS systems. Each system is designed to provide a different level of accuracy and has a different level of complexity. To successfully use the capabilities of GPS surveying systems one must understand the equipment and techniques required to achieve the desired information. Most surveying systems used for obtaining information within the Drain Commissioners office are DGPS units. They have a radio connection to a base station and are setup in the field by the survey crew. This base station is related to known or assumed control point(s) and the rest of the survey information collected by the roving survey units are related to the known point(s).

Gathering survey information for drainage projects is often times the most difficult and costly portion of the design process and in determining the problems with a storm sewer or open drain system. GPS survey systems can be used to significantly reduce the amount of survey time required on projects and thereby reducing the overall cost of projects. An added benefit to obtaining information with GPS survey equipment is that the information can readily be used on other mapping projects and/or Geographical Information Systems.

QUESTIONS AND ANSWERS

1: What is Differential Correction?

A: Differential Correction (Differential GPS, DGPS) is the process of correcting GPS positions at an unknown location in the field with data collected simultaneously at a known or surveyed location, such as U.S. Coast Guard (USCG) beacons or Michigan Department of Natural Resources (DNR) base stations. The process of differentially correcting one receiver location relative to another can be done during post-processing in the office or in real-time in the field. In post-processed DGPS, the base station logs the measurements in a computer file enabling rover users to differentially correct their data upon returning to the office to indicate **where they were**. In real time DGPS, the receiver at the base station calculates error parameters for each satellite as measurements are received then transmits the corrections over a radio beacon, permitting rover users to see differentially corrected data immediately to indicated **where they are**.

2: How and when do we use differential correction?

A: Real-time GPS units have two antennas, one that receives information from satellites and one that receives information from USCG beacon signals. The receivers of these units are collecting and processing satellite and beacon information on the fly that enables the positions you are collecting to be differentially corrected and displayed during field data collection. This process will tell you **where you were** while in the field within given accuracy parameters (2-5m for Geos). Accuracy of 2-5m can be achieved with the Geo receiver, providing differential correction has been activated for the unit currently in use. Pro receivers can achieve sub-meter accuracy under the right conditions.

3: What is GPS?

A: The NAVSTAR GPS (NAVigation Satellite Timing And Ranging) Global Positioning System (GPS) is a space-based radio-navigation and time transfer system. It is an all-weather system operated by the Department of Defense and is available worldwide 24 hours a day.