UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

Office of
Environmental Information

Global Positioning Systems - Technical Implementation Guidance

Revision 2.0

(July 2006)

OFFICE OF
ENVIRONMENTAL
INFORMATION

EPA/250/R-03/001
July 2006

Global Positioning Systems - Technical Implementation Guidance

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Organizational Acronyms

EPA	U.S. Environmental Protection Agency
ORD	Office of Research and Development
OEI	Office of Environmental Information
NEIC	National Enforcement Investigations Center
OGC	Office of General Counsel
DOI	U.S. Department of the Interior
BoR	Bureau of Reclamation

Notice

ACKNOWLEDGMENTS

Given the history of this document, the multiple organizations that contributed knowledge, and the movement of personnel within and between organizations, it is difficult to create a list of contributors with certainty. The concept to create this document rests with the EPA Geospatial Quality Council. Contributors to the first version of this document were

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This update includes contributions from Carrie Middleton and George Brilis. To all who contributed ideas, policies, and practices - thanks for your valued input.

George M. Brilis, Chair, EPA Geospatial Quality Council

In memory of

Mason J. Hewitt III

Mr. Mason J. Hewitt joined the Environmental Protection Agency (EPA) in March 1987. His was asked to direct and manage the EPA Office of Research and Development's Las Vegas Laboratory's Geographic Information Systems (GIS). Mr. Hewitt was instrumental in working with EPA Headquarters, Regional offices, and other agencies in developing GIS software and standardizing computer programs. Mr. Hewitt became nationally and internationally known for his expertise in the GIS world.

Mr. Hewitt also served on the EPA advisory panel for the Global Position System (GPS). This panel developed EPA accuracy standards for the GPS to be used for georeference corrections and to meet Topographic Mapping Standards.

Mr. Hewitt died of injuries suffered from an accident in 1996. His leadership and inspiration have made an impact on the conservation of our environment for many years to come. The EPA has established the Mason J. Hewitt GIS Award in recognition for development of outstanding GIS tools within the EPA during each calendar year. All recipients have their names engraved on the trophy, which is held by the individuals or team for one year. The trophy is then presented to the next award recipients.

Mr. Hewitt laid the foundation for the harmonization of the EPA's approach to GPS data collection and use. He put pen to paper, and it is upon those publications that this work is based.

As a scientist, Mr. Hewitt maintained records so that those who followed him could continue his work. As a husband and father, Mr. Hewitt always put his family first. As a patriot, Mr. Hewitt was entrusted by our country to keep vigilance over our nation's safety. As a friend, he is irreplaceable.

Foreword

The U.S. Environmental Protection Agency (EPA) has long employed data of spatial orientation in pursuit of its mission to understand and protect the environment. For years, these data were applied in standard cartographic presentation techniques, either via hand drawn or digital transposition from a source map. In either case, the map developer or analyst had the ability during this transposition to apply decision rules of logical consistency to make the map "right," shift, and offset map elements so that their relationships to each other did not violate inherent rules of consistency (e.g., streets did not cross buildings; city boundaries followed the delimiting streets). These adjustments and the inaccuracies introduced in the transposition process may or may not be considered viable, depending upon whether these adjustments and errors exceeded traditional map accuracy standards.

Regardless of the acceptability of these errors, they are virtually undetectable to the decision maker or technical analyst, who is presented with a map product. The nature of these errors in hard copy maps is attributable to the medium itself, which is not amenable to overlay and comparison analysis. More often than not, mapped data are presented in its own singular context, with few other types of spatially-correlated data simultaneously presented. However, with the advent of Geographic Information Systems (GIS), digital spatial data sets are generated and stored independently and then combined in analysis, making differences in resolution and accuracy of spatial data visually detectable. Although each separate data set may not violate its own accuracy standard, the use of these differing maps may produce a composite map that is perceived to be flawed. Recognizable inconsistencies may or may not detract from the accuracy of the spatial analysis of interest, depending upon the nature of the analysis. At a minimum, they possibly detract from the credibility of the analysis product.

Global Positioning Systems (GPS), originating from the U.S. military programs, have great potential for ameliorating these types of problems as well, making errors easier to detect. With the ability to locate features with an accuracy of a few meters, this technology essentially lowers the detection limit for positional accuracy at low cost. Indeed, the U.S. National Geodetic Survey acknowledges that the accuracy of GPS positioning may exceed the accuracy of some benchmarks in the National Geodetic Reference System (NGRS) (National Geodetic Survey, 1990). Previously, cadastral surveys, which are relatively expensive, were considered to be the only highly accurate positioning system.

GPS technology is now enjoying many civilian sector applications. With this increasing demand, not only is the cost of units going down, but a tremendous amount of development effort is being applied toward increasing their portability, accuracy, and ease of data integration with popular mapping system applications. Proposals have been made within the EPA to establish networks of survey base stations that would offer complete coverage of a Regional jurisdiction for roving GPS units. Such proposals shed light on the potential future for the use of GPS by the EPA. By integrating GPS into the Agency's regulatory data collection efforts, benefits in improved spatial analysis resolution could result in "lighter" solutions in protection, causation, and restoration decision making. Eliminating the range of uncertainty in positional data may offer opportunities for cost savings.

In comparison to highly accurate GPS data, the relative acceptability of the EPA's existing spatial data, in terms of resolution and accuracy, diminishes. Locational methods previously employed may no longer be suitable for applications and analysis that require the most rigorous spatial data quality available. In order to address this error source, the EPA has adopted a Locational Data Policy (LDP). The purpose of the LDP is to “ensure the collection of accurate, consistently formatted, fully documented locational coordinates in all relevant data collection activities pursuant to the EPA's mission (LDPIG, 1992).” In order to support the accuracy target specified within the LDP, the policy endorses GPS as the technology of choice. Collecting highly accurate GPS data requires careful planning. Once collected, consideration and thoughtful treatment of the data must be given vis-a-vis in its use with data of substantially lower accuracy. This guidance document seeks to provide GPS users with information and guidance on this technology and its potential use in Agency applications.

This foreword was, in large part, derived from the parent document published by Mason J. Hewitt III et al., and is a testament to the timelessness of his work.

George M. Brilis, Chair
EPA Geospatial Quality Council

Background

The U.S. EPA Geospatial Quality Council (GQC) was formed in 1998 to provide Quality Assurance (QA) guidance for the development, use, and products of geospatial activities and research. The long-term goals of the GQC are expressed in a living document, currently the *EPA Geospatial Quality Council Strategy Plan, FY-02*, EPA/600/R-01/063. The GQC is approaching the development of guidance and technical documents in the flow order of the Geospatial Information Lifecycle. The first two major products of the GQC are: a training course *GIS for QA Professionals*, which can be located at http://www.epa.gov/Region06/6en/gis-qa/index.htm, and the *EPA Guidance for Geospatial Data Quality Assurance Project Plans (Peer Review Draft)*, EPA/600/R-01/062. It is important to note that the GQC operates on a volunteer basis and without a budget.

An internal survey conducted jointly by the EPA Data Acquisition Branch (DAB) of the Office of Information Collection in the Office of Environmental Information and the GQC determined that the approach to GPS data collection and disposition throughout the EPA was inconsistent. GQC literature research determined that existing documents were technically outdated and did not address legal considerations, data disposition, and information management. This document is intended to fill that gap and be treated as a living document by its organizational custodian.

Acknowledgments

This document reflects the efforts of the U.S. EPA Geospatial Quality Council (GQC). Members of the GQC that contributed to this effort originated from EPA Regions, Program Offices, the EPA QA Staff, the Office of Environmental Information, and the Office of Research and Development. The GPS Technical Subgroup of the EPA GIS WorkGroup played an essential role in the development of this document as did the U.S. Bureau of Reclamation. These scientists and professionals dropped their organizational ties and worked together in a seamless manner to harmonize the approach used to collect GPS data.

The foundation of this document is based on *GIS Technical Memorandum 3: Global Positioning Systems Technology and Its Application in Environmental Programs,* R. Puterski, J. A. Carter, M. J. Hewitt III (Project Officer), H. F. Stone, L. T. Fisher, and E. T. Slonecker, EPA/600/R-92/036, February 1992. The *GIS Technical Memorandum 3* document was refreshed by the GPS Technical SubGroup of the EPA GIS WorkGroup in 2000. The GQC began its work from a solid foundation of documents and devoted professionals.

Manuscript reviewers provide the critical function of peer review. Their comments, suggestions, and recommendations for this document are greatly appreciated.

Trimble Navigation Limited graciously approved the use of all images/figures contained in this document. All figures/images are copyrighted by Trimble and used by permission [McNabb, July 2, 2002].

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Section I

Introduction

Purpose of Document and Intended Audience

As outlined in the Locational Data Improvement Project Plan (1996), the United States Environmental Protection Agency (U.S. EPA, hereinafter referred to as the "Agency" or the "EPA" for the purposes of this document) has developed this manual to guide the process of collecting, editing, and exporting accurate spatial data using the Global Positioning System (GPS). Each Region will develop their own Standard Operation Procedures (SOP) manual on the regional specific GPS data collection procedures.

The intended audience of this document includes U.S. EPA staff, contractors, and grantees who will be:

1. involved in the planning of a GPS survey,
2. conducting a GPS survey,
3. maintaining and lending GPS equipment, and
4. responsible for processing data sets collected in the field and their conversion to various file formats for use in a Geographic Information System (GIS) database.

This technical implementation guidance will serve as a reference guide for Agency staff who will be using GPS equipment and also the individual(s) responsible for the maintenance of this equipment. Training on the proper use of the GPS equipment maintained by the regional offices will be required of Agency staff, contractors, and grantees prior to its use. Training will be provided either by Agency staff or through vendor contracts.

This document will not attempt to detail the specific functions of the various receivers since the rapid advancements in GPS technology would necessitate constant, diligent updates to this document. Receiver operating procedures will be covered during training sessions through the use of separate documents. The mention of trade names or commercial products does not constitute endorsement or recommendation for use.

Four important points must be understood by the readers and users of this document:

1. The level of effort and detail should be based on a common sense, graded approach that establishes QA and QC requirements commensurate with the importance of the work, the available resources, and the unique needs of the organization.
2. Since this is intended to be a living document, recommendations to include technology that is currently being developed, and new technology that has not yet become an integral part of the EPA's toolbox, were not included in the document. When the new technology has become an integral part of the EPA's geospatial repertoire, this document will be updated by its custodian (OEI).

3. This document is not intended to "micromanage" the GPS community; therefore, suggestions to define limits were excluded. In addition, attempts were made to keep the document "user-friendly" by keeping the volume of the document to a minimum.
4. Users should check the appropriate references for the latest updates, such as the EPA Locational Data Policy, prior to the initiation of work.

Document Contents

A brief overview of the GPS system and the procedures involved in acquiring consistently accurate GPS locational data sets is provided below.

The EPA has long employed information of a spatial nature in the analysis of environmental problems. This information was traditionally applied using standard cartographic techniques such as hand drawn maps and other graphic presentations. Advances in Geographic Information Systems (GIS) have automated the management of spatial data as well as most of the presentation functions (e.g., map production) previously done by hand. Until recently, however, GIS systems relied primarily on transposing, or digitizing, spatial data from existing hard copy maps.

The GPS is a worldwide, satellite-based system with location positioning capabilities. The system is administered and managed by the Department of Defense. It is comprised of:

- a space segment of approximately 24 operational satellites in complimentary orbits,
- a ground control segment made up of a network of control stations around the globe, and
- a users segment, which includes anyone who uses GPS to collect locational information.

The system utilizes precise time and radio signals to determine distances from satellites to user GPS receivers. Distances are most commonly calculated by using the time it takes for a radio signal code to be transmitted from the satellite and received by the GPS unit. Precise time is critical to the successful operation of the system. The control stations ensure that the satellites employ synchronized, atomic clock-derived universal time coordinates (UTC), commonly known as Greenwich Mean Time (GMT). Receiver units collecting four satellite signals can determine the geodetic (x, y, z) location through a process of mathematical triangulation. The satellite signals contain precise time and satellite position information.

GPS technology is used as a method of accurately determining the coordinates of point locations. The three-dimensional position, or the x, y, and z geodetic coordinates, are determined for the point locations; however, only the x and y values are primarily used. This is due to the processes involved in the system; the vertical GPS coordinates are approximately half as accurate as the horizontal GPS coordinates. The position reported by the GPS unit is based on the geodetic model selected. The vertical, or z coordinate, value is not as accurate as the reported position due to the geometry of the satellite constellation relative to the receivers position on the earth.

Utilization of accurate x, y, and z coordinates in a geographic information system is the primary purpose for most GPS use in the Agency. GPS is one of the arrays of tools for accurately determining location in the field. The collection of x, y, and z coordinates (for gross data collection) for locations in the field using GPS is useful for a variety of purposes, including accurate sample locations, locational correlation of remotely sensed data with ground truth locations, and efficiently collecting better spatial data for EPA's information management.

The accuracy required for GPS data collection will vary depending on the reasons for gathering locational information. Different equipment and procedures are needed to identify the outline of a landfill than those needed to determine the location of a ground-water monitoring well used for a hydrologic survey. GPS equipment accuracies can range from about 13 meters (one standard deviation and up to 22 meters at two standard deviations) of horizontal accuracy in a mapping grade unit to a 1-2 cm of vertical and horizontal accuracy in a survey grade unit (note that 1-2 cm vertical accuracy is attainable under conducive environmental conditions, using high quality instrumentation, and exercising skillful operation of the GPS receiver). However, all of these units have a place in the Agency and some elements of GPS use are common to all units and procedures.

Generally, the quality of coordinate information (GPS data) is dependent on the quality of equipment, the understanding and skill of the operator of the GPS receiver, and the signals and factors affecting the signals broadcast by the GPS satellites. Since GPS utilizes high frequency radio waves, interferences with the satellite signals can and do occur. The user may or may not be aware of these, so steps must be taken to minimize the impacts on data quality. Within this document, users will be made aware of tools such as averaging a series of points based on repeated measurements, using higher quality GPS receivers, recording quality information, and using comparisons of the GPS generated coordinates with other georeferenced sources in order to minimize accuracy errors. Alternative field methods are provided to cope with most interferences while providing acceptable results.

Most GPS data collection work includes: project planning and GPS equipment preparation; determination of remote reception points; labeling and identification of point locations; operation of the GPS receivers; dealing with interferences; downloading the collected data to a personal computer; making backup and archival copies of the data files on diskettes; post processing of the data files, if needed, to perform differential correction and averaging of location samples; conversion of the data to GIS format; and the maintenance of the GPS units.

Documentation and proper reporting of what the data represent and method collection are critical to the successful utility of the information. The data documentation, or metadata, should capture the type and description of the location collected, the coordinate units and reference datums, and the method of location determination. These “metadata” are required by both the EPA Locational Data Policy and the Federal Geographic Data Committee’s (FGDC) Content Standard for Digital Geospatial Metadata. Federal agencies are required to follow the FGDC standard according to Executive Order 12906, “Coordinating Geographic Data Acquisition and Access: The National Spatial Data Infrastructure.”

Document Updates

This document is intended to be a “living document.” Two EPA organizational units will work together to update and release revisions. These organizational units are both within the EPA’s Office of Environmental Information, Office of Information Collection (OIC). The duties and responsibilities of the organizational units overseeing this document are both within the OIC. The units within the OIC are, the Data Acquisition Branch (DAB), and the Data Standards Branch (DSB). The revelant duties of each of these units are described below.

The Office of Information Collection (OIC): develops and implements innovative data collection policies and services. The Office promotes the efficient and effective collection and use of data and develops processes to ensure that environmental data and information meet established standards of quality. http://www.epa.gov/oei/collecting.htm

Data Acquisition Branch (DAB): is responsible for working with the Agency's partners at the Federal and state levels on data sharing and exchange projects via electronic and non-electronic means. Functions of the Branch that are relevant to this document are as follows:

- Provide strategic direction, guidance and standards, and support for the geospatial program (remote sensing, Geographic Information Systems, spatial enablement of data and information systems, and visualization) within the Agency and oversee their implementation.
- Obtain and manage, on behalf of the Agency, environmental data from third party sources (especially other federal agencies such as the United States Geological Survey, USGS);
- Manage and/or participate in standing coordinating committees (with states, other Federal Agencies, other countries, and non-governmental entities or other organizations) that facilitate joint strategic and multi year planning for data acquisition and expedite related technology and information exchange;
- Work with the states, tribes, and other government organizations to integrate and share data through current and other emerging and innovative approaches.
- Identify, obtain, and broker data sets with environmentally-relevant information, including non-regulatory data (such as spatial data and "orphan" data sets). Manage EPA Interagency Agreements for data acquisition.

The Data Standards Branch (DSB): is responsible for maintaining a current and comprehensive understanding of the Agency's data architecture, i.e., the "what" and "where" aspects of EPA's data holdings. Functions of the Branch that are relevant to this document are as follows: http://oaspub.epa.gov/edr/EPASTD$.STARTUP

- In concert with state partners, develop and implement standards for the Environmental Data Registry (EDR). http://www.epa.gov/edr
- Develop and oversee the data standards program, including monitoring, measurement, and metadata.
- Develop and oversee the implementation of Agency-wide business rules for new and existing data standards, in concert with the Environmental Council of the States (ECOS).
- Lead the design and implementation of the EPA Facility Registry System.
- Participate in cooperative data standard-setting activities for international environmental information.
- Develop and publish the semi-annual Agency Information Inventory.
- Develop and oversee the implementation of Agency information protection policies, including policies for central docket, confidential business information CBI, and Privacy Act implementation.
- Serve as the Agency Records Officer and oversee the National Records Management Program, including the Agency History Program.

Distribution of document revisions may be a time consuming process. Therefore, readers are encouraged to check the organizational website listed above for the latest update in standards and data collection.

The EPA Geospatial Quality Council (GQC) is available to all for consultation and assistance. At the time of this writing, the GQC website is being developed. GQC contact information is provided at the beginning of this document.

Section II

Alternative Methods of Geopositioning

Conventional Surveying

GPS is a valuable tool for use with other surveying techniques whether they are cadastral, topographic, or geodetic. GPS is valuable for rapidly acquiring position, but other techniques may be used for parcel definition and recording, topographic surface generation, and geodetic modeling. GPS does not totally replace any of the other techniques. In particular, GPS is not always used to generate topographic surfaces. However, it is being used to reference topographic surfaces generated by other methods to a real-world coordinate system. In many cases, GPS is being used to reference boundaries established by other survey techniques to real-world coordinates, and it is very valuable in updating the horizontal and vertical control of the geodetic network.

Where GPS is particularly effective for surveying is in locating site locations, sampling transects, and approximating boundaries between or along features. In addition, it can be used to approximate travel speed and distance between points and the rate of sampling along the vector traveled.

There has been, and will continue to be, a considerable and rapid evolution in geopositioning techniques and technologies, as evidenced by the emergence of systems like GPS. Many of the older, traditional positioning survey methods are being supplemented, and in some cases, replaced by advanced geopositioning systems. These older survey methods tend to require more field time, are highly labor intensive, and are costly per feature identified. Although conventional surveying is still appropriate for high accuracy requirements in localized, accessible study areas, these older methods are best used in concert with other more advanced and cost-effective techniques. Topographic, cadastral, and geodetic surveys are perhaps the three types of conventional surveying most impacted by advanced technologies like GPS.

Topographic surveys determine the elevation heights and contours of land surfaces. These surveys also serve to locate buildings, roads, sewers, wells, and water and power lines. The U.S. Geological Survey (USGS) has historically conducted topographic surveys in order to produce topographic maps at a scale of 1:24,000. These maps provide an excellent base for much of the EPA environmental analysis programs. As these maps become available in digital form, they are providing an important source of locational and geographic data for the Agency. Remote sensing techniques in conjunction with GPS and other positional systems are currently being used to obtain more accurate and detailed surface elevation positional information for many of these land features.

Cadastral surveys are performed to establish legal and political boundaries, typically for land ownership and taxation purposes. A boundary survey is a type of cadastral survey which is limited to one specific piece of property. The U.S. Bureau of Land Management (BLM) relies on cadastral surveying to determine the legal boundaries of public lands. Published cadastral surveys are of importance to the EPA, as for instance, where potentially responsible parties (PRPs) and impacted parties on Superfund enforcement cases are concerned. GPS already can provide highly accurate positional reference information for boundary surveys of these types of facilities.

Geodetic surveys (i.e., control surveys) are global surveys made to establish control networks (consisting of reference or control points) as a basis for accurate land mapping. Geodetic surveys provide quantitative data on the absolute and relative accuracy of reference positions or physical monuments on the Earth's surface. The U.S. National Geodetic Survey (NGS) is responsible for establishing a national geodetic control network for the entire country referenced to a national horizontal datum. NGS also establishes the vertical datum, the location of mean sea level from which most elevation data are determined or referenced. Highly accurate EPA geopositioning requirements should be attained with reference to a well defined geodetic survey or network. All NGS geodetic control points are accessible via the Web [http://www.ngs.noaa.gov] and are searchable by area as well as site name. In addition, there is a network of continuously operating reporting stations (CORS) [http://www.ngs.noaa.gov/CORS]. The importance of both the historic and current network is that they provide the underlying basis for all of map data.

In the event that the EPA will require or avail itself of conventional surveying to meet its geopositioning needs, it is important to understand these techniques, their strengths, and their limitations. The EPA does and will continue to use products derived from conventional surveying methods. The geopositional accuracy of the products generated by EPA, USGS, NGS, and BLM can usually be obtained from these agencies at the time of product acquisition.

Methods of Point Surveying

Global positioning systems technology is one of a number of positioning techniques that have been developed since the late 1950s and is being used for establishing positions of points on or near the Earth's surface. Besides GPS, some of the advanced technology systems being utilized for geopositioning and navigation today include OMEGA, Loran-C, Transit, Inertial Survey Systems (ISS), VHF Omni-directional Range/Distance Measuring Equipment (VOR/DME), Tactical Air Navigation (TACAN), and Instrument Landing System (ILS). The U.S. Department of Transportation (DOT), primarily through the U.S. Coast Guard (USCG) and the Federal Aviation Administration (FAA), is responsible for the application of these technologies for civil navigation. The U.S. Defense Department (DOD) oversees the use of these systems for military users.

Inertial Survey Systems (ISS) are self-contained and highly mobile systems that detect relative compass direction by using gyroscopes. The most effective application of ISS is to measure unknown points that are located between known control points. ISS may serve some EPA needs where the EPA and/or contractual personnel are in the field with vehicles that could potentially be equipped with ISS. When ISS is combined with GIS, they are mutually supportive.

ILS is a passive system used commercially for precision aircraft radar approach navigation. The FAA is currently investigating the continued use of this geopositioning technology and may recommend transitioning to a system based on GPS. A similar active system is precision radar (PAR), which is used mostly by the military. Both systems have a very short range.

Section III

Global Positioning System (GPS) Technology

The Navigation Satellite Time and Ranging (NAVSTAR) GPS is a system that is operated by the Department of Defense (DOD) dating back to 1977 with the launch of the first in a series of satellites that currently orbit approximately 12,500 miles above Earth. There are at least four satellites in each of six fixed orbiting planes. This constellation provides GPS users with four to eight visible satellite signals at all times from any point on Earth. Its initial use was intended for highly accurate, all-weather, instantaneous positioning capabilities for the U.S. military and its allies, but the GPS is also freely available to the public. Many of the surveillance and monitoring programs of the Agency represent some of the civilian applications of the GPS. The decreasing cost of increasingly accurate, portable GPS receivers has allowed this technology to become one of the Agency standards for the acquisition of spatial data.

There are three components of the GPS that allow it to calculate a position:

1. The space segment – approximately 24 NAVSTAR satellites.
2. The ground control segment – five global stations that serve as uplinks to the satellites, making adjustments as necessary to satellite orbits and clocks.
3. The user segment – the ground-based GPS receiver, which is composed of an antenna, preamplifier, radio signal microprocessor, control and display device, data recording unit, power supply (GIS Technical Memorandum 3, 1992), and a clock.

Satellite positioning operates by measuring the time delay of precisely transmitted radio signals from satellites whose position can be very accurately determined. Furthermore, with the help of a few fundamental laws of physics, the positions of these satellites as a function of time (their ephemerides) can be rather easily predicted. By measuring the distances (or range vectors) between a survey point of unknown location on the surface of the planet and the predicted positions of a number of orbiting satellites, it is possible to calculate the position of a point.

Trilateration: A GPS receiver operates on the principle of trilateration, whereby a position is calculated by measuring the distance between the receiver antenna and at least four satellites, which act as precise reference points. Two questions need to be answered in order to calculate a position using the GPS:

1. How far is your receiver from the satellite?
2. What is the location of the satellite?

These questions will need to be answered simultaneously for at least three satellites to calculate a two-dimensional position. However, this manual will require the tracking of four satellite signals in order to calculate a three-dimensional position. The first question of determining the distance between the receiver and the satellite is referred to as satellite ranging. The simplest way to illustrate this is from the following example. The reception of one satellite signal establishes the receivers position on the surface of a sphere centered around the satellite, with the radius representing the range between the satellite and the receiver antenna (Figure 1).

The addition of a second signal will place the receivers location somewhere within the shaded intersection of these two spheres (Figure 2). The intersection of a third sphere, which represents the third satellite signal, into the two other spheres will reduce the location of the receiver to two possible locations (Figure 3). One of these two points is disregarded as a possible solution because it is either in space or moving at a high rate of speed. The fourth satellite is used to solve for x, y, z and time variables (Figure 4).

One measurement narrows down our position to the surface of a sphere

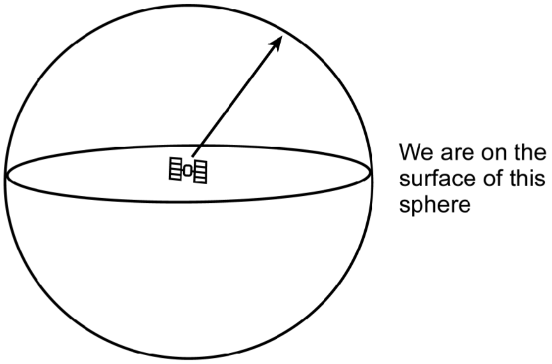


Figure 1

A second measurement narrows down our position to the intersection of two spheres

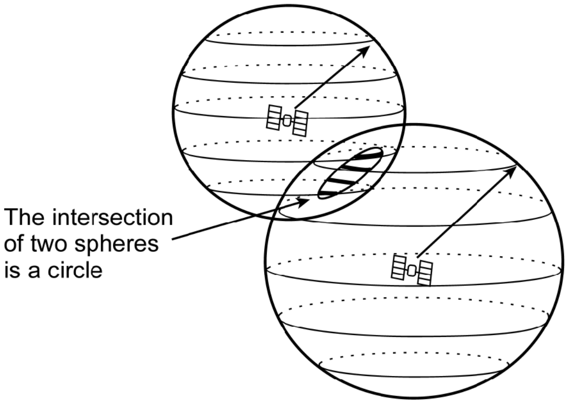


Figure 2

A third measurement narrows down our position to two points

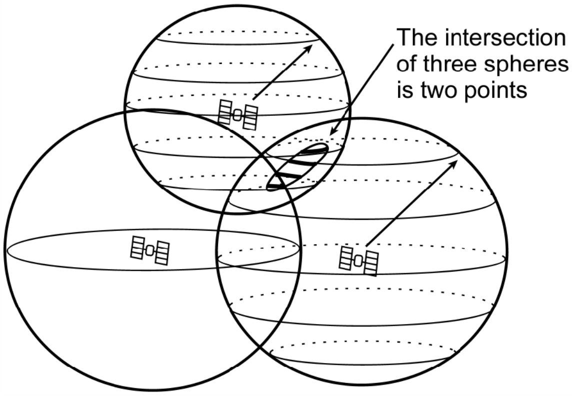
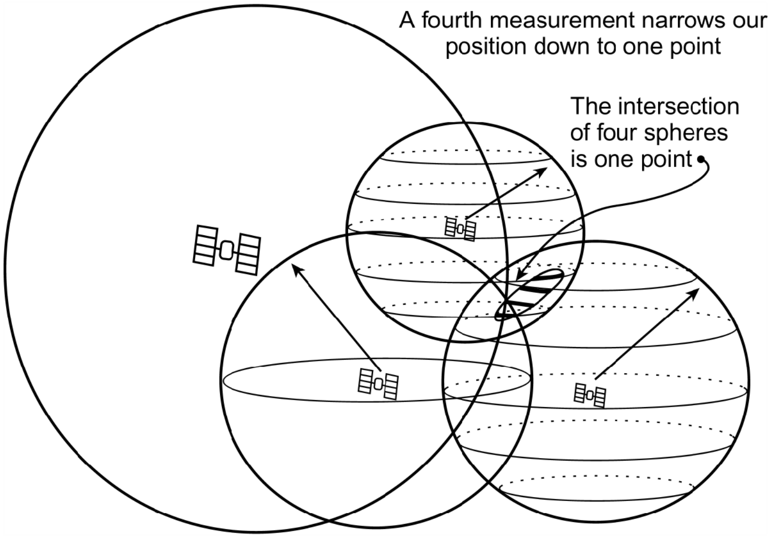


Figure 3

The distance between the receiver and the satellites is calculated by multiplying the speed of the radio signal (speed of light) by the time it takes for the satellite signal to reach the receiver antenna, otherwise known as the time delay, as discussed above.

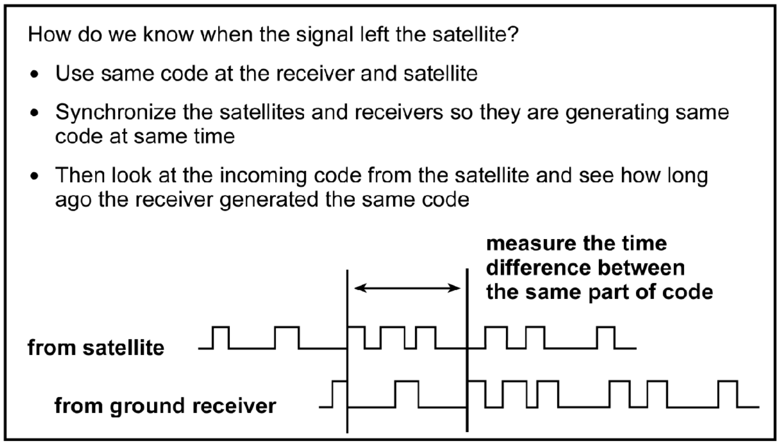


A fourth measurement narrows our position down to one point

The intersection of four spheres is one point

Figure 4

Herein lies the obstacle to satellite ranging: determining exactly when the signal left the satellite in order to determine the distance between the receiver and the satellite. This is accomplished by correlating a pseudo-random noise (PRN) code generated by the satellite with the same code being generated internally by the receiver. Each satellite broadcasts its own unique PRN code which the receiver recognizes and looks for each time it is enabled. The satellite and receiver are synchronized so that they are generating the PRN code at exactly the same time. A tracking loop within the receiver shifts the internal replica of this PRN code in time until maximum correlation occurs between the replica code generated by the receiver and the actual PRN code broadcast by the satellite (Figure 5) (Leick, 1995). This time shift value required to align the two code events multiplied by the speed of light gives a range value from the observer to the satellite.



How do we know when the signal left the satellite?

- Use same code at the receiver and satellite
- Synchronize the satellites and receivers so they are generating same code at same time
- Then look at the incoming code from the satellite and see how long ago the receiver generated the same code

Figure 5

These range values are biased, however, by error inherent in the receivers quartz clock and by the Doppler effect caused by the motion of the satellite, so the range is referred to as a pseudo-range. The satellites contain atomic clocks with nanosecond accuracy while the receivers do not possess that capability and any time difference between the two, even less than a second, would translate into the calculation of an inaccurate position of hundreds of miles. To overcome this problem, the receiver uses the range measurements from a fourth satellite to remove the error caused by the clock discrepancies and generates a three-dimensional position. Essentially, the receiver will adjust the range values until the spheres representing the range all intersect at one point (Figure 4).

The second question of where each satellite is in space is easily predicted because they are placed in precise orbits. Since there is no atmospheric drag on the satellite, it remains, for the most part, in this orbit. These orbits are continuously monitored by the DOD control segment and any deviations in the satellite's condition, referred to as its ephemeris, are corrected. These ephemerides are in turn, continuously transmitted by each satellite so the GPS receiver knows the precise location of each satellite at all times. A better understanding of GPS status and other support information may be found at www.spacecom.af.mil/usspace/gps_support/.

Methods of Satellite Positioning

Autonomous

With the autonomous, or stand-alone method, positions are calculated by one GPS receiver operating at an unknown location. This method can be very useful for many applications that do not require a high degree of accuracy. Autonomous receivers are inexpensive, and with the recent decision by the DOD to turn off Selective Availability, autonomous GPS users have a horizontal accuracy of approximately 13 meters at one standard deviation and 22 meters at two standard deviations.

Differential

The second method, which is used for higher accuracy GPS data collection and when accurate navigation is needed, is the differential correction method. Differential GPS (DGPS) refers to the technique used to improve positioning accuracy by determining the positioning error at a known location and subsequently incorporating a correction factor into the position calculated by another receiver operating in the same area while both are tracking the same satellites. This process involves correcting GPS positions gathered by the roving receiver at an unknown location with GPS positions simultaneously collected at a known location (the base station). Both the rover and base station must be tracking the same satellite signals for this method to work, the idea being that the errors impacting the rover are impacting the base station as well. Since the precise location of the base station has been previously established, usually with sub centimeter accuracy, a correction factor can be calculated continuously at the base station and applied to the positions obtained by the rover.

There are two modes of differential correction:

Real Time: Differential correction employs either a radio link between the rover and base station receivers or subscription to a commercial satellite service such as OmniStar. This method of data collection is necessary for high accuracy navigation. In the ground-based system, correction factors generated by the base station are continuously broadcasted to the GPS receiver acting as the rover. These correction factors are applied almost instantaneously to the uncorrected positions being collected by the rover receiver. In the satellite-based system, used in areas where transmitting base stations are not available, a satellite in a geosynchronous orbit transmits the correction.

Post Processed: Post processing is used when high accuracy data are needed, but the effort does not require real-time high accuracy. Post processing involves the collection of autonomous data with a GPS receiver acting as the rover, then correcting these data after the survey is completed using post processing software. It is similar to the real-time method in which a base station and rover receiver collect GPS data simultaneously from the same subset of satellites. However, there is no need for a radio link between the two. Post processing software compares GPS data from both the base station and the rover after the survey is completed, and it performs any necessary corrections. Post processing is generally available via the web from most GPS receiver manufacturers and other sites. Use of these sites should occur shortly after the GPS data are collected in the field to be able to match the same time frame as the data collected in the field.

Since both the rover and the base station must track the same satellites, they must be within a certain range of each other. This distance is referred to as the length and ideally should not exceed 300 km (186 mi). The number of accessible base stations in each Region will most likely increase to keep pace with the growing public and private sector demand for GPS services.

Wide Area Augmentation System (WAAS)

Wide Area Augmentation System (WAAS) is a GPS signal correction system being developed by the Federal Aviation Administration (FAA) and the Department of Transportation for use in precision aircraft flight approaches. Currently, GPS alone does not meet the FAA's navigation requirements for accuracy, integrity and availability. WAAS corrects for GPS signal errors that can be caused by ionospheric disturbances, timing and satellite orbit errors as well as the integrity and health of each of the GPS satellites. WAAS is not expected to be approved by the FAA for a couple of years but the system is available for civilian use, such as for boaters and recreational GPS users.

The existing WAAS network consists of approximately 25 ground reference stations positioned across the United States that monitor GPS satellite data. These data are collected by two master stations, located on either coast and in turn create a GPS correction message. This correction accounts for GPS satellite orbit and clock drift plus signal delays caused by the atmosphere and ionosphere. The corrected differential message is then broadcast through one of two geostationary satellites, or satellites with a fixed position over the equator. The information is compatible with the basic GPS signal structure, which means any WAAS-enabled GPS receiver can read the corrected signal.

Any GPS unit that is WAAS enabled can receive these more accurate corrected signals. Many inexpensive GPS units are available on the market that are WAAS enabled. Currently, WAAS satellite coverage is only available in North America. For some users in the U.S., the position of the satellites over the equator makes it difficult to receive the signals when trees, buildings, or mountains obstruct the view of the horizon. WAAS signal reception is ideal for open land and marine applications. WAAS provides extended coverage both inland and offshore compared to the land-based DGPS (differential GPS) system. Another benefit of WAAS is that it does not require additional receiving equipment while DGPS does.

GPS Accuracy:

100 meters: Accuracy of the original GPS system, which was subject to accuracy degradation under the government-imposed Selective Availability (SA) program.

15 meters: Typical GPS position accuracy without SA.

3-5 meters: Typical differential GPS (DGPS) position accuracy.

< 3 meters: Typical WAAS position accuracy

GPS and GIS

Most of the cost involved in establishing and maintaining a GIS lies in the acquisition of data, both spatial and tabular. GPS has emerged as an effective tool in the ongoing process of improving data capture efficiency and accuracy. Positions are collected by the receiver along with attribute information, the extent of which is dependent upon the sophistication of the receiver, the data logging device, and the needs of the user. Positions are collected using a variety of receivers and methods (walking, driving, flying).

Positions collected by the GPS receiver are converted to cartographic features:

Points: Collecting positions while a receiver remains stationary.

Lines: Joining of positions in a time sequence; each position acts as a vertex while the receiver is in motion during data collection.

Polygons: Joining of positions in a time sequence with the last position being connected to the first position logged and thereby closing off a line segment.

Along with these spatial features, some GPS data collectors give the user the ability to record tabular data that can be entered and linked to features by using data dictionaries that are customized to fit the specific requirements of a survey. Refer to the appropriate users manual for a detailed description of these data collection tools. After post processing, these features can be exported to a number of GIS formats and used for analysis with other spatial data.

GPS: Direct and Secondary Data

Direct: This document is intended to address the approach for directly obtained GPS data, such as during surveys or other collection events or activities.

Secondary: Caution should be exercised by the user in that GPS results are frequently more accurate than available base map information.

Section IV

Quality Assurance Considerations

This guidance supplements EPA Guidance for Geospatial Data Quality Assurance Project Plans (Peer Review Draft), (EPA QA/G-5G), in that the focus here is to guide the process of collecting, editing, and exporting accurate spatial data using the Global Positioning System (GPS).

Overview of QA Project Plan Requirements for Geospatial Data

The U.S. Environmental Protection Agency (EPA) has developed the Quality Assurance Project Plan as an important tool for project managers and planners to document the type and quality of data needed to make environmental decisions and to provide a blueprint for collecting and assessing those data. The QA project plan is the critical planning document for any environmental data collection or use because it documents how quality assurance (QA) and quality control (QC) activities will be implemented during the life cycle of a project or task. EPA policy requires that all projects involving the generation, acquisition, and use of environmental data will be planned and documented and have an Agency-approved QA project plan prior to the start of data collection. The QA project plan should be detailed enough to provide a clear description of every aspect of the project and include information for every member of the project staff, including data collectors, software users, and data reviewers. Effective implementation of the plan assists project managers in keeping projects on schedule and within the resource budget.

Projects that involve geospatial data have unique QA and QC elements, which must be carefully considered in the strategic planning process and subsequently incorporated into the QA project plan. Such projects often use geographic information systems to retrieve, store, and process spatial, temporal, and related environmental data to produce outputs used in decision making. The geospatial data unique to these projects can be collected by direct measurements (e.g., by ground surveys or aerial photography) or acquired from other organizations (e.g., U.S. Geological Survey maps and elevation data). The EPA Guidance for Geospatial Data Quality Assurance Project Plans (Peer Review Draft), (EPA QA/G-5G) presents detailed guidance on how to develop a QA project plan for geospatial data projects. It discusses how to implement the specifications set forth in EPA Requirements for QA Project Plans for Environmental Data Operations (EPA QA/R-5) for geospatial data, whether collected or acquired from other sources, usually processed by geographic information systems.

Many of the requirements addressed in the EPA Guidance for Geospatial Data Quality Assurance Project Plans (Peer Review Draft), (EPA QA/G-5G) that are applicable to geospatial data project planning and implementation were derived from the American National Standard "Specifications and Guidelines for Quality Systems for Environmental Data Collection and Environmental Technology Programs" (ANSI/ASQC E4, 1994), as cited in contract and assistance agreement regulations and incorporated in the revised EPA Order 5360.1 A2 (EPA 2000) and the EPA Manual 5360 A1 (EPA 2000). The scope of the order's applicability includes "the use of environmental data collected for other purposes or from other sources (also termed secondary data), including . . . [data] from computerized data bases and information systems, [and] results from computerized or mathematical models." It is a frequent and often critical component of this type of project. Implementation requirements include data processing to be performed in accordance with approved instructions, methods, and procedures. Also required are evaluations of new or revised hardware/software configurations and documentation of limitations on use of data.

Graded Approach

The EPA recognizes that the use of quality management components and tools in the Organization/Program and the Project levels is based on a graded approach where components and tools are applied according to the scope of the program and/or the intended use of the outputs from a process. This approach recognizes that a "one size fits all" mentality to quality requirements is not appropriate for an organization as diverse as the EPA and the multitude of stakeholders. For this reason, a tiered approach to accuracy values for locational information is being considered for the Agency's location data. With respect to GPS information, this underscores the importance of documenting the GPS collection method used to collect coordinate data (see Latitude/Longitude Data Standard at http://www.epa.gov/edr).

EPA QA Requirements

The Agency-wide Quality System is a management system that provides the necessary elements to plan, implement, document, and assess the effectiveness of QA and QC activities applied to environmental programs conducted by or for the EPA. These directives, requirements, and guidance documents may be found at the EPA QA website: http://www.epa.gov/quality/.

The root QA document, from which other QA documents applicable to the collection and disposition of GPS data are based, is the EPA Order 5360.1 A2 (2000), Policy and Program Requirements for the Mandatory Agency-wide Quality System, and the EPA Manual 5360 A1 (2000), EPA Quality Manual for Environmental Programs. These documents include coverage of environmental data,[1] including any measurements or information that describe location and information compiled from other sources such as data bases (e.g., georeferenced data) or the literature (maps) under their requirements. Three of the applicable requirements are:

- The use of a systematic planning approach to develop acceptance or performance criteria for all work covered by the EPA Order. See Section 3.3.8 of the EPA Quality Manual for Environmental Programs;
- The approval of Quality Assurance Project Plans (QAPPs), or equivalent documents defined by the Quality Management Plan, for all applicable projects and tasks involving environmental data with review and approval having been made by the EPA QA Manager (or authorized representative defined in the Quality Management Plan); See Chapter 5 of EPA Manual 5360 A1 (2000), EPA Quality Manual for Environmental Programs; and
- Assessment of existing data, when used to support Agency decisions or other secondary purposes, to verify that they are of sufficient quantity and adequate quality for their intended use.

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[1] environmental data – Any measurements or information that describe environmental processes, location, or conditions, ecological or health effects and consequences; or the performance of environmental technology. For the EPA, environmental data include information collected directly from measurements, produced from models, and compiled from other sources such as data bases or the literature.

"QA Project Plans Requirements" are provided in Chapter 5 of the EPA Manual 5360 A1 (May 2000) for EPA personnel and "EPA Requirements for Quality Assurance Project Plans," EPA QA/R-5 (EPA 2001) for extramural personnel.

Project Design Criteria

Systematic planning and the development of project and/or data quality objectives is required for all projects. The EPA Guidance for the Data Quality Objectives Process EPA QA/G-4 and Guidance for Choosing a Sampling Design for Environmental Data Collection Peer Review Draft EPA QA/G-5S should be referenced because the GPS locational data will probably be related to environmental media data in analysis or data processing such as modeling.

In line with the EPA QA System is the EPA Locational Data Policy (LDP). The LDP must be considered in project planning with the EPA QA/G-5 used as a blueprint (specifically QA Project Plan elements A5 and 7).

With regard to statistical analysis in project design, the EPA maintains a "graded approach." Refer to the EPA Guidance for the Data Quality Objectives Process (G-4) EPA/600/R-96/055 for a full discussion of this subject.

Quality Assurance Project Plans are reviewed and approved by EPA Project Managers with assistance and approval of their EPA QA Managers. Technical and quality oversight is conducted as projects or their tasks are implemented to determine whether they are conducted as planned, documented, and approved (controls) or that timely corrective action is taken to assure that objectives are met (e.g., database files and processed results such as hazard maps assessments). Note that a graded approach is used to tailor the QA Project Plan to the project or task and if routine operations can be covered by a generic plan and associated standard operating procedures.

Accuracy and Precision

GPS quality issues are predominantly related to identifying the accuracy of recorded data. In order to ensure that collected data meets the needs of the project, guidelines must be used that maximize the accuracy of the GPS unit. However, before specific guidelines are discussed, it would be instructive to discuss accuracy and precision.

Accuracy is a measure of the amount of deviation of an observation, or a combination of a number of observations, from the true value. Or, how close is the determined result from the known value (this is called "bias"). Considering that the EPA's Quality System maintains a "graded approach," accuracy is presented as a range value (i.e., plus or minus a value) that is determined by calculating the standard deviation or Root Mean Square Error (RMSE) of the observations from the known value. For example, in a normal distribution, a 68 percent confidence interval can be calculated by adding and subtracting one standard deviation from the mean value and a 95 percent confidence interval by adding and subtracting two standard deviations from the mean.

Precision means the closeness, tightness, or scatter of the positions of the points to each other. The second standard deviation, which gives a 95 percent confidence interval, is expressed as "xx meters" from the average value and is used to estimate the quality of code-based GPS points. Optimally, both good accuracy and precision are desired with GPS points, with accuracy being preferred to precision. With code-based GPS, precision is obtained. Depending on the GPS receiver type, it can use different signals from the satellites. For example, Federal agencies have access to Precision Lightweight GPS Receivers (PLGR) which use the encrypted Y code. This improves the accuracy of these hand-held units particularly where tree canopy or other signal interference is a problem. The reported accuracy of most commercial units has not been clearly defined. There is not common agreement on whether the reported accuracy for a unit represents one or two standard deviations. However, locational data are collected with Standard Operating Procedures that specify exactly how the data are to be collected and processed and which have proven to consistently provide accurate positions that make up the point. Then the precision of the data can be used to estimate the quality of the point. If the data are properly collected and processed, the estimate of the quality of the precision of the data can be used with confidence as the estimated accuracy of the data. A graphic of precision and accuracy is shown below in Figure 6.

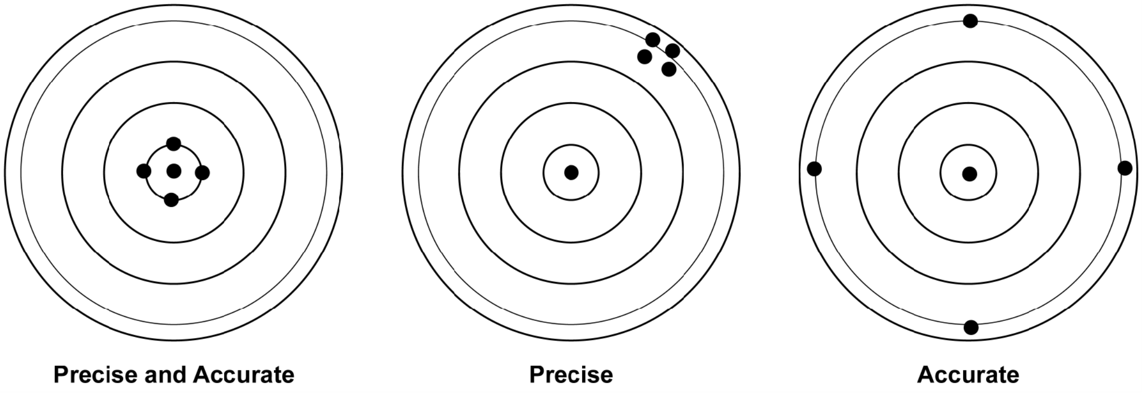

Figure 6

Factors Affecting the Accuracy of the GPS Survey

There are many factors, which when present, have a certain affect on the accuracy of a location calculated by a GPS receiver. Some of these factors are not always present, some cannot be avoided, and the effects of some can be greatly reduced or eliminated. The following is a list of some of the more common occurrences which can or will affect the accuracy of a GPS derived position and some of the ways in which to reduce or eliminate their impacts.

Multipath

Multipath is the arrival of a satellite signal at the receiver along with one or more "reflections" of the same signal which may have bounced off of an object or some atmospheric condition. A variety of factors contribute to the impact of multipath on accuracy, such as the strength and the delay of the reflected signal as compared to the true line-of-sight signal, the attenuation characteristics of the antenna, and the sophistication of the receiver's measuring and processing techniques (Leick, 1995). Multipath effects can introduce errors anywhere from < 1 meter to dozens of meters. Many multipath errors can be prevented by planning a survey in order to avoid reflective surfaces such as buildings and large bodies of water and by providing the GPS antenna with a clear view of the sky. The EPA Guidance for Geospatial Data Quality Assurance Project Plans (Peer Review Draft), (EPA QA/G-5G), Sampling Process Design, Section 2.2.1, can be used to assist in developing a survey plan.

Atmospheric Delays

The density of the ionosphere affects the path of an electrical field such as a GPS signal. Changes in the density of this layer of the Earth's atmosphere are caused by many factors, but they are primarily linked to sunspot cycles. An increase in the activity of these cycles increases the density of the layer causing more disturbances to GPS signals and reduced position accuracy [http://www.trimble.com/gps/]. Water vapor in the troposphere and atmospheric pressure may also have a slight affect on the accuracy of a GPS position.

Baseline Length

The accuracy (actually the precision of positions related to each other, rather than the accuracy) of a position will degrade as the distance increases between the base station receiver and the receiver at the unknown location. For example, for the Trimble GeoExplorer II receiver, the estimate of this degradation is 2 ppm or an accuracy degradation of 2 mm for every kilometer between the base and the rover. So, if a GeoExplorer II, acting as the rover receiver, was collecting positions 200 km (124 mi) from the nearest base station, then a degradation of 40 cm (15.7 in) may be expected in addition to the error values from other sources. The older Trimble Pro XL unit also has a degradation of 2 ppm. The newer Trimble ProXR unit has a degradation of 1 ppm. The best way to minimize this error is to use a base station operating as close as possible to the survey site.

Position Dilution of Precision (PDOP)

This is a measure of the geometry of the satellite constellation which the GPS receiver is tracking. The level of accuracy associated with positional measurements will vary depending upon the relative angles between the range vectors of two or more satellites (GIS Technical Memo 3, 1992). The ideal situation is to have a constellation of satellites which are spread evenly throughout the sky. The receiver automatically tracks the satellites which will yield the best PDOP value. For example, if you are using a six-channel receiver and there are eight available satellites above the horizon, the receiver will track only those four or five satellites which will yield the best PDOP value, leaving one channel free to collect other information such as the satellites' ephemerides. Satellites very low on the horizon adversely affect the accuracy of the vertical component of the GPS position. This condition *can be eliminated by setting a mask angle on the GPS receiver so that it will disregard certain signals.*

Signal-to-Noise Ratio (SNR)

This is a measure of the satellite signal strength in relation to background noise. Accuracy of the position degrades as the strength of the signal decreases. One should refer to the GPS instrument manufacturer's manual to find the range of the particular model's SNR. Subsequently, a determination should be made to assess whether that SNR range is adequate for the purposes of the project or study. A SNR mask set at 8.0 (or higher, but not higher than 10.0) may reduce some multipath reflected signals since higher SNR's have shown to provide better quality signals.

Data Quality Indicators and General Requirements

The following section describes data quality indicators used in GPS data collection and general requirements for GPS use related to each indicator and based on the sources of inaccuracies mentioned above.

Accuracy and Precision Requirements

As mentioned previously, the accuracy needed for a GPS survey is related to the goals of the project and the type of information collected. Since the accuracies of GPS equipment and their procedures varies greatly, different data collection procedures will be required for each purpose. In general, GPS data collection can be divided into four main groups:

1. Gross position collection (13-meter horizontal accuracy) refers to the recreational grade GPS units.
2. Coarse mapping grade collection (2-5 meter horizontal accuracy).
3. Fine mapping grade collection (1 meter horizontal).
4. Survey grade collection (1-2 cm horizontal and vertical accuracy).

The procedures of each of these will be treated separately within each data quality indicator section.

Multipath Avoidance Requirements

Multipath errors can be limited by using newer equipment, augmenting GPS work with laser range finders to keep distance between the receiver and the source of the error, or by using conventional survey techniques in areas of multipath. Many units manufactured after 1997 have software that significantly reduces multipath; for example, Trimble's Everest multipath rejection software. GPS surveys in areas near large reflective flat surfaces (such as buildings) without the benefit of lasers, conventional surveying, or multipath cancelling software must be at a sufficient distance from the large reflective areas so that the GPS antenna sees the sky from 45 degrees and above.

Metadata File Collection Requirements

While it is recognized that many recreational grade units are typically not capable of storing in memory essential method, accuracy, and description values that are required by the Latitude/Longitude Data Standard (L/LDS) each coordinate point collected with a GPS is still required to document this information. It is for this reason that recreation grade units are not encouraged, except where no other option exists for collecting locational data. For mapping grade and survey grade units, the following information should be saved to file in addition to the standard metadata required by the L/LDS:

1. Correction status,
2. GPS unit type,
3. PDOP, and
4. Standard deviation of points.

All of these data provide information on the overall quality of the GPS locations. The standard deviation provides information on the precision of collected data. If the standard deviation is high, there is an indication of possible interference. If the standard deviation of point data is greater than 10 times the horizontal accuracy of the GPS unit, the data should be considered invalid.

Satellite Detection and Position Requirements

Due to the three-dimensional triangulation method used by all GPS units to determine location, a minimum number of signals from at least four GPS satellites in the proper array in the sky are required for accuracy. Unfortunately, most GPS units allow the user to utilize fewer satellites than the minimum, and in less than ideal positions in the sky, than are required for quality data. Fortunately, GPS units also have the ability to limit displaying and recording locational information until the proper number of satellite signals in the right constellation is acquired by the unit. This function must be employed by EPA users.

The utilization of four GPS satellites for 3-D positional fixes, with no significant precipitation, good satellite visibility, a PDOP (indicator of a selected satellite geometric configuration) of no more than eight, and simultaneous data recording of the base and remote units during the duration of the locational data gathering effort, whether in real-time differential correction or postprocessing mode, is required for acceptable location results. For differentially corrected data, the datalogger must be set to read satellites at no smaller than a 15-degree angle above the horizon.

Atmospheric and Ratio Requirements

Perhaps the easiest parameter to adhere to in GPS use is the requirement that no data are collected during heavy precipitation. As far as any errors created by variations in the ionosphere, the gross and mapping grade units have a fixed correction based on average ionosphere activity. The relative accuracies of these units already reflect this limitation. The use of dual frequency receivers for survey grade GPS receivers corrects atmospheric problems by utilizing the difference in real-time travel times of the two frequencies caused by atmospheric variations.

Base Station Distance Requirements

For GPS projects requiring land-based differential correction, the error introduced by the distance from the rover to the base unit, as measured by the manufacturer's specifications for the GPS unit and processing software, should result in an error of no greater than 10 percent of the specified horizontal error of the unit. This requirement applies predominantly to post processed data corrections. For real-time differential correction, actual transmission distances will generally limit the error. For survey grade GPS work, the distance from rover to base is limited by the radio transmission distance of approximately 10 km so no requirements are necessary.

Calibration Requirements

Field calibration is not required for gross GPS work. The "graded approach" to QA is invoked for this type of work.

GPS units, like any field electronic equipment, must be maintained in the proper working order to ensure the highest quality data. A number of checks and procedures are required to ensure that the GPS unit is working properly. These include checks of the software, wiring, and periodic checks against a known location.

Ideally, for mapping grade data collection, if given sufficient notification and where practicable and possible, the user should acquire GPS measurements at a nearby 1st order horizontal National Geodetic Survey (NGS) monument at the beginning of each day of field work to ensure the overall performance of the unit matches its manufacturers stated accuracy. In other words, the observed readings would be compared with the published coordinates of the monument to give the user tangible assurance that the unit is performing within the manufacturer's accuracy. However, this may not be feasible for most field work. Since using or finding NGS monumentation is not always feasible, or possible, the accuracy of the survey will be based on the manufacturer's specifications. Accuracy is determined by using differential corrections for locational data, and by performing quality control checks on the locational data collected. The magnitude of the standard deviation will provide an idea of the quality of the locational data, while the spatial distribution of the individual positions inside a locational data file will provide visual clues for deleting obvious outliers. It is recommended that each Region be allowed to decide what factors, if any, are used to determine the accuracy of the points collected. Another field estimate of quality would be the comparison of two field GPS units of the same type in the same location. The error should be no greater than that due to the unit's specifications. For survey grade work, a first order benchmark (horizontal, vertical, or both depending on the requirements of the work) is required. Therefore, no calibration is necessary.

Completeness Requirements

Types of Samples Required: The types of samples that require GPS use should be determined in the planning stage of data collection. It is not always appropriate to require the highest accuracy to be attained, nor is it correct to say that every GPS survey demands an elaborate design. In some situations, such as in an emergency response, a GPS survey crew may go from start to finish with no more of a plan than a minute-to-minute decision can provide. Again, the graded approach must be applied with good judgement.

Data Collection Time and Frequency Requirements

Keeping the *graded approach* in mind, the time for residing at a particular location is dependent on the accuracy required. If less accurate information is needed, then the unit can be operated in streaming mode where the location is captured by the user based on the unit obtaining a stable result. Generally, this is indicated by the unit, and the time required at the location is minimal. If higher accuracy is required, then the position to be captured should be occupied for a longer duration. Several results can then be captured for the same location. These results can be improved by occupying the same location on different days and different times of the day when the satellite configuration is different. Therefore, course mapping work should require fewer positions for shorter duration than fine mapping work.

The user must specify the requirements of the study in terms of Data Quality Objectives in the planning phase and describe the operations to achieve the criteria in the Standard Operating Procedure. The following examples show a *hypothetical relationship*, between different types of studies, and can be used as “departure points” for establishing data collection time and frequency requirements for a project:

- For gross work with recreational units, a single position is acceptable. However, the use of these units for Agency work is NOT encouraged.
- For coarse mapping work, a minimum of 12 positions is collected over a period of 1-3 minutes for point data collection. The actual requirements should be described in the GPS Data Collection SOP for the study, and any deviation from the SOP should be recorded.
- For fine mapping grade data collection, a minimum of 36 positions is collected over a period of 3-5 minutes. The actual requirements should be described in the GPS Data Collection SOP for the study, and any deviation from the SOP should be recorded.
- For survey grade work, no averaging is required.

Data Evaluation

Once GPS data has been collected, depending on the project goals, the data are evaluated for quality. For gross data collection, recording information to satisfy the Locational Data Policy is sufficient. For mapping grade data, the recorded standard deviation is an indication of the quality of the data and should be used for screening purposes as mentioned. In addition, the recorded PDOP and correction status provides additional quality checks. This raw information should be saved along with any pre-survey calibration surveys with other project data in a database. Data of the locations can also be evaluated against other available geospatial data such as digital orthophoto quads, topographic images, road and parcel databases, etc. Any deviation from the SOP should be recorded.

Section V

Core Elements of GPS Standard Operating Procedures

Planning and Preparation

Planning and Implementing a GPS Survey

The following sections will outline the basic steps involved in planning and conducting a GPS survey. In order to complete a successful GPS survey, several steps must be taken prior to using the receiver in the field. These steps will apply to the use of any of the various GPS receivers maintained by the Agency. Most of the steps in the pre-survey and post-survey process will be conducted in conjunction with, or entirely by, the GPS coordinator. Equipment will be on loan to those employees who have been trained on the use of the GPS receiver. Those who require training or feel that retraining is necessary must notify the GPS coordinator well in advance of a proposed GPS survey so arrangements can be made for training. Training will be provided either on an as needed basis or through scheduled group training sessions.

It is extremely helpful if the field person who will be conducting the survey has some knowledge of the site layout prior to data collection, either through published maps or previous site visits. This knowledge of the survey site will help to expedite the survey by determining what features will be mapped and in what order.

Pre-survey Planning

Contact the GPS Coordinator to identify the following prior to the GPS survey-

- The availability of the GPS equipment for the date(s) it is needed
- Objectives of the survey
- What features will be mapped, sample point location identification, and how they should be represented (points, lines, areas)
- A checklist of each feature to be mapped so that none will be overlooked in the field
- Site maps for determining in what sequence features will be mapped
- The presence of any obstructions to satellite signals such as buildings or tree canopies
- The necessity of a data dictionary
- Required accuracy of the survey (sub-meter, 5 meters)
- Extent and duration of the survey (how many features, how many days)
- Naming conventions for features and GPS file names
- The need to use external sensors such as laser range finders, digital cameras, or depth finders

If an Agency regulated facility is to be mapped, a site description category should be used from the latitude/longitude site description table from the Method, Accuracy, and Description (MAD) code tables (see the reference section). These site descriptions can be added to a data dictionary as feature attributes and installed on a GPS receiver or data collector.

The answers to some of the above questions will determine what type of GPS receiver/data collector combination will be required for the survey. Be mindful that a position represents only one part of a feature.

The following section will outline which tasks will be completed by the GPS coordinator and the staff person(s) requesting the GPS equipment for a survey.

Define Objectives of Survey

It is clearly important to initially establish the ultimate objectives of a GPS survey. Recognition of these objectives early in the project planning process will help to focus the rest of the planning phase. The accuracy requirements for the positional data needs to be defined, paying particular attention to the EPA Locational Data Policy (See the Appendices section). From the discussion above, some distinct survey objectives may include:

- Registration of remotely sensed photography or imagery,
- Evaluation of locational data quality of existing data, and
- Sample data collection following precise coordinates in a monitoring plan.

Define Project Area

This step is designed for establishing the overall project area and defining the limits of the survey. Maps and/or aerial photos should be utilized extensively to familiarize the crew with the area prior to the actual field work. For identifying the study area and surrounding environment, 7.5 minute topographic maps are ideal. For locating particular sites by address a local street map will be required. A complete understanding of the project area transportation network will also enable the field crew to maximize the effectiveness of their field time. Much of this information is already available in digital form and can be used directly in conjunction with GPS site planning as well as validating the capture of the GPS locations.

Determine Observation Window and Schedule Operations

This involves determining the precise window of satellite availability and scheduling accordingly. With approximately 24 satellites available for use, we generally are restricted for very short periods of time (usually less than 40 minutes in a continuous block of time and less than one hour during a 12-hour time period) during the day, in open environments. However, in cities with many nearby tall buildings, GPS is often difficult to get. Optimization of the schedule is dependent upon the size of the crew, the level of accuracy desired, the logistics of setup, and the travel between control points. Many GPS units contain the satellite schedules in their internal software. Updated satellite configuration and orbit information can be accessed via the Internet.

A current satellite visibility almanac is invaluable in planning a survey mission. Provided by several vendors, these almanacs provide information on the availability of satellite coverage. Since satellite orbits are periodically adjusted, these almanacs require updating at least every month. Most vendors provide updates using either electronic bulletin boards or regular mail. For final verification of availability, contact the U.S. Coast Guard GPS Users Service for information on the entire system or any individual satellites that may be deactivated during your scheduled field work. Information is also broadcast by U.S. National Institute of Standards and Technology (NIST) at 15 minutes past each hour http://www.boulder.nist.gov/timefreq/stations/wwv.html.

QuickPlan from Trimble Navigation is an easy-to-use Windows-based software program which provides information critical to the various components of planning a GPS survey: satellite availability, elevations, azimuths, and Geometric Dilution of Precision (GDOP) calculations.

Several rules of thumb exist regarding available windows and angles above the horizon. Most almanac software will yield good results for windows within one half degree of the survey station (approximately 30 miles). If your survey mission will span greater distances, then you may wish to iterate calculations for several planned survey locations. For angles above the horizon, optimal results are achieved with satellites 25 degrees above the horizon; however, as little as 10 degrees works well in areas of minimal obstruction. Be aware that this could present a problem if your going to differentially correct against a base station later on, since the rover has to "see" the same satellites as the base.

Accuracy is heavily dependent upon the amount of observation time and number of observations taken at each point. It is generally agreed that observation time can be reduced by increasing the quality of observation, i.e., observing a maximum number of satellites during 3-D viewing periods. Accuracy can also be increased by repeated visits to the same location at different times.

Establish Control Configuration

For high accuracy work, known control points and/or benchmarks are located for both horizontal and vertical control. This is usually accomplished by researching the records of various Federal, state, and local agencies such as the National Geodetic Survey or the state geodetic survey. It is advisable to have, if possible, at least two control points each for both vertical and horizontal positions so that there is a double check for all control locations. NGS benchmark information can be obtained at http://www.ngs.noaa.gov/.

It is of paramount importance that the reference datum within which the monument is located be defined. The discussion provided later in this section will explain the reasons in detail. For horizontal coordinates, the North American Datum of 1927 (NAD 27) or the newer Datum of 1983 (NAD 83) will be specified. For vertical control coordinates, the National Geodetic Vertical Datum of 1929 (NGVD 29) or the new North American Vertical Datum of 1988 (NAVD 88) will be referenced. If the NGS has redefined the benchmark coordinates to correspond to the newer datums, coordinates will be available for both datums.

If the monument is located in a controlled-access setting, the appropriate individuals should be contacted to obtain admittance. The station recovery section of monumentation data sheets provided by NGS describes in detail how to locate a particular point and whom to contact for access.

Sensitivity to factors contributing to multipath are particularly important for positioning a receiver station and antenna. In particular, control points/areas should not be near power lines, substations, or large metal objects which can cause multipath interference and corrupted data. Since observation of these proximate features may not be possible until the survey reconnaissance is performed, having backup sites ready will save time.

Choosing control points for use as base stations may require a physical inspection of the site. Ideal locations will have a near 100 percent clear view of the sky and be easily accessible. They should also be located in areas of low vehicular and pedestrian traffic. Where real-time kinematic surveys or post processing are being planned, government agencies or other organizations may already have established base stations in the area. They should be contacted to ensure that the base station is recording at the planned time of the survey. In many areas, vendors and other organizations have operating base stations that have web access for use in post processing.

Select Survey Locations

Obtain a list of the facilities or features targeted for data collection. A good suggestion is to organize the site lists alphabetically by city and alphabetically by street name within each city as well as by zip code. This will facilitate initial route planning to visit each and serve as a master list. If possible, plot the general location on a field map and highlight a local street map to serve as a general navigation aid. Similarly, plot potential base stations to serve as control points on a 7.5-minute topographic map and local street map.

If the survey point to be obtained is located on private property, care should be taken to pursue appropriate notification and access protocol. This includes preparation of a letter of introduction and formal contact with the property owner/manager. A sample letter is included in the Appendices section.

The points/areas should have continuous and direct line-of-site to the path of the satellites in the sky. Based on the view provided by satellite window planning software such as QuickPlan, and the survey team's knowledge of the natural and man-made topographic features, it may be possible to predict masking.

As with control points, obstructions and other factors can cause interference and corrupted data during the survey. It is advisable to note any adverse conditions on a form when collecting data. This will be helpful in the postprocessing phase.

If point data being collected are to be used as control for photogrammetric operations, then the point locations must be photo identifiable on the imagery to be used for photo registration. If the registration is to be used with historic imagery, the locations should be landmarks present and identifiable for the entire period of history to be reviewed. Such landmarks might be corners of the street network that have remained constant, street/railroad intersections, hydrants, or other public works.

Equipment Logistics

Survey planning action items in this area include: determination of equipment availability (laptop PC, GPS units, transport vehicle, monumentation equipment) and checking equipment for necessary repair and maintenance (batteries charged in PC and GPS unit, PC disk loaded with necessary software and has available disk space).

This is the time to collect and pack field survey equipment. In addition to the above items, experienced crews carry everything from a compass and tape measure to manuals and almanac printouts. Suggested checklists are provided in the Appendices section.

Reconnaissance

The purpose of this phase is to:

Locate and Verify Control Point Locations

For high accuracy work, this is critical to the success of the overall survey. Often, monuments have been damaged, stolen, buried, or vandalized. If a control point cannot be recovered, a replacement must be located. This can drastically change the schedule and logistics of the field survey. Also, it may be found that a monument's location has shifted somewhat.

Plan to visit each of the control points at least twice during the survey. Collecting redundant data are useful in determining the quality and accuracy of the overall survey. The duration of each fix should be approximately 3-5 minutes, but it may be adjusted depending on data accuracy needs as articulated by the EPA's Quality System graded approach.

Preview Instrument Locations

Obtain permissions and verify accessibility. It will often be necessary to coordinate activities with property owners, local law enforcement, and/or land management officials in order to ensure safe and authorized access to the instrument locations. Verify that there are not any visible multipath-contributing or masking features. Identify any natural or man-made obstacles to direct access of the survey point.

Physically Establish Point Locations

This is accomplished by using a standard surveying marker such as an iron pipe, a hub and tack, or a brass nail. All points should be documented with detailed descriptions in a log book, utilizing, if practical, the descriptive reference points listed in the L/LDS, as this information will be required in the subsequent input of coordinate information in the Locational Reference Tables . If nearby multipath or masking features are unavoidable, note their presence. It may be necessary to physically offset the GPS control point from an obstructed benchmark. This can effectively be accomplished using a compass and tape measure. Whatever approach that is used, the end-use of the project data should drive the establishment of reproducible markings.

Survey Execution

The actual GPS survey consists of:

Establishing a Schedule of Operations

This involves determining the window of satellite configuration availability and scheduling the GPS sessions. This is dependent on the size of the crew, the level of accuracy desired, and the logistics of setup and travel between control points. Maximum data quality and collection efficiency can be obtained by arranging data collection periods to coincide with periods of 3-D or better satellite visibility.

Pre-survey: The Day Before

Plan on arriving the day before. Charge all batteries. Many GPS collection systems utilize a battery system which requires either 8-hour or overnight charging. Review the travel routes to survey sites and base stations, if required, and coordinate with local personnel. Review use of unfamiliar equipment and understanding of procedures.

Pre-data Collection: Establishing a Base Station

The type of survey will dictate if a base control station in the field is required. If required and the location is not secure or if the data collection period is particularly long, part of the survey crew may be required to remain at the site. Logistical considerations will need to be scheduled, i.e., shut down periods for downloading files, changing battery packs, and when to terminate collection. Once a setup at a base station begins, the GPS units will need to be initialized. Depending upon the location and familiarity with equipment, this activity can take anywhere from a few minutes to a couple of hours.

Field collection data should be saved as digital files in order to facilitate depositing the data into Information Management Systems.

Data Collection: Performing the GPS Survey

The crew must warm up, check, and program the receiver for proper operation. Most vendors currently recommend collecting fixes for discrete point data for a period of 3-5 minutes, at a 1- or 2-second interval. Many software packages require approximately 35-40 readings per point to perform statistical analyses. Any deviation from this would be reflected in each Region's SOP.

In some cases, a raster background image is used in GPS units to support the use of georeferenced imagery. Users also have an option to digitize "non-GPS" features using the georeferenced background raster image loaded into the GPS unit. When this method of digitization is used in the field, users should refer to the requirements of georeferenced data that is outlined in the EPA QA G-5G document.

Special note: Recreational GPS Units
Whereas taking 35 - 40 readings may be appropriate for sub-meter survey-grade accuracy, this may not be appropriate for recreational units. Recreational GPS units are widely used by some EPA Programs and stakeholders. The Agency is currently developing standards for recreational units. Though this is intended to be a living document, the reader is encouraged to check the web site for the latest changes in standards, especially recreational units. http://oaspub.epa.gov/edr/epastd$.startup

Depending on the unit being utilized, sufficient battery power must be available. For high accuracy work, the receiving antenna must be leveled on a tripod and centered exactly over the control point location. Log sheets containing critical information on position, weather, timing, height of instrument, and local coordinates must be maintained. Once the session is completed, the receiving equipment must be disassembled, stored, and log and tape files documented.

If the survey to be performed will span over numerous days, it is likely that the data will be transferred from the GPS to a laptop PC with some regularity. Data from the base station as well as the roving unit will need to be collected with equal frequency.

Returning from the Field

This is the time to perform other post-survey tasks. Before leaving the site, document any unique problems. After returning from the field, complete other housekeeping chores such as recharging the system and cleaning the equipment. Use checklists to make sure equipment is in working order and any consumable supplies are reordered. Post processing may be conducted after returning from the field. Tools for post processing are more easily used and controlled in an office environment. The common steps in post processing are transferring the data from the field to the lab, conducting the initial stages of processing, computation of the solutions for critical factors, data conversion for use in a GIS, and the final documentation and reporting. Each of these stages is discussed in detail below.

Data Transfer

There are currently two common methods of collecting data in the field: using a GPS unit with a datalogger or using a GPS unit with a laptop/notebook computer. With the latter method some users subsequently perform all processing directly on the same device. More commonly, data are transferred into a computer. This consists of reading the raw data from the GPS unit into a structured data base for processing. As with any computer data, backup copies should be made immediately.

Initial Processing

The electronic GPS data stream may not be immediately useable. It normally consists of satellite navigation messages, phase measurements, user input field data and other information that must be transferred to various files for processing before computations can be accomplished. Depending upon the hardware and software vendor, many of these operations are transparent to the user. There are five components to the initial processing phase performed by GPS "firmware," software that comes with the GPS units:

1. Orbit Determination: Using satellite navigation messages, one unambiguous orbit for each satellite is computed,
2. Single-Point Positioning: Clock corrections and parameters for each receiver are computed,
3. Baseline Definition: General locations of receiving stations are established, computing the best pairs of sites for baseline definition,
4. Single Difference File Creation: The differences between simultaneous phase measurements and the same satellite from two sites. This is the basic data from which network and coordinate data will be derived, and
5. Data Screening and Editing: Automatic and manual screening of the single difference files and editing of data obviously affected by breaks, cycle slips, or multipath.

In some instances, depending on the type of maintenance and upgrades that are going on to the NAVSTAR constellation at the time of the survey, utilization of the actual ephemeris rather than the ephemeris projected prior to the survey date may improve solution accuracy. Actual ephemerides are available 2 weeks after a given survey date.

In the data screening and editing step above, there are at least three considerations that might be taken in editing. Outlier position data can be removed from a data file. This editing should be guided by establishing an absolute deviation threshold, using the mean coordinate as a reference. The threshold criteria might be varied to determine the sensitivity of the solutions to this editing. Data points collected immediately after a break in the data stream, such as in the event of masking, should be edited out because these positions will be less reliable.

Computation

This component uses the preprocessed data to compute the network of sites and give a full solution showing geographical coordinates (latitude, longitude and ellipsoidal height), distances of the vectors between each pair of sites in the network, and several assessments of accuracy of the various transformations and residuals of critical computations. If the standard deviation for a differential mode position is greater than 5 meters, removal of outlier coordinates and recalculation of a position mean is advised (Lange, 1990). This should be left up to the Regions, since better quality (i.e., +/- 1 meter data) might be desired, or lower quality data may suffice. Also, samples taken while on an unanchored boat or from a helicopter would require individual attention.

Data Conversion to GIS

Data conversion is accomplished by use of Data Export Utilities obtainable from the GPS manufacturer. These utilities should accompany the Data Processing Software packaged with the GPS Equipment. Example formats are: ArcView, ArcInfo, dBase, ASCII, MapInfo, AutoCAD, etc. Before exporting, ensure that the correct coordinate system and datums are chosen. Contact the regional GIS coordinator on the required system for use with GIS layers.

Documentation and Reporting

The documentation and reporting requirements for spatial data are established in the Agency's Latitude/Longitude Data Standard (L/LDS). This data standard draws elements from both the EPA Locational Data Policy and the Federal Geographic Data Committee's (FGDC) Content Standard for Digital Geospatial Metadata.

The Latitude/Longitude Data Standard establishes the requirements for documenting latitude and longitude coordinates, and related method, accuracy and description data for places of interest to the Agency. Places include facilities, sites, monitoring stations, observation points, and other features regulated or tracked under federal environmental programs within the jurisdiction of the EPA. The intent of this standard is to ensure that sufficient information is available with each set of locational data to enable an assessment of the precision and accuracy of that data. Mandatory reporting data elements include:

Latitude Measure: Expressed in Degrees and decimal degrees (DD.dddddd)

Longitude Measure: Expressed in Degrees and decimal degrees (DD.dddddd)

Horizontal Collection Method: Describes the method used to determine coordinates. GPS methods currently recognized include:

Horizontal Collection Method	Definition
GPS Carrier Phase Static Relative Position	The geographic coordinate determination method based on GPS carrier phase static relative positioning technique
GPS Carrier Phase Kinematic Relative Position	The geographic coordinate determination method based on GPS carrier phase kinematic relative positioning technique.
GPS Code (Pseudo Range) Differential	The geographic coordinate determination method based on GPS carrier phase kinematic relative positioning technique.
GPS Code (Pseudo Range) Precise Position	The geographic coordinate determination method based on GPS code measurements (pseudo range) precise positioning service.
GPS Code – Autonomous, Recreation class unit (new method proposed)	The geographic coordinate determination method based on GPS position calculated by one receiver at an unknown location with a recreation class unit
GPS, with Canadian Active Control System	The geographic coordinate determination method based on GPS code measurements (pseudo range) using the Canadian Active Control System
GPS-Unspecified	Global Positioning Method, with unspecified parameters.

Horizontal Accuracy Measure: The measure of the accuracy (in meters) of the coordinates

Reference Point: The text (or code) that identifies the place for which the geographic coordinates were established

Horizontal Reference Datum: The name (or code) that describes the reference datum used to determine the geographic coordinates. Note: **GPS methods should specify WGS84**.

For further reference to the Agency's adopted Latitude/Longitude Data Standard, please go to www.epa.gov/edr and follow the prompts to the final data standards.

Federal agencies are required to follow the FGDC standard according to Executive Order 12906, "Coordinating Geographic Data Acquisition and Access: The National Spatial Data Infrastructure." Information on the policy and standard as well as assistance with the reporting requirements can be obtained from the EPA Envirofacts website, www.epa.gov/enviro/, or the FGDC website, www.fgdc.gov.

EPA established a Locational Data Policy (OIRM Policy 2100, 8 April 1991) to communicate principles for collecting and documenting latitude and longitude coordinates and associated attributes for facilities, sites, and monitoring and observation points regulated or tracked under Federal environmental programs within the jurisdiction of the Agency (ref. Chap. 13 IRM Policy Manual - Locational Data). This policy applies to all Agency divisions and personnel of agents, contractors, and grantees of the Agency who will, in essence, be collecting, compiling, and maintaining spatial data sets for environmental program support. It states that the collection of coordinates using latitude/longitude has become the preferred coordinate system for identifying features and that the use of the GPS is the preferred method for obtaining these coordinates.

In August2005, the EPA Chief Information Officer (CIO) released *the EPA National Geospatial Data Policy* (NGDP). The NGDP establishes principles, responsibilities, and requirements for collecting and managing geospatial data used by Federal environmental programs and projects within the jurisdiction of the U.S. Environmental Protection Agency (EPA). This Policy also establishes the requirement of collecting and managing geospatial metadata describing the Agency's geospatial assets to underscore EPA's commitment to data sharing, promoting secondary data use, and supporting the National Spatial Data Infrastructure (NSDI). The NGDP supercedes the 2100 Information Resource Management (IRM) Policy Manual , Chapter 13, EPA National Locational Data Policy, 1991. The EPA Locational Accuracy Task Force (LATF) provided it's input to the NGDP regarding Geospatial Data Accuracy.

In recognition of the varying levels of accuracy and precision appropriate for different program business needs, the NGDP requires that EPA Program Offices, Regions and/or Laboratories explicitly state their requisite accuracy and precision goals for specific programmatic purposes based on the Geospatial Accuracy Ties adopted by the NGDP (see Appendix C of this document). In the absence of program-specific procedures addressing minimum accuracy requirements of geospatial data, this policy requires a minimum accuracy requirement of Tier 5.

Section VI

Management of Locational Data

The power of place has demonstrated exceptional potential to serve the Agency in addressing its mission and business needs. The ability for programs, regions, and the public to easily access, analyze, and use geospatial information is recognized as a key component of environmental management. The EPA has placed a heightened emphasis on mapping and integrating data across programs to support environmental protection. As programs increasingly rely on mapped data to guide environmental protection activities, the EPA needs to ensure that locational data are of sufficient quality for intended uses.

To improve the Agency's locational data for facilities and other environmental features, the EPA launched the Locational Data Improvement Project (LDIP) in 1996. The goal of this project was to populate the Envirofacts database and other repositories of spatial information with locational information (e.g., latitude and longitude records) of documented origin, for all data subject to the EPA's Locational Data Policy, including regulated facilities and sites, operable units, and environmental monitoring and observation locations. A secondary objective is to support the infrastructure needed to manage these data in a manner that yields integration across national, regional, tribal, and state systems. The intent is to support the EPA's movement toward data integration based on location, thereby promoting the use of the EPA's data resources for a wide array of cross-media analysis, such as community-based ecosystem management and environmental justice.

The launching of the EPA's Office of Environmental Information (OEI) in October 1999 resulted in more foci on the LDIP to help ensure the acquisition, documentation, storage, and use of locational data to help meet the geospatial needs of the Agency. Critical LDIP activities include maintaining locational information in the Envirofacts Warehouse, improving facility identification through geocoding (i.e., calculating a coordinate value for an entity based on the reported full location address for that entity), supporting the Facility Linkage Application (FLA), and providing the Geographic Information System (GIS) community in program system offices with access to locational data.

Another important aspect of the LDIP is the requirement that all locational information in Envirofacts retain Method, Accuracy, and Description (MAD) codes. These codes, which conform to the Locational Data Standard, describe every aspect of the collection of that particular location. Experience also suggest that it is often critical to record not only the typical MAD code information but also the results of verification or other comparisons. This helps provide users with some assurance that data entry or conversion errors have not occurred.

The locational information in Envirofacts is stored in the Locational Reference Tables (LRT). The LRT act as a storehouse for the actual locational data and business rules that are applied to them in order to provide the most accurate information available for depicting the locations of federally regulated entities.

Although the LDIP has improved the EPA's locational data, challenges still remain. To address these challenges and other concerns of locational data, the Locational Data Improvement Subcommittee (LDIS) was established in March 2001. The vision of the LDIS, as stated in its Action Plan, is to ensure that locational data are collected and documented as an integral part of the Agency's regional and program business. One of the key goals of this vision as it relates to this guidance is that Global Positioning System (GPS) and related technologies are well supported and used within the programs, regions, states, and tribes to collect, document, and quality check locational data.

The Value of Documenting Locational Data: One of the challenges when doing an environmental assessment or analysis is finding documentation about data, commonly called metadata. Documentation provides secondary data users with information about data sets that will help users understand the data and can be used to evaluate the data set's appropriateness for a specific project. A well-documented data set will increase the confidence in the conclusions made after using the data. In summary, documenting data facilitates data sharing and reuse. Complete documentation includes information about:

1. Content
2. Quality
3. Accuracy
4. Methods
5. Intended use
6. Lineage (source information)
7. Availability
8. Distribution and Access
9. Contact

Documentation involving methods, accuracy, and content are significant metadata entities for geospatial data. Geospatial metadata that describes the data collected by GPS can have information about the quality of the positional accuracy for horizontal and vertical coordinates. This information is useful when determining the data's fitness for use. Contact information can also be a source for providing further data set clarification if it is needed. One of the impediments of merging data layers when conducting an environmental assessment is the confusion over the data element names and definitions in each layer. Full documentation will clarify this ambiguity enabling integration and analysis of data layers to occur.

The Agency has a suite of metadata tools for documenting data that are available to everyone in the Agency, states, regions, and the public via the Internet. For documenting a data set, users can enter information into the Environmental Information Management System (EIMS). For documenting the individual data elements, users can enter information into the Environmental Data Registry (EDR). These two cataloging systems will be integrated in the near future. EIMS is an online metadata repository with links to data files and databases. There are built in quality assurance controls within EIMS, including the review of metadata content by a metadata librarian. EIMS supports the Dublin Core metadata initiative, the complex FGDC Content Standard for Digital Geospatial Metadata, and supports Executive Order 12906 serving as the EPA's Clearinghouse for Geospatial data on the National Spatial Data Infrastructure (NSDI).

To learn more about EIMS visit http://www.epa.gov/eims or call the EIMS Support Center at 800-334-2405. To learn more about EDR visit http://www.epa.gov/edr.

LRT Return Format:

The Locational Reference Tables (LRT) serve as a repository for locational information that has been collected and documented as a result of the EPA Locational Data Improvement Project. The LRT are a series of tables that store facility-level locational information collected from the program system databases in Envirofacts and from the EPA regional data stewards. This information includes geographic attributes; coordinate data; and Method, Accuracy, and Description (MAD) qualifiers.

To design the LRT, the EPA solicited feedback from regional and program office stakeholders in regular LDIP meetings. A requirements document was drafted based on this input, and the LRT was designed and released in February 1997 to serve as a repository of latitude and longitude coordinates and associated documentation. The original data load consisted of latitude and longitude coordinates acquired as a result of geocoding. These tables were synchronized with the Envirofacts refresh process to be updated monthly, and it served as the source for spatial data used to depict EPA-regulated facilities in GIS applications developed within the EPA. To access the LRT, go to: http://www.epa.gov/enviro/html/locational/index.html.

Regarding the relationship of LDIS Action Plan Efforts and GPS-Technology Implementation Guidance (TIG), it is important to recognize that there is collaboration between the efforts of the GPS-TIG and LDIS Action Plan. In 1994, the Agency had advocated an Agency-wide accuracy goal of 25- meters. The current best technology for GPS acquisition of data is < 10-meter accuracy. GPS has been acknowledged by the Locational Accuracy Task Force (LATF) as the coordinate data collection technology of choice. Therefore, the work of the LDIS Action Plan and the EPA Geospatial Quality Council would be better served by coordinating and closely aligning the efforts. Revising the Locational Data Policy had been identified as an action item in the LDIS Action Plan and was addressed soon after the release of the GPS-TIG revision 1.

In August2005, the EPA Chief Information Officer (CIO) released *the EPA National Geospatial Data Policy* (NGDP). The NGDP establishes principles, responsibilities, and requirements for collecting and managing geospatial data used by Federal environmental programs and projects within the jurisdiction of the U.S. Environmental Protection Agency (EPA). This Policy also establishes the requirement of collecting and managing geospatial metadata describing the Agency's geospatial assets to underscore EPA's commitment to data sharing, promoting secondary data use, and supporting the National Spatial Data Infrastructure (NSDI). The NGDP supercedes the 2100 Information Resource Management (IRM) Policy Manual, Chapter 13, EPA National Locational Data Policy, 1991. The EPA Locational Accuracy Task Force (LATF) provided it's input to the NGDP regarding Geospatial Data Accuracy. The results of the LATF efforts are provided in Appendix C of this document

In recognition of the varying levels of accuracy and precision appropriate for different program business needs, the NGDP requires that EPA Program Offices, Regions and/or Laboratories explicitly state their requisite accuracy and precision goals for specific programmatic purposes based on the Geospatial Accuracy Ties adopted by the NGDP (see Appendix C of this document). In the absence of program-specific procedures addressing minimum accuracy requirements of geospatial data, this policy requires a minimum accuracy requirement of Tier 5.

Section VII

Legal Considerations

Certain types of locational data can present legal issues relating to the collection, storage, maintenance, and dissemination of the information. If the data are sensitive, due to privacy concerns, confidential business concerns, or post-September 11 security issues, the Agency may need to limit dissemination of the data, or release it only in masked or aggregated form. The Agency discloses data generally for three reasons: because a statute requires the disclosure, because the data has been requested under the Freedom of Information Act, or because the Agency has decided that it is in the public interest to make the information available on its own initiative. With expanding use of computers and the Internet, publishing data on web sites has become a common means of making information widely available. With the increase of information available to the public, it has resulted in a heightened concern about potential misuse of sensitive data.

Collection of Data

Agencies may not collect information from 10 or more persons by means of identical questions, or identical reporting or record-keeping requirements, unless the collection is cleared by the Office of Management and Budget (OMB). This is required by the Paperwork Reduction Act, 44 U.S.C. § 3501 et seq. If information is requested from 10 or more persons by means of identical questions, the Agency must obtain a control number from OMB and display the control number in accordance with OMB regulatory requirements. If there are any questions whether the Paperwork Reduction Act applies to a collection of information, Agency legal counsel should be consulted.

Storage and Maintenance of Data

The Federal Records Act (FRA), 44 U.S.C. § 3101 et seq., and § 3301 et seq. The FRA requires agencies to maintain and dispose of official records in accordance with formally adopted records retention schedules. Official records include material that is required by law to be developed or that documents EPA actions or the formulation of EPA policies or decisions. Data files and raw data may be official records for purposes of the FRA if the data are necessary to document the decision trail of the Agency's action. The records retention schedules and other information about the FRA may be found at http://www.epa.gov/records.

Release of Data Pursuant to Freedom of Information Act Requests

The Freedom of Information Act (FOIA), 5 U.S.C. § 552, provides that agencies will make records available to the public upon written request, unless one of nine specific exemptions apply. The Electronic FOIA amendments of 1996, Pub. L. No. 104-231, require agencies to provide records in electronic format if requested, and if reasonably possible. Agencies must also develop electronic reading rooms and make agency-created documents that have been requested and released available electronically if the agency decides they will be subject to subsequent requests. It is important to note that, for the purposes of responding to FOIA requests, agency "records" are not necessarily limited to agency "records" as defined under the FRA. Responsive records for FOIA purposes include all non-personal documents in existence at the time of the FOIA request that are in the agency's possession. Once records have been identified as responsive to a FOIA request, they must be retained pursuant to the FOIA records retention schedule even if they otherwise would not be agency records under the FRA.

EPA FOIA regulations are found at 40 C.F.R. Part 2; the Department of Justice FOIA Guide may be accessed on the Internet at http://www.usdoj.gov/oip/foi-act.htm.

Privacy Concerns

The Privacy Act, 5 U.S.C. § 552a, covers systems of records from which information is retrieved by an individual's personal identifier, such as name or Social Security Number. Most Agency records are not maintained in Privacy Act systems. However, many agency records may contain information that is personal to an individual, and if the personal privacy interest of the individual outweighs the public's interest in the information, the information is withheld from disclosure pursuant to Exemption 6 of the FOIA.

In addition, there are prohibitions on the use of information generated from research on human subjects. See, for example, 28 C.F.R. Part 46, Protection of Human Subjects; 28 C.F.R. Part 22, Confidentiality of Identifiable Research and Statistical Information.

A-110

In 1997, the EPA refused to obtain data from the Harvard School of Public Health that had been used in EPA grant-funded studies. Due in large part to adverse reaction to this situation, Congress directed OMB to revise OMB Circular A-110 to "require Federal awarding agencies to ensure that all data produced under an award will be made available to the public (pursuant to FOIA)." The Supreme Court had previously ruled that records in the possession of a Federal grantee but not in the Agency's possession were not considered "agency records" and therefore not subject to the FOIA. Agencies previously had no obligation to obtain records from grantees.

OMB published its final revision to Circular A-110 on October 8, 1999 (64 Fed. Reg. 54926), and the EPA adopted the amendment March 16, 2000 (65 Fed Reg. 14407, 14417). Under new 40 C.F.R. §30.36(d), in response to a FOIA request, the EPA must request from its recipients, and the recipients must provide, "research data relating to published research findings produced under an award that were used by the EPA in developing an agency action that has the force and effect of law." The term "published" is defined as either when the findings are published in a peer-reviewed scientific or technical journal or when a Federal agency publicly and officially cites the findings in support of agency action that has "the force and effect of law."

The revised regulation also narrows the definition of "research data" to exclude preliminary analyses, drafts of scientific papers, plans for future research, peer reviews, communications with colleagues, and physical objects. It also excludes confidential business information, personal privacy material, and similar information protected by exemptions under FOIA.

Data as Confidential Business Information

Locational data, or secondary data, may be claimed by a company to be confidential business information, commonly referred to as “CBI.” EPA regulations governing the determination of CBI claims are found at 40 C.F.R. Part 2, Subpart B.

Toxics Release Inventory (TRI)

The TRI is a publicly available, searchable database that includes information on over 20,000 facilities and the releases and transfers of toxic chemicals at or from those facilities. The TRI was developed under the Emergency Planning and Community Right-to-Know Act (EPCRA) and the Pollution Prevention Act (PPA), and it is required by statute to be made publicly available by computer telecommunications and other means. Currently, the main methods of accessing the data are the Internet and the EPA Public Data Release, which is a report that compiles much of the data on a yearly basis. The EPA currently collects facility identification information, including facility name, street, city, county, state, zip, mailing address (if different), latitude and longitude, Dun and Bradstreet number, EPA ID Number (RCRA ID number), NPDES Permit numbers, and Underground Injection Well Code ID numbers. In addition, the EPA currently collects the name of the facility's parent company, if applicable, and the parent company's Dun and Bradstreet number. All of these data are currently publicly available.

Locational Data as Intellectual Property

Under the Copyright Act, 17 U.S.C. § 101 et. seq., data are not generally subject to copyright protection. However, information about data, or software programs, may be copyrighted. Licensing agreements are common in the software industry. Since these are contracts binding the Agency, they must be reviewed by Agency legal counsel to ensure compliance with Federal law. If there are questions about the ability to release or disseminate secondary data that are copyrighted, Agency legal counsel should also be consulted.

This section only presents a summary of the main issues raised. For further information, or if you have questions about the legal issues, please contact Agency legal counsel.

Section VIII

References

Ackroyd, Neil, and Robert Lorimer. Global Navigation: A GPS User's Guide. Lloyd's of London Pr Ltd., 1990.

American National Standards Institute. Specifications and Guidelines for Quality Systems for Environmental Data Collection and Environmental Technology Programs. ANSI/ASQC E4, 1994.

Aronoff, S. Geographic Information Systems: A Management Perspective, WDL Publications, Ottawa, Canada, 1995.

Bodnar, Captain A. Nicholas. National Geodetic Reference System Statewide Upgrade Policy. National Geodetic Survey, June 1990.

Corn, David. Surveying By Satellite. Catalyst, February 1990, pp. 43-44.

Denaro, R. P. and R. Kalafus. Advances and Test Results in Differential GPS Navigation. The Journal of Navigation, vol. 43:1, pp. 32-40, 1990.

Dewhurst, W. T. Shift-On-A-Disk. Converting Coordinate Data from NAD 27 to NAD 83. ACSM Bulletin, No. 126, 1990, pp. 29-33.

Giles, John, Bob Greenlaw, and Charles Wordell. "Maine City Quickly Improves Infrastructure Management." ArcUser: The Magazine for ESRI Software Users, July-Sept. 2000: 28-29.

Hartl, P. H. Remote Sensing and Satellite Navigation: Complementary Tools of Space Technology. Photogrammetric Record, vol. 13:74, pp. 263-275, 1989.

Hurn, J. GPS, A Guide to the Next Utility. Trimble Navigation Ltd., Sunnyvale, California, 1989, 76 pp.

Kruczynski, L. R. Differential GPS: A Review of the Concept and How To Make It Work. Trimble Navigation Ltd., study report, 1990.

Kruczynski, L. R., W. W. Porter, D. G. Abby, and E. T. Weston. Global Positioning System Differential Navigation Test at the Yuma Proving Ground. The Institute of Navigation, 1986.

Kruczynski, L. R. and A. F. Lange. Geographic Information Systems and the GPS Pathfinder System: Differential Accuracy of Point Location Data. Trimble Navigation Ltd., study report, 1990.

Lang, Laura. Managing Natural Resources with GIS. Redlands, California, ESRI, Inc., 1998.

Lange, A. F. and L. R. Kruczynski. Global Positioning System Applications to Geographic Information Systems. Proceedings from the Ninth Annual ESRI ARC/INFO User Conference, Palm Springs, California, 1989, 4 pp.

Langely, R. B. Innovation Column: Why is the GPS Signal So Complex? GPS World, Vol. 1:3, pp. 56-59, 1990.

Leick, Alfred. GPS Satellite Surveying, 2nd Edition. New York: John Wiley & Sons, 1995.

McDonald, K. D. GPS Progress and Issues. GPS World, Vol. 1:1, p. 16, 1990.

McDonald, K. D., E. Burkholder, B. Parkinson, and J. Sennott. GPS for the Environmental Protection Agency, Course 355. Navtech Seminars, Inc., November 1991.

National Geodetic Survey. National Geodetic Reference System Statewide Upgrade Policy. 1990.

Puterski, R. GPS Applications in Urban Areas. Proceedings from the Tenth Annual ESRI ARC/INFO User Conference, Palm Springs, California, Vol. 1, 1990, 12 pp.

Slonecker, E. T. and J. A. Carter. GIS Applications of Global Positioning System Technology. GPS World, Vol. 1:3, pp. 50-55, 1990.

Trimble Navigation Limited - Operations Manuals for the following GPS Receivers: GeoExplorer II (1996) P/N 28801-00. Revision B. Version 2.11; Pathfinder Basic (1990) P/N 16848. Revision B. Release 1.00; Pathfinder Professional (1990) P/N 16177. Revision G. Release 1.42; Pathfinder Pro-XL (1996) P/N 28380-00. Revision B. Version 3.00; TDC2 Asset Surveyor Software Users Guide (1996) P/N 31175-00. Version: 3.10.

Trimble Navigation Limited. Mapping Systems (Figures). General Reference. P/N 24177. Revision B, 1996.

Trimble Navigation Limited. A New Level of Accuracy for Differential GPS Mapping Applications Using EVERESTJ Multipath Rejection Technology. Mapping and GIS Systems Division. Document #102. pp. 1 - 7, 1997.

U.S. Department of Defense/Department of Transportation. Federal Radionavigation Plan. Final Report: March 1982-December 1984. U.S. Department of Defense Document #DOD-4650.4 and U.S. Department of Transportation document #DOT-TSC-RSPA-84-8, 1984.

U.S. Environmental Protection Agency. Locational Data Policy, IRM Policy Manual, Chapter 13, 2100 Chg 2, Office of Administration and Resources Management, 1991.

U.S. Environmental Protection Agency. Locational Data Policy Implementation Guidance (LDPIG). Office of Administration and Resources Management, PM-211D, 220 B-92-008, Washington, D.C., 1992.

U.S. Environmental Protection Agency. GIS Technical Memorandum 3: Global Positioning Systems Technology and its Application in Environmental Programs, Office of Research and Development (PM-225). EPA/600/R-92/036, 1992.

U.S. Environmental Protection Agency. Method Accuracy Description (MAD) code v. 6.1. Information Coding Standards for the U.S. EPA's Locational Data Policy. Prepared by the Locational Data Policy Sub-Work Group of the Regional GIS Work Group, 1994.

U.S. Environmental Protection Agency. Locational Data Improvement Project Plan, Office of Administration and Resources Management, Contract Number 68-WI-0055. Delivery Order Number 065, Prepared by: EPA Systems Development Center. SDC-0055-065-JB-5057A, 1996.

U.S. Environmental Protection Agency. EPA Quality Manual for Environmental Programs, EPA Manual 5360 A1, EPA Quality Staff, Office of Environmental Information, May 2000.

U.S. Environmental Protection Agency. Policy and Program Requirements for the Mandatory Agency-wide Quality System, EPA Order 5360.1 A2, EPA Quality Staff, Office of Environmental Information, May 2000.

U.S. Environmental Protection Agency. EPA Guidance for Geospatial Data Quality Assurance Project Plans (Peer Review Draft), (EPA QA/G-5G), EPA Quality Staff, Office of Environmental Information, 2002.

U.S. Environmental Protection Agency. Business Rules for Latitude/Longitude Data Standard (Locational Data Standard), Office of Environmental Information, 2000.

Van Sickle, J., GPS for Land Surveyors, Ann Arbor Press, Second Edition, 2001.

Wells, D., N. Beck, D. Delikaraoglou, A. Kleusberg, E. J. Krakiwsky, G. Lachapelle, R. B. Langley, M. Nakiboglu, K-P Schwarz, J. M. Tranquilla, and P. Vanicek. Guide to GPS Positioning. Canadian GPS Associates. Fredericton, New Brunswick, Canada. 1988.

Appendix A

Glossary of GPS Terms

Almanac: Information describing the orbit of each GPS satellite, including clock corrections and atmospheric delay parameters. An almanac is used by a GPS receiver to facilitate rapid satellite signal acquisition and is also required by Trimble's Mission Planning Software.

Baseline: Consists of a pair of stations for which simultaneous GPS data has been collected.

Cadastral Survey: Survey performed to establish legal and political boundaries, typically for land ownership and taxation purposes.

Channel: A channel of a GPS receiver consists of the radio frequency, circuitry, and software necessary to tune the signal from a signal GPS satellite.

Control Segment: A worldwide network of GPS monitoring and control stations that ensure the accuracy of satellite positions and their clocks.

Cycle Slip: A discontinuity of an integer number of cycles in the measured carrier beat phase resulting from a temporary loss-of-lock in the carrier tracking loop of a GPS receiver.

Dilution of Precision: The multiplicative factor that modifies range error. It is caused solely by the geometry between the user and his or her set of satellites; known as DOP or GDOP.

Ephemeris: The predictions of current satellite position that are transmitted to the user in the data message.

Federal Radionavigation Plan (FRP): Congressionally mandated, joint DOD and Department of Transportation (DOT) effort to reduce the proliferation and overlap of federally funded radionavigation systems. The FRP is designed to delineate policies and plans for U.S. government-provided radionavigation services.

Geodetic Surveys: Global surveys done to establish control networks (consisting of reference or control points) as a basis for accurate land mapping.

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

Ionosphere: The band of charged particles 80 - 120 miles above the Earth's surface.

Mask Angle: The minimum acceptable satellite elevation above the horizon to avoid blockages of line-of-sight.

Multipath Error: Errors caused by the interference of a signal that has reached the receiver antenna by two or more different paths. This is usually caused by one path being bounced or reflected.

North American Datum of 1927 (NAD 27): Older and obsolete horizontal datum of North America. NAD 27 depends upon an early approximation of the shape of the Earth, known as the Clarke Spheroid of 1866, designed to fit only the shape of the conterminous United States, and utilizing a specific Earth surface coordinate pair as its center of reference.

North American Datum of 1983 (NAD 83): Official horizontal datum of North America. NAD 83 relies on the more precise Geodetic Reference System of 1980 (GRS 80), employs a geocentric ellipsoid model, and utilizes the Earth's center of mass as its center of reference.

North American Vertical Datum of 1988 (NAVD 88): Effort underway by NGS to readjust the North American Vertical datum. The NAVD 88 readjustment will remove distortions from the continent-wide vertical geodetic (height) reference system.

Point Positioning: Positioning mode in which a position is identified with respect to a well-defined coordinate system, commonly a geocentric system (i.e., a system whose point of origin coincides with the center of mass of the Earth).

Positional Dilution of Precision (PDOP): Measure of the geometrical strength of the GPS satellite configuration.

Pseudo-Random Noise (PRN) Code: A signal with random noise-like properties. It is a very complicated but repeated pattern of 1's and 0's.

Pseudo-Range: 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 Configuration: The state of the satellite constellation at a specific time, relative to a specific user or set of users.

Satellite Constellation: The arrangement in space of a set of satellites.

Selective Availability (S/A): Intentional degradation of the performance capabilities of the NAVSTAR satellite system for civilian users by the U.S. military, accomplished by artificially creating a significant clock error in the satellites.

Space Segment: The space-based component of the GPS system (i.e., the satellites).

User Segment: The component of the GPS system that includes the receivers.

Y-Code: Classified PRN code, similar to the P-code, though restricted to use by the military.

Appendix B

Examples of GPS in Environmental Applications

New Jersey Department of Environmental Protection Assesses Water Quality

The New Jersey Department of Environmental Protection has been using GIS to assess water quality of the state's major river basins and to communicate its findings to local governments, community groups, and businesses. The department studies entire watersheds, so scientists, planners, and regulators can understand all sources of contamination and can work together to restore water quality.

Scientists collected samples from the Whippany River which is located near an urban area. The Whippany watershed receives pollution from sewage treatment plants, factories, farms, and storm water runoff. Scientists took samples of the river's sediment and water and measured the concentrations of nutrients, organics, and metals. They also took readings of temperature, dissolved oxygen, and pH. The data were compared to standards set by state and Federal agencies to keep the waters clean enough to provide healthy fish habitats and to provide swimming opportunities for the public.

The scientists also collected biological samples, looking in particular for creatures sensitive to pollution. If the samples are composed mostly of animals that can tolerate pollution, or if the number and types of insects are different from past samples, the scientists are alerted to changes in water quality, change that could be missed by chemical sampling alone.

As samples were collected, the researchers collected their exact field positions with GPS receivers. These positions, along with their associated chemical and biological data, were used in a GIS to create a map of the watershed's streams and lakes. Other map layers were added. One was a layer of potential sources of pollution, representing locations, such as factory sites, where pollutants are known to be discharged. The inclusion of land use data made it possible to take into account more diffuse types of pollution, like that from farms and storm runoff. The GIS was queried to determine the proximity of known sites of contamination to the rivers and streams being monitored. Finally, the biological sampling data were added and the GIS was used to show impairment ratings for stream segments. The impairment rating is a measure of the health hazard it poses to fish and human swimmers.

Given this information, the department was able to find the severely impaired segments and take action. The department did this by going into the field and checking for possible causes of this severe contamination. Further water sampling was also done to help the regulators determine where the contamination was entering the stream. With all the collected information, the polluter was identified as being a leaking storage tank at a nearby factory.

Portland, Maine Quickly Improves Infrastructure Management

Like many old cities, Portland had much old infrastructure data that were not accurately reported in the city's paper records or incorporated in the city's growing GIS. The GIS coordinator for Portland wanted a one-person data gathering system that was quick, affordable, and database ready. The impetus for developing this system occurred when city officials asked the engineering section to supply detailed information about the condition and location of the city's culverts as part of the city's participation in Project Impact, a Federal Emergency Management Agency (FEMA) program designed to minimize and prevent damage resulting from disasters. However, extensive culvert information was not readily available in the city's database records.

The engineering section responded by acquiring a GPS/GIS two-way data collection system. This unit enabled users to accurately create and edit submeter accuracy position or attribute data in the field. For this culvert project, the team divided the city into sections and created paper maps of culvert locations gleaned from existing city records. Based on information from these maps, a mapping technician began inspecting streets with recorded culverts and attempted to locate unrecorded culverts. Once a culvert was found, the position of the inlet and outlet were recorded, in most areas, to submeter accuracy.

Portland also planned to periodically reinspect the culverts. Survey crews were usually sent out in teams of two when operating more conventional systems. With the GPS units, it became a one-person job. In addition, when it was time for reinspection, the culverts were located in less time because they were all clearly marked and the GPS units were used to guide them back to the locations.

Pre-survey Checklist

- Obtain List of Facilities
- Obtain Current Almanac
- Call Coast Guard to Verify Satellite Availability
- Obtain Control Points from NGS or Local Source
- Obtain 7.5 min Topographic Maps
- Obtain Local Street Maps
- Prepare Letter of Introduction
- Collect and Pack Field Equipment

Field Equipment

- GPS Equipment
- Laptop or Other Field Computer
- 7.5 min Maps
- Aerial Photo if Available
- Camera
- Film
- Compass
- Tape Measure
- Binoculars
- Field Forms
- Clip Board
- Calculator
- GPS Hardware/Software Manuals
- Mini Tape Recorder
- Hard Copy of Almanac

Field Equipment, Continued

- Rain Gear
- Two-way Radio Communication (i.e., CB, cellular phone, etc.)

Last Minute Checks

- Charge Batteries
- Verify Almanac
- Target Travel Route

In the Field Checks

- Find Base Stations
- Initialize Equipment
- Begin Collecting Data

Sample Letter of Introduction

Note: All letters requesting access to property should be on official stationary, include both a day and evening phone number, and any other appropriate information.

July 4, 1991

To Whom it May Concern,

The below named individuals are employees of the Bionetics Corporation and under contract to the U.S. Environmental Protection Agency (contract Number 68-03-3532). These individuals will be collecting field data in the area of Chattanooga, Tennessee, during the month of November 1990:

Mary Brown
Bill Johnson
John Smith

Their efforts are in support of official U.S. Environmental Protection Agency research. Please extend them all possible courtesy and consideration.

Additional information may be obtained by calling (703) 349-8970.

Sincerely,

E. Terrence Slonecker
Environmental Scientist
U.S. Environmental Protection Agency

APPENDIX C

GEOSPATIAL ACCURACY TIERS

Tier Level	Accuracy and Precision	Examples of Horizontal Collection Method	Example of Program Application
Tier 1	<1 m	Classical Surveying Techniques; plus GPS Carrier Phase Static Relative Position	Surveying to support definition of Institutional Controls to return land to productive use
Tier 2	1-5 m	GPS Carrier Phase Kinematic Relative Position	Definition of contamination boundaries of site
Tier 3	6-25 m	GPS Code (Pseudo Range) Standard Position	Stack location; drinking water intake location
Tier 4	26-100 m	GPS unspecified; Photo/GIS Interpolation	Site centroid; large area facility boundary
Tier 5	101-200 m	Urban style address matching	Preliminary site location
Tier 6	201-999 m	Public Land Survey – Sixteenth Section	Prediction of Local Air Dispersion
Tier 7	1000-2000 m	Address Matching – Block Face	Batch Geo-coding
Tier 8	2001-5000 m	Census Block Centroid	State-level Population Statistics
Tier 9	>5000 m	Zip Code Centroid	Generalized National Mapping
Tier 10	Unknown	N/A	Relative contextual data

A full listing of current technologies capable of achieving the Geospatial Accuracy Tiers is provided in the technical Implementation Guidance document.