Using Global Positioning Systems (GPS): How it Works, Limitations, and Some Guidelines for Operation

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The information contained within this document is subject to change without notice. This document was revised on May 24, 2000 to reflect the discontinuation of selective availability by the U.S. Military on May 1, 2000.

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1.1 Executive Summary

As the Department of Ecology (Ecology) continues to develop its research capabilities in support of its growing commitment in environmental monitoring, watershed and coastal zone modeling, and facility management many programs have purchased Global Positioning Systems (GPS). These systems are being used on an ongoing basis to obtain horizontal and vertical position information for several different research and management activities.

As the cost of mapping grade GPS systems (±10.0 to 0.50 meter accuracy) have dropped over the last few years the number of GPS users within Ecology has increased. A concern has been raised by the Geographic Information Systems Users Group at Ecology that the purchase of this equipment may be occurring in a haphazard fashion and that many of the new users are unaware of the limitations of the equipment and potential legal ramifications associated with it use. Based on this concern, an ad-hoc committee was established to develop a proposed set of guidelines and standards for the use of GPS at Ecology.

These guidelines are not designed to mandate a particular make, model, or manufacturer of GPS receiver. Rather, these standards are designed to assist new and old GPS users alike in:

1. identifying GPS receivers that are suitable for their needs,
2. selecting the correct datum, projection, and coordinate system for data collection,
3. collecting data in the field, and
4. transferring their data to geographic information systems (GIS) for analysis or mapping.

This document is divided into several sections. Section 1.2 and 1.3 provide a primer to assist new users in understanding how the GPS system works. Section 1.4 discusses the types of GPS receivers and the common modes and methods that are used when operating them. Section 1.5 discusses the datum and projection issue, while Section 1.6 provides a checklist of questions that should be answered by the GPS user prior to any field activity. Failure to answer the questions in Section 1.6 can make it a difficult task to convert the collected GPS data to a form suitable for use in a GIS. Section 2 contains a brief description of survey networks and what they consist of and provides the coordinates for a GPS benchmark located at Ecology's Lacey building. In addition, Sections 3 and 4 of this document contain a review of current state law as related to the use of GPS equipment by Ecology employees and a glossary of terms commonly used in the GPS surveying community, respectively.

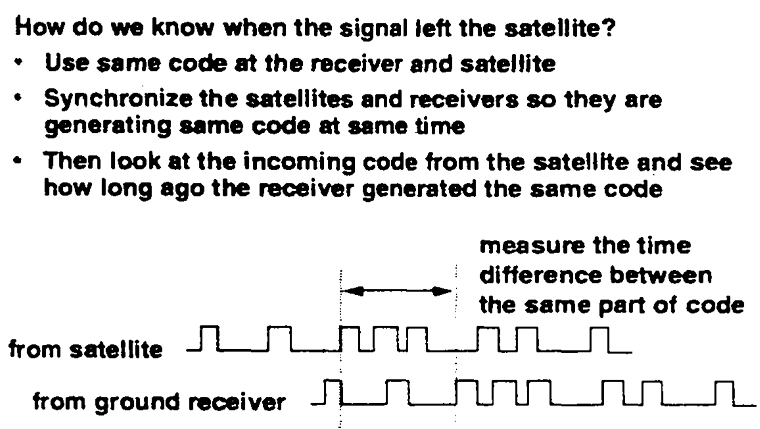
Based on the cursory review of current laws and regulations governing the practice of land surveying in the State of Washington the following observations were made concerning the collection of GPS data and the use of GPS for survey work at Ecology.

1. The retracing of existing records of survey does not require the services of a Registered Land Surveyor.
2. The collection of point, line, and other survey data does not constitute land surveying as described in law as long as the data is not used for the delineation of a boundary for legal purposes or for the division of land. (E.g., construction of a digital elevation model from GPS point data would be allowed, but the generation and use of a specific contour elevation from the data for regulatory purposes would require the supervision of a Registered Land Surveyor).
3. The placement of markers and reference stations in support of the work of Ecology does not require the services of a Registered Land Surveyor as long as the markers do not delineate a legal boundary.
4. When the proper performance of a proposed survey requires technical knowledge and skill and will be used for determining a legal boundary, the services of a Registered Land Surveyor are required.

1.2. GPS, How it Works

The whole idea behind GPS is to use satellites in space as reference points for locating positions here on earth. If we can accurately measure the vector from three objects we can "triangulate" our position anywhere on earth. Our distance from the satellite is measured by calculating the time it takes for a radio wave to travel from the satellite to our GPS receiver. We multiply this time by the speed of light to get our distance. Because radio waves travel at 300 million meters a second, the clocks used to measure the travel time must be extremely accurate (i.e.: hundredths of a nanosecond, 1 nanosecond = 1 billionth of a second).

For one satellite, the distance *(d1)* of a GPS unit is equal to the time its takes the radio signal to travel between the two, multiplied by the speed of the radio signal (the speed of light). The time of the signal is determined by measuring the difference between the same parts of the coded signals, as shown in the figure below. The set of all points where our GPS receiver could be at that distance (*d1*) can now be represented as the surface of a sphere in the second figure below.



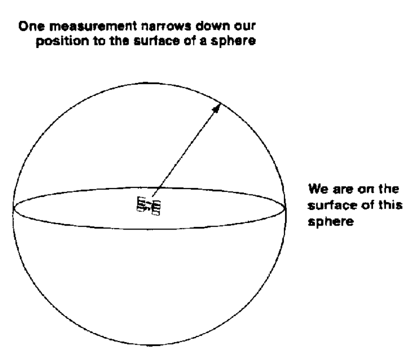


Figure 1. Sphere formed using time to calculate a distance from a receiver position to a satellite (Trimble 1994).

If we measure our distance to a second satellite and find out that it is (*d2)* meters away. That tells us that we're not only on the first sphere but we're also on a sphere at its respective distance from the second satellite. Or in other words, we're somewhere on the circle where these two spheres intersect. This intersection is the circle as seen in Figure 2 below.

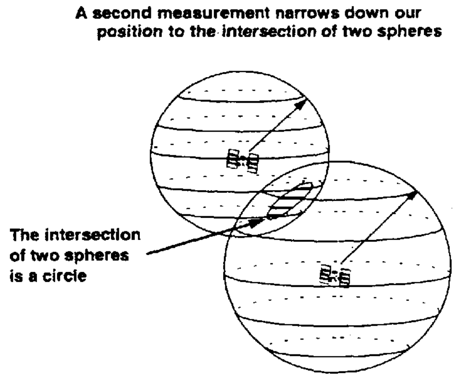


Figure 2. Circle formed by measuring the distance from our position to two satellites (Trimble 1994).

If we make another measurement to a third satellite at distance (*d3*), this narrows our possible positions down to two points shown in Figure 3. So by ranging from three satellites we have narrowed our position down to two points in space.

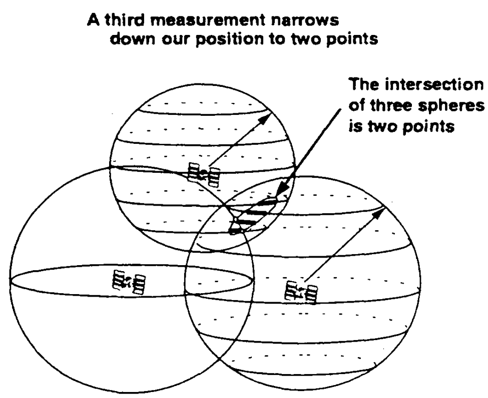


Figure 3. Two points formed by measuring the distance from our position to three satellites (Trimble 1994).

To decide which of these two points is our true location we could make a measurement from a fourth satellite. However, usually one of the two points is a ridiculous answer (either out in space, underground, or traveling at an impossible velocity) and can be rejected without a measurement.

To be able to fix our position with only three satellites requires that there be accurate clocks not only in the satellites but also in the receiver units. A clock at the receiver unit is needed to ensure that the signals are perfectly synchronized. Because these clocks are so expensive, it is impossible to put them in receivers. Instead, receivers use the measurement from a fourth satellite to remove clock errors. Figure 4 shows how the receiver senses the error.

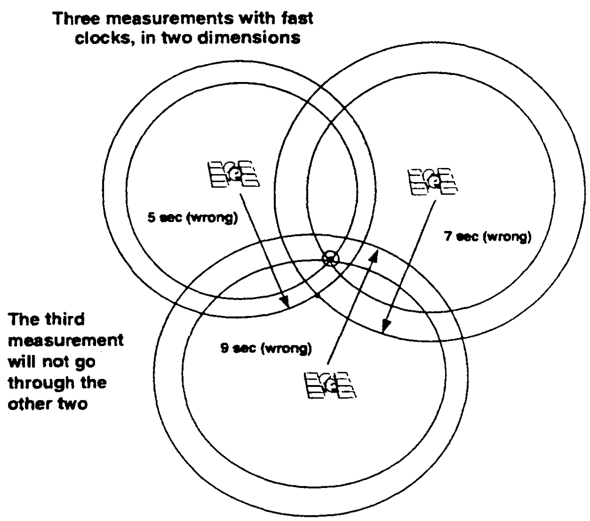


Figure 4. Clocks errors prevent the three ranges from intersecting in a single point (Trimble 1994).

When a GPS receiver gets a series of measurements that do not intersect at a single point, the computer inside the receiver starts subtracting (or adding) time until it arrives at an answer that lets the ranges from all satellites go through a single point. It then works out the time offset required and makes appropriate adjustments. Because of this, four satellites are required to cancel out time errors if you require three dimensions. Figure 5 shows the employment of a fourth satellite for 3D work.

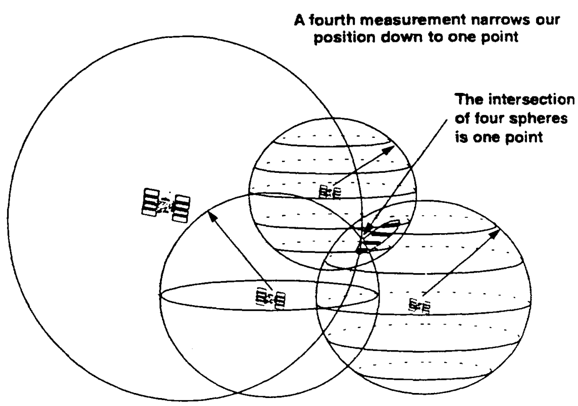


Figure 5. Fourth satellite used to solve the four unknowns, X, Y, Z, and time (Trimble 1994).

Errors Sources. Because no system is perfect, it is important to analyze specific sources of error that can exist in our GPS measurements. The typical error sources and values for most receivers are shown in Table 1.

Table 1. Error sources that must be considered when calculating position with GPS.

Error Source	Size of Error
Satellite Clocks	< 1 Meter
Ephemeris Error	< 1 Meter
Receiver Errors	< 2 Meters
Ionosphere	< 2 Meters
Troposphere	< 2 Meters
Selective Availability (SA)	< 33 Meters*

Note: SA was turned off by order of the President on May 1, 2000.

Theses values correspond to averages of many readings rather than the error which might result from a single reading. Although experimentation shows that the more fixes you record the better the data become, the increase in accuracy after collecting about 180 fixes at a given location is minimal and seldom worth the extra time it takes to record them. Later in this paper, better methods are discussed to get really accurate data.

Clock Errors. The ability of a GPS receiver to determine a fix depends on its ability to determine how long it takes a signal to get from the satellite to the receiver antenna. This requires that the clocks in the satellite be synchronized. Even a small amount of difference in the clocks can make large differences in the distance measurements.

Ephemeris Errors. The receiver expects each satellite to be at a certain place at a particular given time. Every hour or so, in its data message, the satellite tells the receiver where it is predicted to be at a time “t” hence. If this ephemeris prediction is incorrect, and the satellite not where it is predicted to be, then the measurement of the range from the receiver antenna to the satellite will be incorrect.

Receiver Errors. The receiver cannot exactly measure and compute the distance to each satellite simultaneously. The computer in the receiver works with a fixed number of digits and is therefore subject to calculation and rounding errors.

Atmospheric Errors. For most of its trip from the satellite to the receiver antenna, the GPS signal travels through the virtual vacuum of “empty space”. Half of the mass of the earth’s atmosphere is within the first 3.5 miles of the surface. Virtually all of it lies within the first 100 miles of the surface. This means that the signal gets to go the speed of light for more than 19,000 of its 20,000 kilometer trip. When it gets to the earth’s atmosphere, however, the speed drops by an amount that varies somewhat randomly. This small change in speed induces a small error in distance and therefore errors in position (about 4 meters). These errors from the ionosphere are primarily from charged particles under the influence of the earth's magnetic field. More sophisticated GPS units are able to calculate and remove the effects of the ionosphere. The troposphere, the denser atmosphere closer to the earth, generates error primarily due to changes in atmospheric pressure and depth. Currently, this error source is ignored for most applications.

Selective Availability (SA). As you can see from table above, that the lion's share of the error in the GPS system is from the deliberate corruption of the signal by the U.S. Department of Defense (DoD). The DoD does not want a potential adversary to be able to use our own technology against the United States. Un-tampered with, the system is accurate enough to be used for the guidance of weapons in real time, which means they could potentially use a GPS unit as a guidance device on ballistic missile. Selective availability is one technique the military uses to keep the system from being too accurate. The error is induced by randomly dithering the exact time of the signal (making it inaccurate). This random dithering affects Coarse/Acquisition or (C/A) code, the one which most GPS receivers use. GPS satellites also transmit a "Precise" code (P-Code). The P-Code is more accurate and generally used by military and survey accuracy receivers. The military has the ability to encrypt the P-Code and make unavailable to any but military users with the properly encryption equipment. The encryption of the P-Code signal is called "Anti-Spoofing" and once it is done the encrypted P-Code is referred to as the Y-Code.

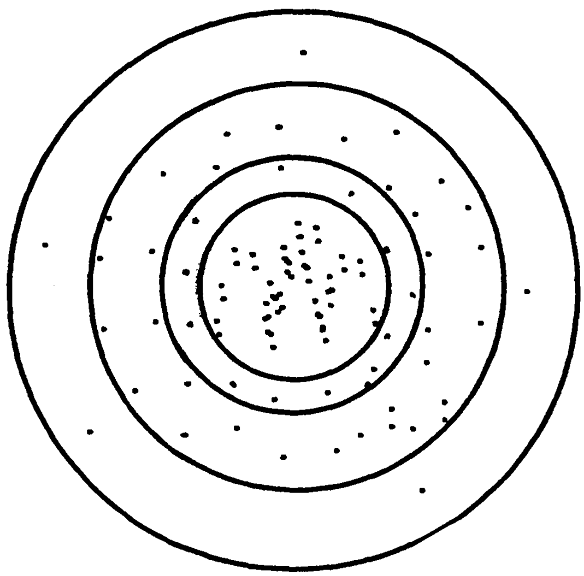
Getting Accuracy. When you take a single position with a GPS unit, even with selective availability on, you are 95% guaranteed that you will be within 100 meters of the point's true position. In 5% of the cases you will be further away. You can improve your accuracy in the autonomous mode, by taking many readings at a fixed location. This is because GPS readings tend to cluster around the true value and averaging a large number of readings cancels out the random errors.

Another method related to averaging is called "over-determined " position. This method requires five or more satellites to be used. By selecting different sets of four satellites (required for a 3D fix) you obtain a different opinion or solution of your position. The average solution of these different groupings gives a better determination of your actual position. Some but not all receivers will collect data this way. Experimentation has shown that when taking a large number of points that 50% of the points will lie within 40 meters horizontally and 70 meters vertically of the true position. This 50% statistic is sometimes referred as Circular Error Probability (CEP). Figure 6 on the next page shows how points are distributed when taking many readings.

With averaging it is possible to drive down the error down to one to two meters but it would take several weeks to months of data collection to obtain this accuracy. By averaging over 180 positions, you can improve your fix accuracy to about ±30 meters. If you recorded 1 fix per second, it would take you about 3 minutes to achieve this accuracy.

There are other methods like differential correction that allow you to collect very accurate points very quickly.

1st ring (inner) is CEP at 50% of the fixes
2nd ring is RMS at 63% of the fixes
3rd ring is 2DRMS at 95% of the fixes
4th ring (outer) is 3DRMS at 100% of the fixes



CEP (circle error probability) is based upon a circle of one half the fixes of a specified point. For example: 100 fixes, the CEP would encompass 50.

rms (route mean square) includes 63 of the original 100 fixes.

2drms (twice the distance root mean square) includes 95 of the fixes (95%).

3drms (three times the distance root mean square) includes 100 fixes (100%).

The rings of accuracy describe CEP and the RMS figures used for the definition of GPS accuracy.

Figure 6. CEP scatter for positions for 100 fixes (Trimble 1994).

1.3 The GPS Network

Satellites

The U.S. GPS satellite design calls for a total of 24 solar-powered radio transmitters, forming a constellation where several are "visible" from any point on earth at any given time. The first satellite was launched in secrete on February 22, 1978. Additional satellites were launched until mid-1994 when all 24 satellites were broadcasting. This became the standard GPS constellation of 24 satellites, which includes three spares. Figure 7 shows the various satellites and their launch dates.

Satellite launches

The oldest currently working (at the time of this writing) Block I satellite was launched in 1984. Subsequent launches have been as follows (in date order of launch):

SVN	PRN	Launched	Set operational
		Block I Satellites	
9	13	6-13-84	7-19-84
10	12	9-8-84	10-3-84
11	3	10-9-85	10-30-85
		Block II Satellites	
14	14	2-14-89	4-15-89
13	2	6-10-89	8-10-89
16	16	8-18-89	10-14-89
19	19	10-21-89	11-14-89
17	17	12-22-89	1-11-90
18	18	1-24-90	2-14-90
20	20	3-26-90	4-18-90
21	21	8-2-90	8-31-90
15	15	10-1-90	10-15-90
		Block IIA Satellites	
23	23	11-26-90	12-10-90
24	24	7-4-91	8-30-91
25	25	2-23-92	3-24-92
28	28	4-10-92	4-25-92
26	26	7-7-92	7-23-92
27	27	9-9-92	9-30-92
32	1	11-22-92	12-11-92
29	29	12-28-92	1-5-93
22	22	2-3-93	4-4-93
31	31	3-30-93	4-13-93
37	7	5-13-93	6-12-93
39	9	6-26-93	7-20-93
35	5	8-30-93	9-28-93
34	4	10-26-93	11-29-93

NOTE: SVN refers to the satellite number and PRN indicates the pseudorandom noise code of the satellite.

Figure 7. Satellite vehicle numbers and launch dates (Kennedy 1996).

The satellites are at a “middle altitude” of 20,000 kilometers (km), or roughly 12,600 statute/10,900 nautical miles (nm), above the earth’s surface. This put them above standard orbital heights of the space shuttle and most other satellites but below most geosynchronous communication satellites. The constellation of satellites is called NAVSTAR their paths are neither Polar nor equatorial, but slice the earth’s latitudes at about 55 degrees. Each satellite orbits the earth in about 12 hours, and an observer on earth will see the satellite rise and set 4 minutes earlier each day. There are four satellites in each of six distinct orbital planes. The orbits are almost exactly circular and produce a wide variety of tracks across the earth’s surface. Figure 8 shows what the constellation looks like from space.

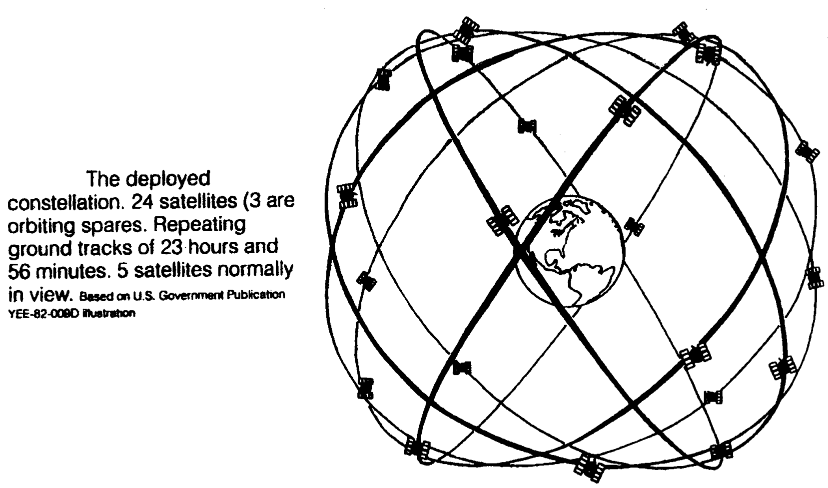


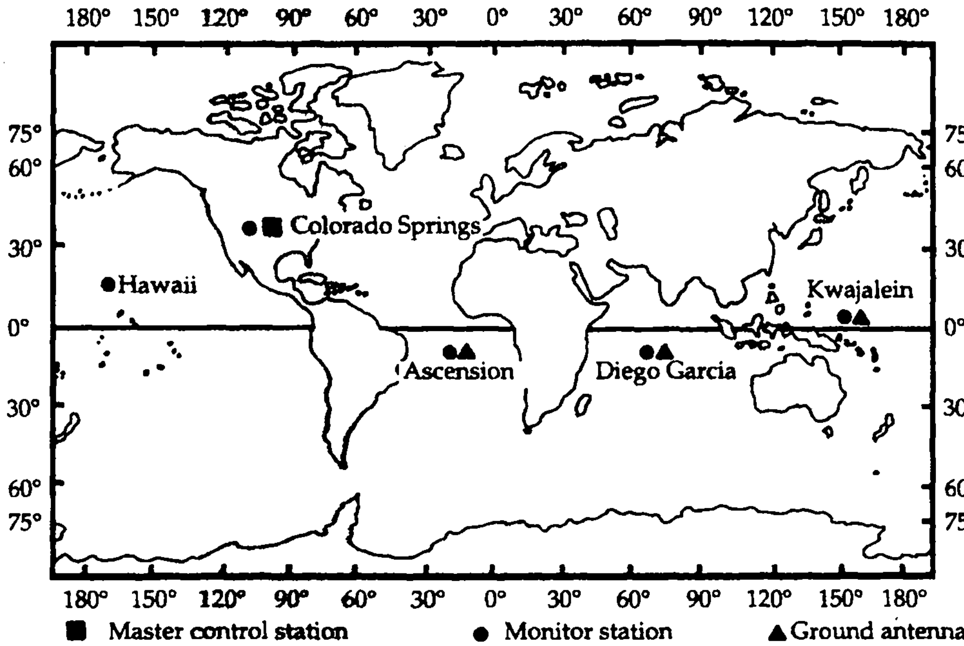
Figure 8. Satellite constellation (Trimble 1994).

Ground Stations

While the GPS satellites are free from drag by the air, their tracks are influenced by the gravitational effects of the moon and the sun, and by the solar wind. Further, they are crammed with electronics. Because of this their tracks and inner workings require constant monitoring. This is accomplished by four ground base stations, located on Ascension Island, at Diego Garcia, in Hawaii, and at Kwajalein atoll in the Pacific. Each satellite passes over at least one monitoring station twice a day. Information developed by the monitoring station is transmitted back to the satellite, which in turn re-broadcasts to GPS receivers. The broadcasts contain information on the health of the satellite’s electronics, how the track of the satellite varies from what is expected, the current almanac for all the satellites, and other information. Other ground-based stations exist, primarily for uploading information to the satellites. The master control station is in Colorado Springs, Colorado at the Air Force Space Command Center. See Figure 9 on the following page.

The MCS is the central processing facility for the network and is manned 24 hours per day, 7 days per week. It is tasked with tracking, monitoring, and managing the GPS satellite constellation and for updating the navigation data messages.

The task of the monitor stations is to passively track all GPS satellites in view



Locations of control segment installations. U.S. Government Publication YEE-82-009D

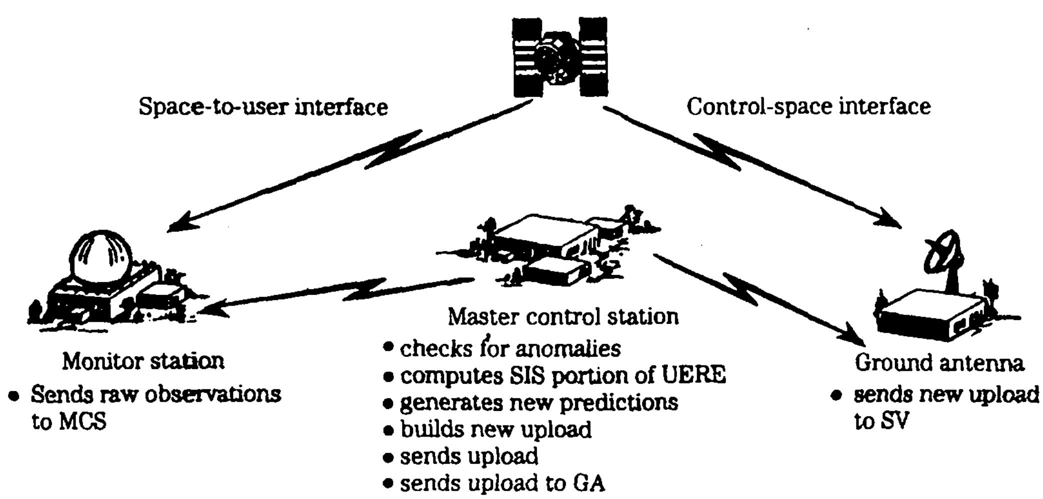


Figure 9. Ground Station and their locations (Trimble 1994).

1.4 GPS Receiver, Modes, Methods, and Types

GPS receivers are available in a wide range of configurations and price levels. Receivers may be purchased for as little as $99 or as much as $50,000. This range in cost is directly related to the features and precision that are achievable with the given unit. Users need to be wary of any low price unit that claim to be accurate to ±10 or better, as the advertised precision of a unit is often based on the best case scenario, which may or may not be achievable in the field.

The precision of a GPS receiver is determined based on the signals the receiver utilizes to calculated its position as well as the methods and modes used while it is in operation. Please note that the ***precision*** of a unit is based on the smallest significant unit (centimeter, decimeter, meter, tens-of-meters) that the receiver is able to repeatable measure. The ***accuracy*** of the coordinates obtained from the receiver is a function of both the receiver/antenna combination used and the projection, datum, and coordinate system selected by the user (see Section 1.5). Use of an unsuitable datum, projection, or coordinate system may degrade the accuracy of the data collected by the receiver or make it unusable when the data are downloaded and entered into a GIS.

GPS receivers calculate location based on the radio signals received through their antenna. The antenna should be positioned in such a way as to maximize its visibility to the open sky, as GPS signals will not penetrate vegetation, metal roofs or human bodies! Note that the position calculated by the receiver is actually the phase-center of the antenna, not the location of the receiver. As such, the GPS antenna should be placed on or over the position to be surveyed and the offset between the antenna and the known object (e.g., the antenna is on a 2.00 meter "range pole" and the tip of the range pole was set on top of the well head cover). By keeping track of these offsets, the GPS derived locations may be corrected to obtain the actual X, Y, Z, location of the point of interest.

The GPS user should be aware of the limitations inherent with the receiver/antenna configuration they are using, as the combination required often varies based on the type of survey being conducted.

GPS Modes

An individual GPS receiver may be able to operate within several different positioning modes. In order of precision these modes are autonomous, differential, kinematic, and static.

Autonomous positioning is a mode of operation of a GPS receiver where the receiver calculates position in real-time from satellite data alone without reference to data supplied from another receiver that is located at a fixed, known, location (i.e., base station). This is the least precise mode of operation. Point coordinate accuracy of ±100 m RMS is obtainable when selective availability is in effect and ±10 m when it is not.

Differential positioning is a mode of GPS surveying that uses two or more receivers with one receiver acting as a base station that is located at a known, fixed location and the other receiver roving to unknown points. The base station computes corrections based on the differences between its known location and its location as computed from the satellite C/A code. These corrections are applied to positions collected by the roving unit. This correction can be done in real-time via a radio link or during post processing back in the office. Point coordinate accuracy of ±30 m RMS is obtainable when selective availability is in effect and ±1 m when it is not.

Kinematic positioning is a mode of GPS surveying that uses two or more receivers with one receiver acting as a base station that is located at a known, fixed location and the other receiver roving to unknown points. The receivers use the L1/L2 carrier-phase observation (including both the C/A code and P-code) and requires short (1 second to 10 minute) occupation times at the locations being visited by the roving GPS receiver. This method uses *baselines* to calculate position and has the potential to obtain greater accuracy than is possible with differential positioning methods. Point coordinate accuracy of ±1 m RMS is obtainable when selective availability is in effect and ±0.02 m when it is not.

Static positioning (a.k.a., geodetic survey) is a mode of GPS surveying that uses two or more receivers. The receivers monitor the L1/L2 carrier-phase observations (including both the C/A code and P-code) and use long occupation times (> 20 minutes). This method uses *baselines* to calculate position and has the potential to obtain greater accuracy than is possible with differential and kinematic positioning methods. Location is determination when the receiver's antenna is stationary on the earth. Point coordinate accuracy of ±0.05 m RMS is obtainable when selective availability is in effect and better than ±0.01 m when it is not. At least three of the points visited during the survey should have known horizontal and vertical position. These known points are held fixed when calculating the baselines and insure that the newly surveyed points are tied into the local geodetic control network.

GPS Methods

The three methods used by GPS receivers to obtain position information are autonomous, post processed, and real-time. The autonomous method occurs when the GPS receiver is used as a stand-alone data collector and no further processing of the data will be done on return to the office. The location information collected is transcribed onto paper in the field or stored in the GPS unit for later transfer in the office to a database for mapping purposes. This method is the simplest and the least accurate of the three methods.

The post processing method is used when the GPS receiver is used as a data collector and further processing of the position data will be completed after down loading the data at the office. This method assumes that a base station receiver (located at a known, fixed, position) was collecting data simultaneously with the roving unit. Based on the types of receivers and antennas used during the survey and the positioning data collected either the differential, kinematic, or static processing mode may be used.

The real-time method occurs when the GPS receiver is used as a data collector and the positions obtained are corrected on-the-fly based on information received via radio signal received from a base station (located at a known, fixed, position). Based on the types of receivers and antennas used during the survey either the differential or kinematic mode may be used.

GPS Receiver Types

As the previous description of positioning methods and modes may have indicated, both the receiver and antenna directly impact the precision to which one may survey. For example, the Coastal Monitoring and Analysis Group within the Shorelands and Environmental Assistance Program currently has two Trimble 4400 survey grade receivers. These receivers are able to track both the C/A code and P-code and monitor both the L1 and L2 frequency of the GPS satellite signal. These receivers are used with L1/L2 Geodetic Antennas with a removable groundplain (a device that minimizes the effects of multipath on position calculations) and a real-time radio link.

The Trimble 4400 receiver configured as the base station uses a L1/L2 antenna with groundplain. In this configuration the base station commonly obtains a point position precision of ±0.01 m. When the second receiver is used as a rover (i.e., the groundplain is removed from the antenna), and real-time kinematic positioning method is used positions good to ±0.05 to 0.02 m are obtained. However, if we had used an L1 Compact Antenna (often used with Trimble mapping grade receivers) on the rover instead of the L1/L2 Geodetic Antenna, we would have obtained positions accurate of about ±0.5 m.

Table 2 shows in a general sense, the relative positioning accuracy that can be expected by different receiver types when using different modes of operation. Remember that the reported accuracy is usually reported as a RMS error and that any single GPS measurement may vary significantly from the mean

Table 2. Common horizontal accuracy of different GPS receiver configurations based on different modes of operation. There is a 95% probability that a single measurement will fall within a circle of the diameter shown (values in meters).

			Mode		
Receiver Type	**Autonomous**		**Differential**	**Kinematic**	**Static**
Navigation Unit Using L1 C/A Code ($99 to $1,000)	±100	(10)	±30 to 10 (5)	n/a	n/a
Mapping Unit Using L1 C/A and P Code ($1,000 to $8,000)	±30	(5)	±10 to 1	± 0.50	n/a
Survey Grade Unit Using L1 C/A, L1 P, and L2 P Code ($8,000 to $50,000)	± 30	(5)	±10 to 0.5	± 0.02	±0.001

Note: Both differential and kinematic modes may use the real-time method.
Note: SA was turned off on May 1, 2000, increased accuracy is shown in parentheses.

The range of accuracy's shown in Table 2 are controlled by two major factors, the status of SA and anti-spoofing (on or off) and the codes and frequencies the receiver uses to calculation position. For example, most mapping grade units only use the C/A and P Code from the L1 GPS signals to calculate position. Since they do not monitor the L2 frequency these units are unable to correct for position error introduced by atmospheric delay effects. In addition, the autonomous and differential modes of operation often use the Course Acquisition (C/A) code to calculation position. As the name indicates, use of the C/A code limits the *maximum* obtainable precision to ±30 m in autonomous mode and ±1 in differential mode.

SA was turned off by order of the President of the United States on May 1, 2000. Removal the SA "random error" from the GPS signal has increased the accuracy of standalone and autonomous GPS receivers by a factor of 10, improving the predicted accuracy of GPS for civilian users from within 100 m to within 20 m. This performance boost will enable GPS to be applied in its most basic form to a variety of civilian activities. Figure 10 shows the impact of the removal of SA on the calculated position of a stationary GSP receiver during the change over from with to without SA. Note that CEP stands for circle error probability (2 D coordinates) and SEP stands for spherical error probability (3 D coordinates).

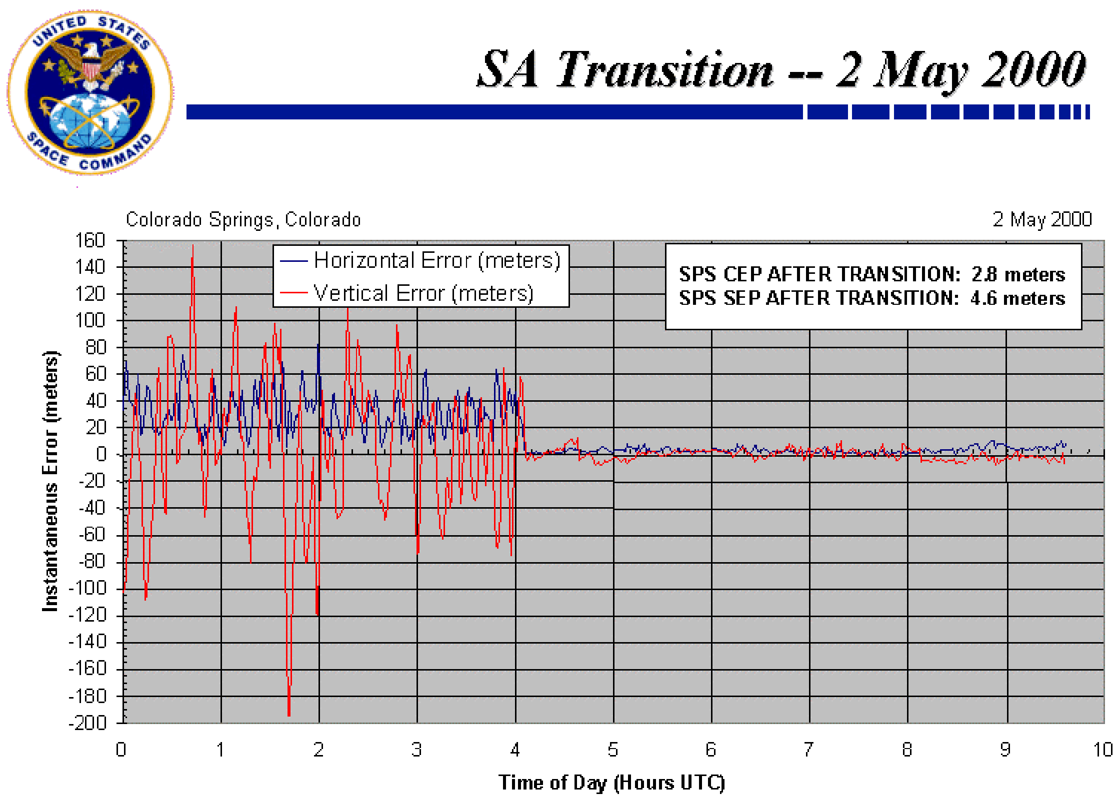


Figure 10. Accuracy of GPS derived position for a stationary GPS receiver before and after selective availability (SA) was turned off.

1.5 Projections, Coordinate Systems, and Datum's

The projections, datum's, and coordinate selected for use during survey or other data collection projects directly impact the obtainable accuracy of the final data. Every GPS user should have a basic understanding of the projection they are using, no mater how much computers seem to have automated the process.

A map projection is a systematic representation of all or part of the surface of a round body (e.g., the Earth) on a plane. Since one can not depict a round body on a plane with out distortion one must select those features of the map to be shown accurately at the expense of others. If the region to be mapped covers a large area such as a continent the distortion will be visually apparent. In contrast, if the area to be mapped covers a small area, such as a single state, distortion may be barely measurable if the correct projection is used.

There are an infinite number of projections that may be devised. Most of these projections are rarely used novelties that should be avoided when using GPS equipment. The most commonly used projections for mapping purposes are based on the Lambert Conformal Conic, Transverse Mercator, or Universal Transverse Mercator (UTM) projections. Once a projection has been selected a rectangular grid (e.g., Washington State Plain South or UTM zones) may be devised that allows the use of basic trigonometry functions to calculate position (a requirement in the past for rapid, error free, mapping while in the field).

In addition, a simple spherical coordinate systems may be devised (e.g., latitude and longitude) and used for mapping. Note that the latitude and longitude values are not arbitrary, the values are measurements from the Earth's center to a point on the Earth's surface and represent the angles of a line extending to that point. Latitude and longitude values are represented as degrees (360 degrees in a circle) and each degree can be divided into 60 minutes, and each minute into 60 seconds. Thus, the latitude and longitude coordinates for a given point on the Earth varies based on the size of the sphere, or shape of the ellipsoid, used to represent the Earth.

As noted above, the coordinate of a given location on the Earth, be it latitude and longitude or Northing and Eastings, vary based on the model the Earth used. In a spherical coordinate system this model is referred to as an ellipsoid or spheroid. In a rectangular grid system the model is optimized for a particular region of the world by combining an ellipsoid and other parameters (e.g., offsets) to define a datum.

Conversion of coordinates to or from spherical reference systems and rectangular systems that are defined based on a mathematical ellipsoid or datum model may be done with a minimal loss of accuracy. It is this constraint that must be considered when using GPS equipment as many older datum's, such as the North American Datum of 1927 (NAD 27), are based on ellipsoids that are quite different from the one currently used by the GPS system.

The GPS system uses the World Geodetic System of 1984 (WGS 84) as its standard datum. The North American Datum of 1983 (NAD 83) is used for precise horizontal positioning within North American and other near-by areas. The ellipsoid used by NAD 83, Global Reference System of 1980 (GRS 80), is nearly identical to WGS 84. Since both of these two datums are defined based on precise mathematical model of the Earth, direct conversion between the two is possible.

The previous discussion of datums was predominantly concerned with horizontal coordinates systems. When one needs elevations tied to a vertical datum in the United States other issues arise. In the U.S. there are three commonly used vertical datums, Mean Lower Low Water (MLLW) as defined by a tide gauge, Mean Sea Level (MSL) or National Geodetic Vertical Datum of 1929 (NGVD 29), and the North American Vertical Datum of 1988 (NAVD 88). Of these only NAVD 88 is directly supported by GPS.

Why is this? Recall that GPS obtains positions in the WGS 84 datum. This datum supports horizontal and vertical coordinates, where the vertical coordinate is represented as a distance from the center of the Earth. This value is often converted based on a geoid model (a model of a surface of constant gravitational pull, specifically the one that most closely coincides with mean sea level over the entire surface of the earth) to a value more closely resembling a traditional elevation.

The conversion between the WGS 84 datum and a local coordinate system, such as Washington State Plain South, NAD 83, involves several steps (Figure 2). Each step is a well-defined mathematical process that depends on a known set of parameters that are used to convert the GPS coordinates into coordinates in the projection needed. Many GPS receivers allow many of these transformations to be done on-the-fly by the software loaded in the data collector.

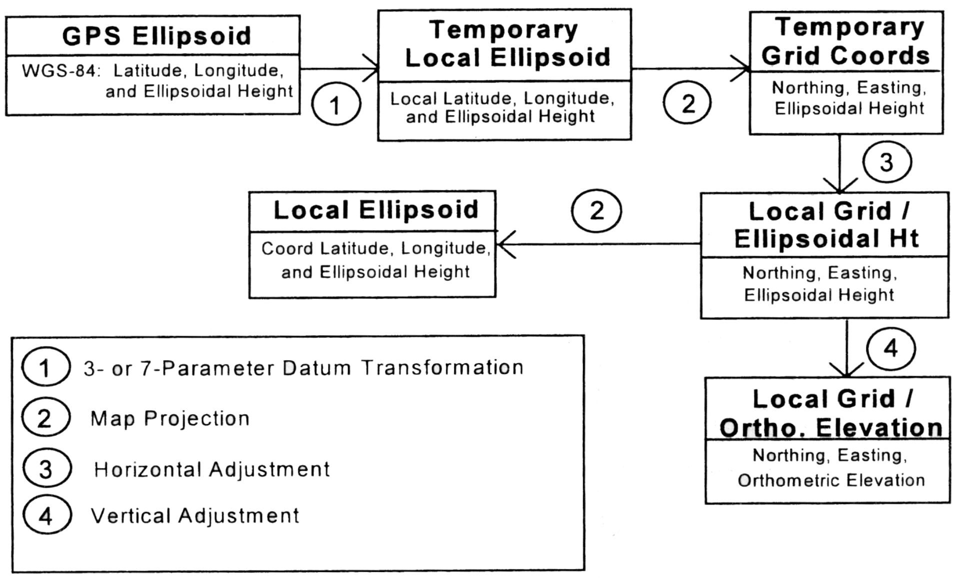


Figure 11. Converting between WGS 84 and a local map grid such as Washington State Plain South NAD 83 (Trimble 1996).

The current geoid model, known as GEOID 99, developed by the National Geodetic Survey (http://www.ngs.noaa.gov) supports the direct conversion of GPS elevations into NAVD 88. Note that the conversion to NGVD 29 is not support by the National Geodetic Survey. Thus, to obtain an estimated elevation in NGVD 29 (MSL) or a MLLW datum requires that the user to obtain a GPS measurement at a reference station with a known elevation in the older datum and that the offset or correction be determine. The calculated correction may then be apply to other GPS derived NAVD 88 elevations to obtain an elevation expressed in the older datum. Such a correction is only valid near the observed benchmark or reference station (< 50 km).

1.6 Standard Practices and Guidelines

The goal of this document is not to dictate the type or model of GPS receiver purchased by a particular group within Ecology. Instead this document is designed to provide a basic level of information that all GPS users should know and consider when designing a particular GPS survey or data collection effort. Failure to consider the factors described here may result in the loss of valuable data or the collection of data that does not meet the stated need of the project.

To assist the user in identifying the inherent limitations associated with their equipment and in documenting the settings used during a particular data collection effort Figure 12 has been prepared. When completed this form provides a record of the equipment types used and how it was configured for a particular survey. This information is the minimum information that a third party (e.g., your GIS Analyst or the person doing your Post Processing) will need to convert the raw GPS data to meaningful information.

GPS Data Collection Record

WASHINGTON STATE DEPARTMENT OF ECOLOGY

Contacts (Who)

Project Leader: ______________________ Region: ______________________

Phone: ______________________ E-Mail: ______________________

Division/Section/Unit: ______________________

Field Crew Members

Name/phone (1): ______________________

Name/phone (2): ______________________

Name/phone (3): ______________________

Names of additional members: ______________________

Primary computer operator: ______________________

Location of computer files: ______________________

Survey Description (Where & Why)

Location Surveyed: ______________________

Purpose of Survey: ______________________

Continue on the back of form if needed

Equipment

Mode of Operation (Circle one): Autonomous Differential Kinetmatic FastStatic Static

Method of Operation (Circle one): Standalone Post Processing Real Time

Base Station used (Circle one)? Yes No

Tripod/range poles used (Circle one)? Yes No

If YES, list make and height of pole used next to each receiver.

Make & Model of GPS Receivers/Antennas. If a receiver was used as a base station check box on right.

Receiver/Antenna (1): ______________________ ☐

Receiver/Antenna (2): ______________________ ☐

Receiver/Antenna (3): ______________________ ☐

List additional receiver/antenna configurations on the back of form

GPS Settings

Epoch (Seconds): __________ Mask Elevation (degrees): __________

Horizontal Datum (e.g., NAD 83): ______________________

Horizontal Projection (e.g., WA State Plain, South, NAD83): ______________________

Horizontal Units (e.g., meters): __________

Vertical Datum (e.g., NAVD 88): ______________________

Vertical Units (e.g., meters): __________

Note, the native GPS receiver horizontal and vertical datum is WGS 84. Vertical elevations are represented in meters above/below the WGS 84 ellipsoid.

Figure 12. Record of equipment, equipment settings, and procedures used for GPS data collection efforts.

1.7 References

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Department of Licensing. 1998. The Law Relating to Engineers and Land Surveyors. RCSC-651-001, Washington Department of Licensing, Olympia, WA.

Trimble. 1996. *GPS Surveying General Reference*. Part Number 25748-20, Revision A, Trimble Navigation Limited. Sunnyvale, CA.

Trimble. 1994. *Mapping Systems General Reference*. Part Number 24177-00, Revision A, Trimble Navigation Limited. Sunnyvale, CA.

Kennedy, M. 1996. *The Global Positioning System and GIS*. Ann Arbor Press, Chelsea, MI.

Zilkoski, D.B., J. D. D'Onofrio, and S. J. Frakes. 1997. *Guidelines for Establishing GPS-Derived Ellipsoid Heights (Standards 2 cm and 5 cm), Version 4.3*. NOAA Technical Memorandum NOS NGS-58, National Geodetic Survey, Silver Spring, MA.

SECTION 2: SURVEY NETWORKS

2.1 What is a Network?

What is a “network” and why do I need one? This question is often asked by new GPS users. To begin with, the new GPS users needs to realize that when they are collecting points or lines on the ground they are performing a survey. With this realization one should ask how will this data be connected or related to the real world. For projects where accuracy’s of ±30 m or less are suitable, the “network” is actually formed by the constellation of satellites that are in view during the survey. These satellites provided “control” to the survey by transmitting radio signals that are received by the GPS receiver on the ground. The receiver computed the distance to each satellite and via triangulation is able to determine its location on the Earth.

For data collection projects (surveys) with more stringent accuracy requirements, e.g., ±10.0 to 0.5 m, an additional point of reference is added to our “network”. This addition is the location of the base station. The base station may be a GPS receiver that you setup and operate during the survey or may be a receiver owned by a third party (e.g., U.S. Coast Guard, King County, etc.). In either case, the base station is assumed to be located at known position. The data collected by the base may be stored for later retrieval (for a post-processed survey) or may be transmitted over radio to the user in the field (for a real time survey).

Surveys that require an accuracy of ±0.50 to 0.02 m need additional control (Zilkoski et al. 1997). This control is obtained by visiting locations in the field during the survey that have known coordinates (of similar quality to the base station). These points are surveyed for a few seconds to several minutes and are used to calibrate the project. Calibration is the process where software in the receiver further constrains the results of the correction provided by the base station to obtain sub-decimeter accuracy levels.

Thus, to be able to conduct surveys of relatively high accuracy one needs to have a network of survey stations with known coordinates distributed throughout the project area. The development of such a network is a time-consuming process (e.g. Daniels et al. 1999). Fortunately, the National Geodetic Survey, U.S. Corps of Engineers, Washington State Department of Transportation, and many county and city governments have develop their networks to support ongoing operations. By taking advantage of these networks one should be able to perform sub-meter surveys almost any location within the state of Washington.

2.2 Survey Station PARK

To support the increasing use of GPS within Ecology, the Shorelands and Environmental Assistance Program (Coastal Monitoring and Analysis Program) has installed and surveyed a control station at the Ecology Headquarters building in Lacey, Washington. This survey station was installed to provide a fixed reference point with known coordinates at Ecology. This control point may be used in three ways,

1. as a base station site during surveys within the area (~100 km),
2. as a control point for use during training of new GPS field personnel,
3. as a reference point to which the coordinates obtained by less expensive mapping and navigation grade receivers may be compared.

The coordinates derived by Ecology for station PARK were obtained using the static observation method and followed NGS guidelines (Zilkoski et al. 1997). During the survey six, forty-five minute GPS sessions were conducted using Trimble 4400 series GPS receivers. The receivers were setup over stations PARK (at Ecology), Q 13, HOSP RM 4, and A 461.

Stations Q 13 (PID SY0708), A 461 RESET 2 (PID SY1600), and HOSP RM 4 (PID SY3193) were installed by the NGS and provided the control for the survey and the ties to the national geodetic network. Station Q 13 served as the primary control for this survey. Q 13 had been resurveyed in 1998 by the NGS as part of observations conducted for the Washington High Accuracy Reference Network (HARN). The coordinates of Q 13 were held fixed during the final adjustment as the station had both a first order vertical elevation and a B order horizontal coordinate (the horizontal order, or accuracy, of a station may range from AA, A, B, 1, 2, 3 -with AA being the best). Stations HOSP RM 4 and A 461 provided additional secondary control to the survey.

The baselines obtained by this survey agreed to within ±0.011 m over a distance of 3,821 m from station Q 13 to PARK, to within ±0.006 m over a distance of 6,196 m from station A 461 to PARK, and to ±0.015 m over a distance of 3,821 m from station HOSP RM 4 to PARK.

2.3 Observation Plan for Station PARK

The new survey mark, PARK, is located in Lacey, Washington. The mark is a four foot stainless steel rod mark set flush with the ground with an aluminum logo cap stamped PARK 2000. The station is being surveyed to provide local control for use by Ecology personnel during training and as a base station site during GPS work within 50 miles of the Ecology HQ building.

The following ties will be made to obtain a GPS ellipsoid elevation, NAVD 88 height, and second order horizontal coordinates for the new station. UTC date for paper work and job names: UTC on 27 March is 087. UTC time is +8 hours from Pacific Standard Time.

27 March 2000

Session	Receiver	Station	Type	Time
101	R1	Q 13	Primary	1310 to 1425
	R2	PARK	New Station	
102	R1	HOSP RM 4	Secondary	1450 to 1535
	R2	PARK	New Station	
103	R1	A 461 RESET 2	Secondary	1615 to 1705
	R2	PARK	New Station	

28 March 2000

Session	Receiver	Station	Type	Time
201	R1	Q 13	Primary	0945 to 1030
	R2	PARK	New Station	
202	R1	HOSP RM 4	Secondary	1100 to 1145
	R2	PARK	New Station	
203	R1	A 461 RESET 2	Secondary	1215 to 1300
	R2	PARK	New Station	

Note: sessions are 45 minute sessions with 5 second epoch intervals, 15 degree masks, and QA 1 and 2 on.

Equipment

R1	Tripod:	Sakko, 2m fixed, HT + PCO = 205.6455 cm
	Antenna:	Trimble L1/L2 Compact W/Groundplain, PN 220220-00, SN 0220079730
	Receiver:	Trimble 4400, PN 29887-11, SN 3652A18127
R2	Tripod:	Omni, 2m fixed, HT + PCO = 204.2625 cm
	Antenna:	Trimble L1/L2 Compact W/Groundplain, PN 220220-00, SN 0220079600
	Receiver	Trimble 4400, PN 29887-11, SN 3652A18099

2.4 Station Description and Coordinates

The coordinates shown were derived by the Washington Department of Ecology and are not available from the National Geodetic Survey. NAVD 88 elevations were derived from GPS observations. Elevation accuracy is estimated to be ±0.02 m. Horizontal coordinates meet Second Order standards.

DESIGNATION: PARK
STATE/COUNTY: WA/THURSTON
USGS QUAD: LACEY (1986)
STAMPING: PARK 2000
UPDATE: October 16, 2000

COORDINATES

WA STATE PLAIN SOUTH (NAD 83, M)	192,957.682 N 324,710.351 E	ADJUSTED
WA STATE PLAIN SOUTH (NAD 83, FT)	633,062.00 N 1,065,320.54 E	ADJUSTED
NAD 83 (1991)	47° 02 46.47702 N 122° 48 25.87235 W	ADJUSTED
WA STATE PLAIN SOUTH (NAD 27, FT)	1,425,198.65, 633,115.79	NADCON
NAD 27	47° 02 47.13049 N 122° 48 21.38606 W	NADCON

ELEVATIONS

NAVD 88	49.78 M	GPS OBS
NGVD 29	159.90 US FT	VERTCON
NAD 83 ELLIPSOID	27.948 M	GPS OBS
GEOID	-21.839 M	GEOID99
GEOID	-21.630 M	GEOID96

REFERENCE STATION	DISTANCE (M)	WA STATE PLAIN SOUTH (NAD 83, M)	ELEVATION (NAVD 88, M)
PARK RM 1	101.48	193,035.100 N 324,644.708 E	49.439

DESCRIPTION

STATION MONUMENTED ON MARCH 22, 2000 AND IS LOCATED IN THE CITY OF LACEY AT THE WASHINGTON DEPARTMENT OF ECOLOGY BUILDING. TO REACH FROM INTERSTATE 5 AND MARTIN WAY HEAD EAST ON MARTIN WAY 0.4 MILES TO A STOP LIGHT AND INTERSECTION WITH DESMOND DRIVE ON RIGHT. TURN RIGHT (SOUTH) ON DESMOND DRIVE AND FOLLOW SIGNS TO THE ECOLOGY BUILDING. CONTINUE PAST THE MAIN ENTRANCE TO VISITORS PARKING ON LEFT AND PARKING GARAGE ON RIGHT. TURN RIGHT AND PROCEED SOUTH ABOUT 150 M TO THE SOUTHERN MOST PARKING LOT AT ECOLOGY. THIS LOT IS ADJACENT TO THE SOUTH WING OF THE ECOLOGY BUILDING.

PROCEED TO THE SOUTH END OF THE SOUTH WING OF THE ECOLOGY BUILDING. THE STATION IS 39.85 M (138 DEGREES MAGNETIC) FROM THE SOUTHWEST CORNER OF A 29.5 BY 9.7 M CEMENT PATIO, 22 M SOUTH OF A GATED ACCESS ROAD, 2.4 M SOUTH OF AND CENTERED ON A BENCH, AND 8.5 M WEST AND 1.22 M HIGHER THAN THE WEST CURB OF A PARKING LOT.

THE STATION IS A 3-INCH ALUMIUM SURVEY DISK ATTACHED TO A 4 FT STAINLESS STEEL ROD DRIVEN INTO THE GROUND AND CEMENTED IN PLACE WITH SIXTY POUNDS OF CONCRETE. THE STATION IS STAMPED PARK 2000.

REFERENCE MARK NUMBER 1 (NO STAMPING) IS THE CENTER OF A ½ INCH BOLT ATTACHED WITH A PK NAIL TO THE PAVEMENT OF A FIRE ACCESS ROAD AND IS ABOUT 3 M SOUTH OF A FIRE HYDRENT, ABOUT 0.4 M NORTH OF THE SOUTH EDGE OF PAVEMENT, AND 0.1 M NORTHWEST OF A WATER VALVE ACCESS COVER (PAINTED RED). THE MARK IS 77.42 M NORTH, 65.643 M WEST, 0.34 M LOWER, AND AT A BARRING OF 319 DEGREES 42’ 18” (GRID) FROM THE STATION.

SECTION 3. THE LAW RELATING TO LAND SURVEYORS

Several state laws and administrative codes apply to the practice of land surveying and engineering in the State of Washington (Department of Licensing 1998). It is important to be aware that these laws exist and that they may have an impact on the how you define, perform, and document a survey or data collection activity. This section contains extracts from several regulations and codes that may apply directly to you as a state employee. Additional information on the laws and codes that cover the practice of surveying may be obtained by consulting the complete text of the laws and administrative codes listed in the following table.

Table 3. Laws and administrative codes of the State of Washington concerning the practice of Land Survey and Engineering.

Law or Administrative Code	Description
State Law	
Chapter 18.43 RCW	Engineers and Land Surveyors
Chapter 38.80 RCW	Contracts for Architectural and Engineering Services
Chapter 58.04 RCW	Boundaries
Chapter 58.09 RCW	Surveys – Recording
Administrative Code	
Chapter 332-130 WAC	Surveys and Land Descriptions
Chapter 196-09 WAC	Practice and Procedure
Chapter 196-12 WAC	Registered Professional Engineers
Chapter 196-16 WAC	Registered Professional Land Surveyors
Chapter 196-20 WAC	Engineers-in-Training
Chapter 196-21 WAC	Land Surveyors-in-Training
Chapter 196-24 WAC	General
Chapter 196-25 WAC	Business Practices
Chapter 196-26 WAC	Engineers and Surveyors - Fees
Chapter 196-27 WAC	Rules of Professional Conduct

The practice of land survey is a regulated and licensed profession within the State of Washington. As such it is "unlawful for any person to practice or to offer to practice … land surveying, as defined in the provisions of this chapter, or to use in connection with his name or otherwise assume, use, or advertise any title or description tending to convey the impression that he is a professional engineer or a land surveyor, unless such a person has been duly registered under the provisions of this chapter" (RCW 18.43.010).

RCW 18.43.020 goes on to state that a Registered Land Surveyor must be the approving authority or supervise any work that deals with the "surveying of land for the establishment of corners, lines, boundaries, and monuments, the laying out and subdivision of land, the defining and locating of corners, lines, boundaries, and monuments of land after they have been established, the survey of land areas for the purpose of determining the topography thereof, the making of topographical delineation's and the preparing of maps and accurate records thereof, when the proper performance of such services requires technical knowledge and skill."

The complete text of RCW 18.43 makes it clear that only Registered Land Surveyors may certify the accuracy and correctness of land surveys that are recorded as legal documents (i.e., a record of survey). In addition, individuals performing land surveys must be supervised by a Registered Land Surveyor. This fact may lead one to believe that a Registered Land Surveyor must be involved in all survey type work.

Fortunately for us this is the not case. RCW 58.09.090 exempts many of the common survey or mapping tasks that would be conducted by a public employee from this regulation. Specifically, RCW 58.09.090 states that a record of survey is not required (and thus a Registered Land Surveyor) "when it (the survey) has been made by a public officer in his official capacity and a reproducible copy thereof has been filed with the county engineer of the county in which the land is located" the RCW goes on to state that "a state agency conducting surveys to carry out the program of the agency shall not be required to use a land surveyor as defined by this chapter when the survey is of a preliminary nature; when a map is in preparation for recording or shall have been recorded in the county under the local subdivision or platting law or ordinance; when it is a retracing or resurvey of boundaries, platted lots, tracts, or parcels shown on a filed or recorded of survey."

When surveys are conducted by Ecology to establish geodetic control the project design should be reviewed by the National Geodetic Survey State Advisor (currently located at the Department of Transportation) or a Registered Land Surveyor. In addition, the project design must conform to WAC 332-130-160, which states that the "datum for horizontal control network(s) in Washington shall be NAD-83 (1991) as officially adjusted and published by the National Geodetic Survey of the United States Department of Commerce." The code further states that all "horizontal and vertical control work must meet or exceed accuracy and specification standards as published by the Federal Geodetic Control Committee in the bulletin titled *Standards and Specifications for Geodetic Control Networks*" for the class of control specified in the survey plan.

On the matter of setting monuments during a survey (i.e., physical marker set in the ground that serves as a reference station for later surveys); RCW 58.09.120 allows a public officer to place or install a monument. The regulation states that any "monument … set by a public officer … shall be marked by an appropriate official designation" and should be set in such a way that it can not be confused with those placed by a Land Surveyor. However, the placement of new monuments, "posting, and/or marking of a boundary line between two existing corner monuments constitutes the practice of land surveying" (WAC 196-24-110) and would require the use of a Registered Land Surveyor.

Based on this review of current laws and regulations governing the practice of land surveying in the State of Washington the following observations may be made concerning the collection of GPS point and line data by Ecology.

1. The retracing of existing records of survey does not require the services of a Registered Land Surveyor (Note, if discrepancies are found between a filed record of survey and ground conditions, they should be reported to the local governing public body).
2. The collection of point, line, and other survey data does not constitute land surveying as described in law as long as the data is not used for the delineation of a boundary for legal purposes or for the division of land (e.g., construction of a digital elevation model from GPS point data would be allowed, but the generation and use of a specific contour elevation from the data for regulatory purposes may require the supervision of a Registered Land Surveyor).
3. When employees of Ecology design a new geodetic survey network a recognized expert in the field should review the plan. Examples of this include Registered Land Surveyors as well as members of the National Geodetic Survey.
4. The placement of markers and reference stations in support of the work of Ecology does not require the services of a Registered Land Surveyor as long as the markers do not delineate a legal boundary.
5. When the proper performance of a proposed survey or project requires extensive technical knowledge and skill in surveying or will be used for legal purposes the services of a Registered Land Surveyor are required.

SECTION 4: SURVEY/GPS TERMS AND DEFINITIONS

The following definitions were collected from several sources, the majority which were obtained from Trimble (1994) and Trimble (1996).

Acquisition
The process of locking onto a satellites C/A code and P-code signal. Once a receiver acquires a satellite it tracks the satellite until the signal becomes unavailable.

Almanac
Information about GPS satellite orbits that includes clock corrections, atmospheric delay parameters, and health status of the transmitting satellite. See also ephemeris.

Altitude Reference
The datum used as a vertical reference for height measurements. GPS applications use the WGS-84 reference ellipsoid as the altitude reference. See also ellipsoid.

Ambiguity
The unknown integer number of cycles or wavelengths of the reconstructed carrier phase signal contained in an unbroken set of GPS measurements (i.e., the receiver does not know, and must estimate, the number of wavelengths between the satellite and the GPS antenna). Also known as integer ambiguity.

Anti-Spoofing (AS)
A security feature that allows the U.S. Department of Defense to encrypt the P-Code transmitted by the GPS satellites. When the P-code is encrypted it is known as the Y-Code.

Anywhere fix
The ability of a receiver to start position calculations without being given an approximate location and approximate time.

Autonomous Positioning
A mode of operation of a GPS receiver where the receiver calculates position in real-time from satellite data alone without reference to data supplied from a base station. This is the least precise mode of operation. Point coordinates accuracies of ±100 m RMS are obtainable when selective availability is in effect and ±10 when it is not.

Azimuth
The angle between a reference direction (e.g., magnetic north) and another point as seen by an observer in a specific location.

Bandwidth
The range of frequencies in a signal.

Baseline
The computed three-dimensional vector between a pair of stations utilizing GPS carrier-phase data collected simultaneously. This mode of operation offers the most accurate GPS result.

Blue Book
The informal name of the procedures developed by the National Geodetic Survey that must be followed for survey data to be submitted for inclusion in the national geodetic network.

Broadcast Ephemeris
See ephemeris.

C/A Code
The standard (Coarse/Acquisition) GPS code. A sequence of 1023 pseudo-random, binary, biphase modulations on the GPS carrier at a chip rate of 1.023 MHz. Also known as the "civilian code."

Carrier
A signal that can be varied from a known reference by modulation.

Carrier-aided tracking
A signal processing strategy that uses the GPS carrier signal to achieve an exact lock on the pseudo random code.

Carrier frequency
The frequency of the unmodulated fundamental output of a radio transmitter.

Carrier phase GPS
GPS measurements based on the L1 or L2 carrier signal.

Channel
A channel of a GPS receiver consists of the circuitry necessary to receive the signal from a single GPS satellite.

Chip
The transition time for individual bits in the pseudo-random sequence.

Clock bias
The difference between the clock's indicated time and true universal time.

Coarse Acquisition Code
See C/A Code.

Code phase GPS
GPS measurements based on the pseudo random code (C/A or P) as opposed to the carrier of that code.

Constellation
All satellites visible to a GPS receiver at a give time.

Control segment
A worldwide network of GPS monitor and control stations that ensure the accuracy of satellite positions and their clocks.

Coordinate System
Any two- or three-dimensional reference system which can be used to locate objects in space.

Cycle
See Epoch.

Cycle slip
A discontinuity in the measured carrier beat phase resulting from a temporary loss of lock on a satellite in the carrier tracking loop of a GPS receiver antenna.

Datum
A model of the earth consisting of an ellipsoid and an origin. GPS is based on the WGS-84 datum.

Data message
A message included in the GPS signal, which reports the satellite's location, clock corrections and health. Included is rough information on the other satellites in the constellation.

DGPS
See Differential Positioning.

Differential Positioning
A positioning procedure that uses two or more receivers with one receiver acting as a base station that is located at a known, fixed location and the other receivers roving to unknown points. The base station computes corrections based on the differences between its known location and its location as computed from the satellite C/A code. These corrections are applied to positions collected by the roving units. This correction can be done in real-time via a radio link or during post processing back in the office.

Dilution of Precision (DOP)
A factor that indicates the potential for ranging errors within a measurement. DOP is determined solely by the geometry between the user and the visible set of satellites (the

constellation). DOP provides an indicator of the “goodness” of the satellite constellation visible to the receiver. The smaller the DOP value the better, values less than 3 are considered “very good” while values greater than 7 are “bad”. Other flavors of this factor are PDOP (position dilution of precision) and VDOP (vertical dilution of precision).

Dithering
The introduction of digital noise. This is the process the DoD uses to add inaccuracy to GPS signals to induce Selective Availability.

Doppler-aiding
A signal processing strategy that uses a measured doppler shift to help the receiver smoothly track the GPS signal. Allows more precise velocity and position measurement.

Doppler shift
The apparent change in the frequency of a signal caused by the relative motion of the transmitter and receiver.

Dual Frequency
Referring to the use of both the L1 and L2 signals from the GPS satellites. Its primary use is to measure and correct for timing delays introduced by the signal traveling through the atmosphere.

Elevation
A vertical distance above or below a geoid.

Elevation mask
The lowest elevation in degrees at which a receiver will track a satellite. Normally set by the user to ten degrees or above to avoid atmospheric effects and interference caused by nearby objects (e.g., trees).

Ellipsoid
The three-dimensional mathematical figure formed by rotating an ellipse around a minor axis. The earth’s axis is the polar axis; its semimajor axis is the equatorial radius.

Ephemeris
The predictions of current satellite position that are transmitted to the user in the data message. Satellites transmit ephemeris information that was predicted based on the speed and trajectory of the craft. The US Coast Guard and National Geodetic Survey publish exact ephemeris information every week that covers the previous seven days. The exact ephemeris should be used to calculate locations for geodetic grade surveys.

Epoch
One complete wave of a radio signal (i.e., 360 degree phase shift). The length of each period in which a GPS receiver makes one set of satellite measurements.

Fast switching channel
A single channel which rapidly samples a number of satellite ranges. "Fast" means that the switching time is sufficiently fast (2 to 5 milliseconds) to recover the data message.

Frequency band
A particular range of frequencies.

Frequency spectrum
The distribution of signal amplitudes as a function of frequency.

Geodetic
Of, or concerning, the field of geodesy. Measurements that are referenced to a defined ellipsoid that allow for effects of a curved earth to be corrected for when computing direction and distance.

Geographic coordinates
A coordinate system used to locate a point on the surface of the earth. Customarily referred to as latitude, longitude, and the height above the ellipsoid.

Geoid
A surface of constant gravitational pull that most closely coincides with mean sea level over the surface of the earth. The geoid undulates in response to gravitational forces that affect spirit level vials in theodolites and differential levels.

Geoid Height
The distance between the geoid and ellipsoid at a given point.

Geometric Dilution of Precision (GDOP)
See Dilution of Precision.

GMT
Greenwich Mean Time (Pacific Standard Time is +8 hours). See also UTC.

GPS Time
The time used by the GPS system based on the atomic clocks on the satellites. GPS time was the same as UTC when the system was activated. However, variations in the rotation period of the earth have caused the two to diverge.

GPS Week
A period of seven days beginning and ending at 0000 hours on Sunday, GPS Time.

GRS-80
Geodetic Reference System of 1980. The ellipsoid on which the North American Datum of 1983 is based. This datum has the same semimajor and semiminor axis as WGS-84 (the reference ellipsoid for GPS) and differs slightly in the flattening value.

Hardover word
The word in the GPS message that contains synchronization information for the transfer of tracking from the C/A to P code.

Integer Ambiguity
See Ambiguity.

Ionosphere
The band of charged particles 80 to 120 miles above the earth's surface.

Ionospheric refraction
The change in the propagation speed of a signal as it passes through the ionosphere.

Julian date
The day of the year represented as a number, starting with 1 on January 1 and ending on 365 (366 in leap years) on December 31.

Kinematic Positioning
A method of GPS surveying which requires a base station at a fixed, known, position and uses the L1/L2 carrier-phase observables (including both the C/A code and P-code) and requires short (1 to 10 minutes) occupation times at the unknown locations being visited by the roving GPS receiver. This method uses *baselines* to calculate position and has the potential to obtain greater accuracy than is possible with differential positioning methods.

L-band
The group of radio frequencies extending from 390 MHz to 1550 MHz. The GPS carrier frequencies (1227.6 MHz and 1575.42 MHz) are in the L band.

L1
The primary carrier band (1575.42 MHz) used by GPS satellites to transmit data. The band is modulated with the C/A code, P-code, and navigation message.

L2
The secondary carrier band (1227.6 MHz) used by GPS satellites to satellite data. The band is modulated with the P-code and navigation message.

Land Surveyor
A person registered by the state to practice land surveying. In the state of Washington the person is licensed under RCW 18.43.

Meter
The official unit of linear measurement for NAD-83, defined in 1983 as the length traveled by light in a vacuum during 1/299,792,458 of a second.

Multipath error
Errors caused by the interference of a signal that has reached the receiver antenna by two or more different paths. Usually caused by one path being bounced or reflected.

Multi-channel receiver
A GPS receiver that can simultaneously track more than one satellite signal.

Multiplexing channel
A channel of a GPS receiver that can be sequenced through a number of satellite signals.

Mean Sea Level (MSL)
A model of the earth's surface that represents sea level as averaged over time at specific points.

North American Datum of 1983 (NAD-83)
A horizontal reference system based on the GRS-80 ellipsoid. This datum is used for precise horizontal coordinates in North America and near-by countries.

North American Datum of 1927 (NAD-27)
An older horizontal reference system based on the Clarke 1866 ellipsoid. This datum is used for horizontal coordinates in North America and other near-by countries. Conversion between WGS-84/GRS-80 and Clarke 1866 ellipsoid is not well defined and geodetic quality coordinates derived from GPS can not be obtained in NAD-27.

National Geodetic Survey (NGS)
The United States National Geodetic Survey, the geodetic surveying agency of the United States Government.

Observation
A set of measurements made at a mark. One to many measurements may comprise a single observation.

Orthometric height
The perpendicular or vertical distance between a point on the surface of the earth and some geoid.

P-Code
The Precise code. A very long sequence of pseudo random binary biphase modulations on the GPS carrier at a chip rate of 10.23 MHz which repeats about every 267 days. Each one week segment of this code is unique to one GPS satellite and is reset each week.

PDOP
See Dilution of Precision.

Precise Ephemeris
See Ephemeris.

Precise Positioning Service (PPS)
The most accurate dynamic positioning possible with standard GPS, based on the dual frequency P-code and no SA.

Pseudolite
A ground-based differential GPS receiver which transmits a signal like that of an actual GPS satellite, and can be used for ranging and in limited visibility areas to artificially increase the number of “satellites” visible to the receiver.

Pseudo random code
A signal with random noise-like properties. It is a very complicated but repeating pattern of 1's and O's.

Pseudorange
A distance measurement based on the correlation of a satellite transmitted code and the local receiver's reference code, that has not been corrected for errors in synchronization between the transmitter's clock and the receiver's clock.

Satellite constellation
The arrangement in space of a set of satellites.

Selective Availability (SA)
A policy adopted by the Department of Defense to introduce some intentional clock noise into the GPS satellite signals thereby degrading their accuracy for civilian users. SA works by introducing controlled errors into the C/A code transmitted by the GPS satellites. SA is not the same as anti-spoofing (AS).

Slow switching channel
A sequencing GPS receiver channel that switches too slowly to allow the continuous recovery of the data message.

Space segment
The part of the whole GPS system that is in space, (i.e. the satellites).

Spread spectrum
A system in which the transmitted signal is spread over a frequency band much wider than the minimum bandwidth needed to transmit the information being sent. This is done by modulating with a pseudo random code, for GPS.

Standard Positioning Service (SPS)
The normal civilian positioning accuracy obtained by using the single frequency C/A code.

Static Positioning
A method of GPS surveying which uses multiple receivers that monitor the L1/L2 carrier-phase observables (including both the C/A code and P-code) and use long occupation times. This method uses *baselines* to calculate position and has the potential to obtain greater accuracy that is possible with differential and kinematic positioning methods. Location is determined when the receiver's antenna is stationary on the earth. This allows the use of averaging techniques that improve accuracy by factors of over 1000.

User interface
The way a receiver conveys information to the person using it. The controls and display.

UTC
Universal Time Coordinated. Time as deduced directly from observations of stars and the fixed numerical relationship between universal and sidereal time.

US Survey Foot
The official unit of linear measurement for NAD-27, defined as 39.38 inches = 1 meter (exact).

User segment
The part of the whole GPS system that includes the receivers of GPS signals.
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VDOP
See Dilution of Precision.

WGS-84
World Geodetic System of 1984, the current standard datum for GPS.

Y-Code
An encrypted form of the information contained in P-Code, which GPS satellites transmit in place of P-Code when Anti-Spoofing is in effect.