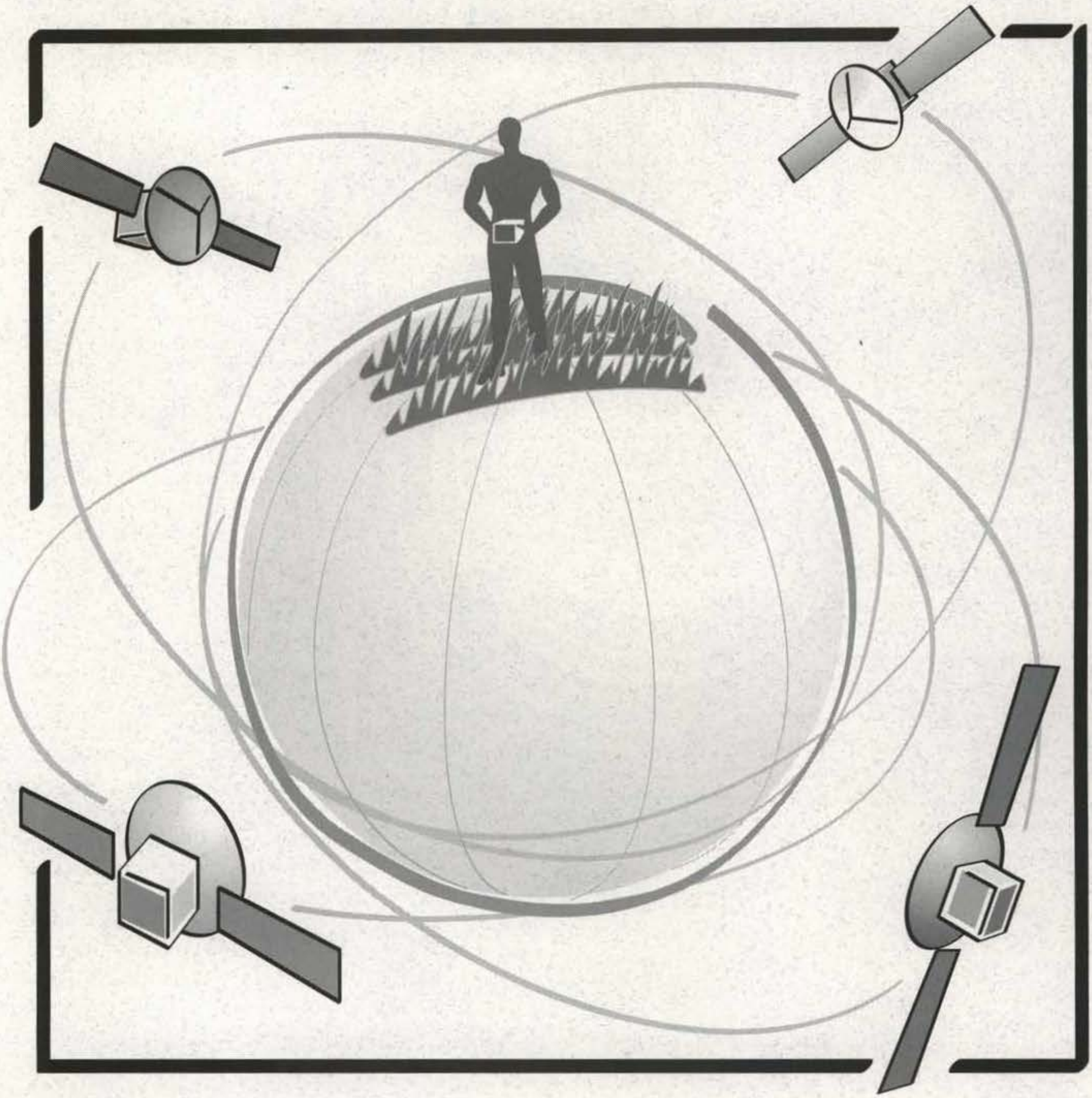
Global Positioning Systems



A Guide for Land Managers and Consultants

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Cooperative Extension System

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Summary

Practical technology for recording exact locations within a field without ground-based reference markers has become possible with the development of global positioning systems (GPS). GPS technology, developed by the Department of Defense, enables accurate determination and documentation of Cartesian coordinates anywhere on the earth's surface. This technology allows for accurate and rapid surveying, mapping, and positioning.

Positions and boundaries of any site may be located with 30-foot or better accuracy when the GPS receiver is continuously moving and with 6-foot or better accuracy when the receiver is held at a single site for repeated sampling. GPS data agree closely with U.S. Geological Survey data from 1:24,000 maps.

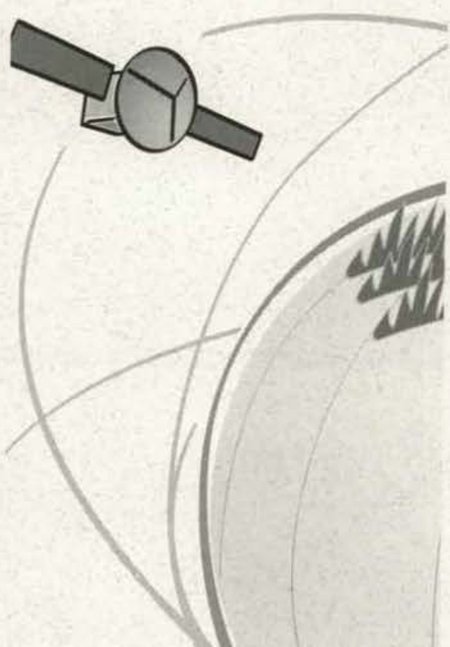
Coordinates for a site may be relocated for resurvey work, evaluation, management, or other purposes. Computerized map features from geographic information systems (GIS) or sources of information about the feature may be integrated with results from GPS readings to develop resource management plans.

Introduction

GPS is a computer-based radio transmitting and receiving system developed for and controlled by the Department of Defense. The system can calculate the position of a receiver by using special radio frequencies generated by satellite-mounted transmitters.

LORAN is the prototype of electronic positioning systems and uses terrestrial transmitters. GPS has an advantage over LORAN in hilly and mountainous terrain since both systems are dependent on line-of-sight signal reception.

GPS can record site and boundary location data as you travel through the field. The GPS receiver generally weighs between 0.5 and 3 pounds, depending on the manufacturer. Units tested by the University of Idaho are light enough to use in a backpack or as hand-held instruments.



How GPS works

The GPS measurement process works on the same principle you use when you determine your distance from lightning by counting the number of seconds between a flash of lightning and the peal of thunder. Satellite transmitters send signals containing time, location, and identification number. A receiver records the times when the coded signals arrive, and calculates its distance from each transmitter by determining the difference between the times the signals were transmitted and the times they were received. The receiver uses these distances from the transmitters and the locations of the transmitters to calculate its position on the earth's surface.

Signals from three satellite transmitters are necessary to determine two-dimensional coordinates (latitude and longitude), provided altitude is known or assumed. Four transmitters are required to determine three-dimensional coordinates of latitude, longitude, and altitude.

The satellites transmit data on two frequencies referred to as L1 and L2. The L1 frequency contains a Course/Acquisition GPS Code (C/A-code) and Precise GPS Code (P-code). The L2 frequency contains only the P-code.

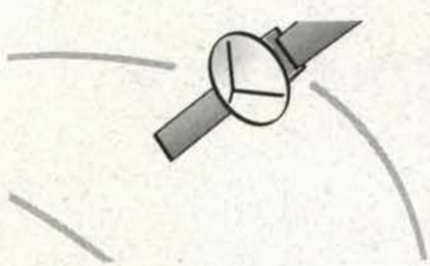
Many low-cost receivers use the C/A code to calculate position. The accuracy of the receiver is higher if it also uses the P-code when calculating positions. Receivers used for surveying track and measure C/A- and P-codes by using both L1 and L2 frequencies.

Common mathematical terms used in GPS

The accuracy of GPS depends on errors associated with atmospheric discontinuities, equipment conditions (clock error, orbital variation, humidity, temperature, etc.), and purposeful signal degradation by the Department of Defense. The receiver increases accuracy by using several algorithms that automatically restrict use of unreliable signals in its calculations when errors are too high.

Algorithms calculate geometric dilution of precision (GDOP), position dilution of precision (PDOP), horizontal dilution of precision (HDOP), and vertical dilution of precision (VDOP) and enable GPS to predict when errors will occur (Massatt et al. 1990). Most GPS units display these errors and will automatically restrict use of the GPS.

Some users may be able to increase the threshold of the errors. For this reason we include the definition of each algorithm. The GDOP algorithm estimates error in position relative to the ratio of the clock error in the receiver and root mean square of its position error to the satellite ranging error. The satellite ranging error is the difference between the receiver's calculated distance from the transmitter and the real distance as calculated by the Department of Defense. The position error without the receiver's clock inaccuracies is determined from the PDOP. PDOP is estimated from the ratio of the root mean square of the position error to the satellite ranging error.



Department of Defense signal skew

The Department of Defense uses computer-based mapping programs commonly called Geographic Information Systems (GIS) and GPS to position and guide equipment and personnel in the battlefield (Anon. 1991). The department controls the accuracy of the position calculated by the receiver by systematically skewing the signal from the transmitter, referred to as "making the signal selective available (S/A)." This procedure prevents the enemy from effectively using the signal (Trimble Navigation 1989).

Without correction, selective available (S/A) may result in errors ranging from 0 to 3,200 feet and averaging 64 feet. To correct for S/A, the military uses special GPS receivers. Civilian users must compute the skew using a second receiver (base station) at a geographically known point. To determine the true position of the remote receiver, data from that receiver are differentially calculated using data gathered simultaneously by the base station. Software used to remove S/A will also correct errors not accounted for when receivers were correcting for atmospheric and equipment conditions.

Once S/A has been corrected and adjustments for atmospheric and equipment conditions have been made, accuracy in the true position has been from 3 to 30 feet with navigation-quality receivers. Survey-quality receivers with the capability of radio linking to multiple base stations can produce data accurate to 0.006 foot or less.

Some things that can be recorded and mapped with GPS

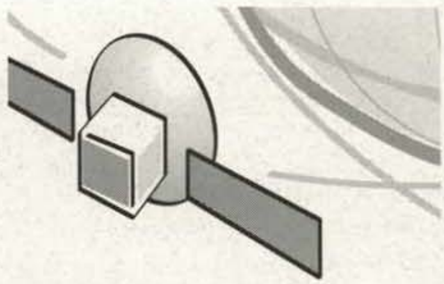
1. Field divisions for crops grown in each field, by year.
2. Permanent work records—maps of tillage, planting, and agrichemical treatments done each day, week, month, or year.
3. Noxious weed infestations—a map per species per year, stored on disks, can be presented in year-after-year overlays, countywide and locally, to monitor progress.
4. Hydrologic data—water tables, springs, wells.
5. Directions to crews.
6. Fence, bridge, and field road positions.
7. Land ownerships or individual fields.
8. Pesticide monitoring studies.
9. Recreation or other special-use areas.
10. Experiment sites.
11. Animal distribution records—numbers, grazing period, pasture performance, and response.
12. Crop loss areas.
13. Contour crop strip positions.
14. Problem soil locations.
15. Biological control parasite release sites, rate and direction of spread.
16. Local weed control districts.
17. Special weed management zones.
18. New pest appearances—insects, diseases, weeds.
19. Road conditions and construction sites.
20. Plant climate zones within a county.
21. Any other geographically distributed county data.

Accuracy of GPS

The University of Idaho has validated GPS accuracy at McCall and Moscow, Idaho. Accuracies ranged from -214 to 153 feet for longitude and -288 to 160 feet for latitude when recording was done at a single point. The standard deviation (SD) of the x value (east-west) was 14.4 feet and the SD of the y value (north-south) was 18.5 feet. The frequencies of the errors in x and y were distributed normally (F=0.01).

In the worst case (y values with highest SD), one sample was necessary to estimate a position with 40-foot accuracy 95 percent of the time, six samples were necessary to estimate with 15-foot accuracy 95 percent of the time, and 57 samples were necessary to estimate with 5-foot accuracy. To obtain 3-foot accuracy it would be necessary to take 158 samples. If the SD were 22, twice as many readings would be required to achieve the same accuracy. If the SD were 32, the number of required readings would quadruple.

Accuracy of 6 to 40 feet is adequate for many management applications but not for benchmark quality points. A 40-foot position error in surveying an area with a perimeter of 1 mile would result in a 5-acre error in area. Locating a single point with 3-foot precision is possible with navigation-quality GPS units, but the amount of memory in the unit and the time required to fix many points may make attainment of 3-foot accuracy impractical.



Time interval between readings

In tests at the University of Idaho, the time interval between sample readings did not influence the number of readings necessary to establish a position with a 15-foot accuracy. In all cases, six samples were necessary to establish a mean position with 15-feet accuracy regardless of sequential sampling time (1, 2, 4, 8, and 16 seconds). Rapid sampling of a position was thus possible.

The time required to position a location with 15-foot accuracy would be 6 seconds if the GPS measured a position every second. Proportionately longer time periods would be necessary to achieve greater accuracy or if equipment were slow to sequence among satellites. Other users have found a slight improvement in accuracy when interval times were extended to 30 seconds to 2 minutes, but the required number of samples only slightly decreased. The decreased number of sample readings was offset by an increased length of time spent at a location.

Why you need 3-D position fixes

For land-based GPS units, the calculation of elevation is important to achieve horizontal accuracy. At least four satellites are required for the GPS to calculate elevation for a three-dimensional (3-D) position. Currently a three-dimensional fix (latitude, longitude, and elevation) is obtainable most of the day.

Periodically a GPS will calculate two-dimensional fixes (latitude, longitude) from signals from three satellites. The GPS obtains two-dimensional fixes when the signal from one of the four satellites fails because the arrangement of the satellites is poor for the receiver's position or because the satellite signal is blocked by objects like trees, buildings, or mountains.

The University of Idaho examined the potential of using two-dimensional fixes with manual elevation adjustments for determining positions with 3-foot accuracy. The accuracy of GPS decreased as the error in elevation increased. The decreased accuracy was caused by miscalculating the distances the coded signals traveled. In the worst case, y position errors increased about 3 feet for every 6-foot error in elevation (fig. 1).

The elevation error would not be significant in relatively flat terrain (where the elevation does not vary by more than 50 feet). In hilly or mountainous terrain, the error would likely become a significant factor and will change with satellite geometry. In such terrain, use GPS only when three-dimensional positioning is available, or when you add the accurate elevation manually.

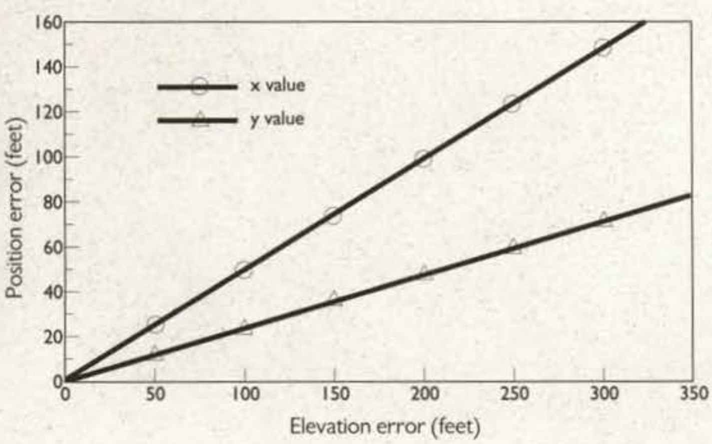


Figure 1. *Effects of elevation error on GPS accuracy.*

Integrating GPS data with USGS Digital Line Graph data

The integration of GPS data with existing Digital Line Graph (DLG) data from 1:100,000 maps was tested by the University of Idaho during a weed management study. Single-point readings along a wilderness foot trail were compared with the position of the trail as mapped in the DLG transportation file.

GIS indicated 60 percent of the trail positioned with the GPS was within 80 feet of the trail's previously mapped position according to USGS DLG file data, and 90 percent of the trail positioned by GPS was within 160 feet (fig. 2). The GPS positioned and plotted detailed switchbacks, while DLG data did not show those switchbacks on USGS 7.5-minute topographic maps.

This is an important consideration for field crew deployment and orientation. For example, the GPS positioned a new short trail branching from the northern trail and showed better access to a weed infestation. Results of this test showed that USGS maps agree sufficiently with GPS data and demonstrated that GPS can add new data to USGS maps or update old features with accuracy at least equivalent to USGS DLG data. Correction of slight DLG positioning errors with GPS may be necessary if GPS positions are to be recorded adjacent to DLG features.

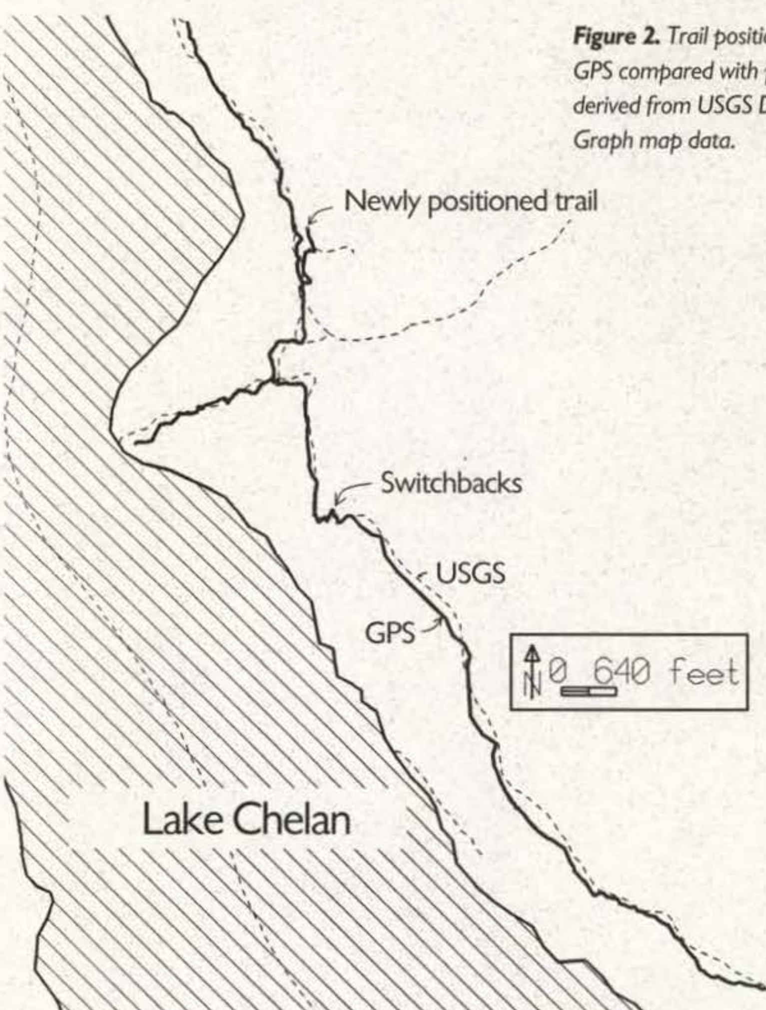


Figure 2. *Trail positions recorded by GPS compared with positions derived from USGS Digital Line Graph map data.*

Data collection with GPS units

Collecting base station data

If your GPS unit can correct for the Department of Defense signal skew you will need to establish a method of collecting base station data. Contact your GPS manufacturer's sales representative for names of agencies or private surveyors with community base stations from which data are available. Many federal, state, and county agencies; public utilities; and several commercial companies have base stations and will provide data for less than the cost of owning a second GPS unit.

Determine if you need to contact the base station prior to using the GPS unit or if the station collects data continuously. You will need to know the base station's latitude and longitude, signal elevation mask, datum, record-collection time interval, and the length of time the data are stored. Determine whether the time on your remote receiver needs to be synchronized with the base station and set it if necessary.

Determine the best method of transferring data to your computer. A typical base station file covering about 6 hours is about one-half megabyte when compressed.

Set your GPS receiver to a signal elevation mask 1.5 degrees above the base station for each 100 miles from the base station. The base station may be useful up to 300 miles away from your GPS unit if you set the correct elevation mask. The elevation mask of your GPS unit should be set to a higher elevation than that for the base station because your unit must receive signals from the same satellites, and at the same time, as those received by the base station. Setting the mask too high will reduce the number of satellite signals available for positioning.

Planning for satellite availability

Most GPS units come with optional software that can determine the number of available satellites, the time each satellite is available, and the orbits of the satellites. The software usually uses an almanac file containing the locations of the satellites. If the almanac file is more than 2 months old consider making a new file or obtaining one from the manufacturer's electronic bulletin board.

The software will need the general location of the area to be positioned, the date and time of expected use, and the elevation of the horizon. Select an elevation mask high enough to reduce the effects of increased atmospheric density near the earth's surface and to cover the same satellites as the base station. This elevation mask is usually 12 degrees but may range between 8 and 20 degrees. If objects such as buildings, tall trees, or high mountains block the satellite signal at the site to be positioned, raise the elevation mask or consider using the GPS receiver during times when satellites are not blocked.

Determine the number of satellites and when and where they are available. Print a satellite availability schedule before you go to the field to gather GPS records.

Receiving data with GPS units

Test the system prior to use.

Before going to the field, set up the GPS unit completely by attaching the antenna wire and batteries as outlined in the GPS manufacturer's manual. Check the battery level and voltage level from the antenna. If voltage levels are close to the manufacturer's specified lower limit, replace the battery or carry extra batteries. Most fully charged batteries will run most GPS units for 3 to 5 hours.

Start the system in the field.

Turn on the GPS unit. Many units display the codes for satellites from which the receiver is receiving signals. Switch to the satellite tracking mode and wait 1 to 3 minutes while the receiver scans for satellites.

The GPS unit must receive at least four satellites to start in the 3-D mode to determine elevation. Failure to start in 3-D mode can produce errors of 300 feet or more.

Determine the desired level of accuracy.

The accuracy of the instrument is determined by many factors (see "Accuracy of GPS," page 4). You can reduce the influence of these factors if you know the number of readings to take for a given level of accuracy at one position. Before documenting a position, take a few minutes to determine the level of accuracy and the daily expected errors.

You can determine daily expected errors by recording a position, commonly called a way point. Allow the receiver to remain at the location of the way point. Change the mode of the GPS unit to navigation and set it to navigate to the way point just recorded.

Table 1. Number of readings required for a given GPS accuracy in feet and standard deviation.

	Accuracy in feet																
Std. dev.	0.25	0.5	1	2	3	4	5	6	7	8	9	10	15	20	25	30	35
0.5	17	5	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	64	17	5	2	1	1	1	1	1	1	1	1	1	1	1	1	1
2	252	64	17	5	3	2	2	1	1	1	1	1	1	1	1	1	1
3	566	142	36	10	5	3	2	2	2	2	1	1	1	1	1	1	1
4	1,005	252	64	17	8	5	4	3	2	2	2	2	1	1	1	1	1
5	1,569	393	99	26	12	7	5	4	3	3	2	2	1	1	1	1	1
6	2,259	566	142	36	17	10	7	5	4	3	3	2	2	1	1	1	1
7	3,075	769	193	49	22	13	9	6	5	4	3	3	2	1	1	1	1
8	4,015	1,005	252	64	29	17	11	8	6	5	4	4	2	2	1	1	1
9	5,082	1,271	319	80	36	21	14	10	7	6	5	4	2	2	2	1	1
10	6,274	1,569	393	99	45	26	17	12	9	7	6	5	3	2	2	1	1
15	14,114	3,529	883	222	99	56	36	26	19	15	12	10	5	3	2	2	2
20	25,092	6,274	1,569	393	175	99	64	45	33	26	20	17	8	5	4	3	2
25	39,205	9,802	2,451	614	273	154	99	69	51	39	31	26	12	7	5	4	3
30	56,455	14,114	3,529	883	393	222	142	99	73	56	45	36	17	10	7	5	4
35	76,841	19,211	4,803	1,202	535	301	193	134	99	76	60	49	22	13	9	6	5
40	100,363	25,092	6,274	1,569	698	393	252	175	129	99	78	64	29	17	11	8	6
45	127,022	31,756	7,940	1,986	883	497	319	222	163	125	99	80	36	21	14	10	7
50	156,817	39,205	9,802	2,451	1,090	614	393	273	201	154	122	99	45	26	17	12	9
60	225,816	56,455	14,114	3,529	1,569	883	566	393	289	222	175	142	64	36	24	17	13
70	307,360	76,841	19,211	4,803	2,135	1,202	769	535	393	301	238	193	86	49	32	22	17
80	401,450	100,363	25,092	6,274	2,789	1,569	1,005	698	513	393	311	252	113	64	41	29	21
90	508,085	127,022	31,756	7,940	3,529	1,986	1,271	883	649	497	393	319	142	80	52	36	27
100	627,265	156,817	39,205	9,802	4,357	2,451	1,569	1,090	801	614	485	393	175	99	64	45	33

Most GPS units will show a distance from the way point. Determine the maximum distance the GPS shows it is from the way point and divide that number by 2 to estimate the standard deviation (SD).

Use the estimated SD to determine the number of readings necessary for your desired accuracy. Table 1 shows the number of points required for a given accuracy with a calculated SD. For example, if you want an accuracy of 5 feet and the SD is 10, you would need to take 17 readings.

Some GPS units have limited memory and storage capabilities. Learn the memory storage limits of your GPS, found in the GPS manufacturer's manual. Divide the number of readings the GPS can store by the number of readings for the desired accuracy to determine the number of positions that may be taken. The size of the memory in the GPS equipment will limit the number of locations, and some accuracy may need to be sacrificed to increase the number of locations positioned.

Some GPS units overcome a small memory size by averaging several readings and storing a single mean position. S/A is not usually correctable from data recorded as a single mean position.

Set the time interval.

Some GPS units allow continuous recording while the unit is traveling. Others require you to press a button when taking a reading. For continuous recording set the time interval to reflect the speed of travel, the number of points necessary for accuracy, and the amount of memory in the receiver. An ideal interval would be 1 second. It is not uncommon to need to use a 5-second interval when traveling at slow speeds and when using the equipment all day. Set time intervals to maximize accuracy and minimize memory use in the equipment.

Take GPS readings.

Move to the starting point, then check the number of satellites to ensure 3-D positioning. To save editing time, record the starting position and stopping position at the same point if the area is to be a polygon.

Start to record positions either by starting the log mode or by pressing the save button, depending on the type of GPS. Stand at the point long enough to collect enough readings for the desired accuracy.

Move around the perimeter of the area to be positioned. Stop at each point long enough to gather enough data for the desired accuracy. Stop recording data at the finish point if the GPS is in the continuous recording mode.

Move to the next area to be positioned. If using a continuous recording, start a new file before starting to take more points. After recording all desired locations turn off the GPS.

Data processing

Downloading data to the computer

Most downloading errors occur after a long day of positioning and the rush of end-of-day activities. Check to make sure the battery level is sufficient to allow transfer. Consult the manual for the minimum necessary battery level.

Securely plug in the transfer cables and follow the instructions in your GPS manual. Once transfer has been completed view the data to ensure that all data have been transferred before erasing them from the GPS units.

Some GPS software packages improve accuracy of 2-D data by adjusting it to simulate 3-D data. If you took recordings when 2-D visibility was present, you will need to adjust the elevation to calculate the correct position. Consult your manual for instructions on making adjustments.

If your GPS unit can correct for Department of Defense skew, obtain the base station data and either download it via modem or copy it from a disk, depending on the arrangement you have made with the community base station source. Check the time and date to make sure both you and the base station were taking data on the same day and time block. Run the skew correction software as specified by the GPS manual.

Some software used for correction will indicate where errors have occurred. If your software detects an error, or if it lacks the capability for detecting errors, recheck your data for points that may have recorded too many satellite identification numbers or for points where the location appears to be incorrect. The base station file probably will not need editing, so concentrate on the file from your GPS unit.

Two errors are common to GPS. The receiver produces multipathing errors when it records two signals from the same satellite at the same time. Generally multipathing errors occur when the signal is reflected from buildings, water, or power lines. Some multipathing errors produced by water and buildings can be reduced by shielding the antenna from bouncing signals with a piece of plywood.

The receiver produces a missing elevation data error when a reading is skipped. To detect errors, use an editor to examine the data with special emphasis on satellite numbers and elevation. Use either the editor supplied with the GPS unit or a text editor, depending on the type of GPS unit. After editing the data, you may need to recalculate the statistics; therefore, consult the GPS manual. Rerun the correction software using the edited data.

Grouping point data

If the map feature is point data (e.g., wells, benchmark, telephone poles, or highway signs) you will need to group the data if you took all readings as a single file. Grouping data averages the multiple records taken at each location into a single point. Grouping may not be necessary in continuously recorded files, because a new file should have been started at each point. If your GPS software does not offer the grouping option, you may group the data in a spread sheet after exporting it to a GIS.

Generating a GIS format file

In the GPS software, select the format required by the GIS software. Select the correct projection and datum (i.e., state planes, UTM, or degrees latitude and longitude) and units (i.e., feet or meters) for your GIS software. Download the GPS file into a GIS file using the commands outlined on your software manual.

Conclusion

GPS is still in the experimental stage and periodic problems should not discourage its use. Currently there is 3-D coverage 24 hours each day, with about 20 minutes 2-D coverage due to poor satellite configuration. Satellite launches are behind projected schedules. The GPS system is continually being improved with additional satellites. Most of the time there are enough signals to get the work done in the field. Some scheduling of times when satellites are available and not blocked by tall objects will be necessary.

GPS satellites are under the control of the Department of Defense, and about two weekends each year availability seems to be restricted to a few hours per day for civilian receivers. During these times there are shifts in satellite geometry and strange readings on the clocks of the GPS receivers. Otherwise, GPS signals are available.

The recognized advantages of GPS for land management are two-fold. One is the ability of GPS to accurately record the boundaries of any feature. The other is its ability to interface with GIS to accurately position an area or point in relationship to other recognizable physiographic map features such as wilderness borders, roads and trails, streams, soil types, and established structures such as fences or buildings.

The limitations of these systems should be recognized to prevent inappropriate use, however. The accuracy of GPS is dependent on many factors, but with knowledge of its limitations, 3-foot accuracy is obtainable with many navigation-quality units. The integration of GPS data with GIS data enables effective, efficient mapping and provides information accurate enough for use in land management.

The University of Idaho offers a simplified GIS-type mapping software package for land management called COUNTYCAD. This computer-mapping software displays roads, streams, other bodies of water, towns, and political boundaries within a county. Positions or boundaries of areas of interest are easily entered with a mouse, digitizer, or GPS. The system is designed for recording and tracking more than 200 kinds of information for 15 years. Data may be exchanged with most GIS packages.

The University of Idaho offers similar software called REGIONCAD for larger areas such as one or more states.

The programs use EasyCad 2.0 and run on any IBM or compatible computer with a hard disk and printer. Best performance is obtained on a 386 with a math co-processor or on a 486. A mouse, color monitor, and laser printer improve efficiency. For information contact the Weed Diagnostic Lab, Department of Plant, Soil, and Entomological Sciences, University of Idaho, Moscow, ID 83844 (208) 885-7831.

One-day Extension workshops on GPS and COUNTYCAD are available.

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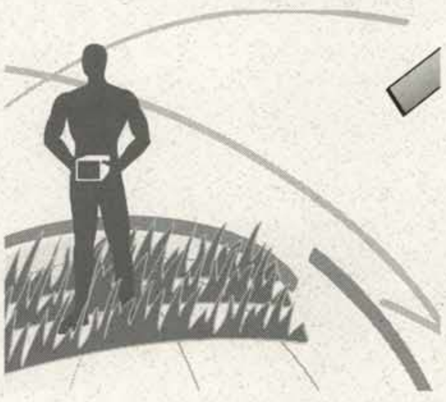

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