Exhibit A

GPS

Land Navigation

"Finally, Mike Ferguson brings us a much needed GPS guide that demystifies this wonderful technology. Learn why GPS units will become as common as compasses for backcountry recreation in the future. I recommend this guide for anyone who's wondering if they need to buy a GPS unit. Check it out — it'll unveil a whole new bag of tricks for route-finding in the outdoors."

Stephen Stuebner
Freelance Journalist & Outdoor Guidebook Author

"Mike has done his homework with this book, must reading for all GPS backcountry users."

Bob Meredith
Director, Mountain Rescue Training Center

Now you can unlock the full potential of the most incredible navigation tool ever invented by man. GPS can provide you with accurate navigation and positioning (to within 100 yards!) world-wide, in any weather, any time of day or night.

This book provides the information you need to fully understand how GPS works, and how to make GPS work for you. Regardless of the brand of receiver you own, ***GPS Land Navigation*** will give you the knowledge to use it with confidence. You will find yourself referring to this book often as the wonders of this amazing technology unfold before you.

Happy Trails...

GPS Land Navigation

A Complete Guidebook for Backcountry Users of the NAVSTAR Satellite System

Michael Ferguson

illustrations by Leah Tucker

A practical guide to effective use of the Global Positioning System. Written for hikers, backpackers, cross-country skiers, mountain bikers, fishermen, hunters, equestrians, snowmobilers, 4-wheelers and other land-based outdoor recreation enthusiasts (and the good folks who occasionally have to rescue them).

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DISCLAIMER: The information provided in this book is accurate to the best knowledge of the author and publisher. However, much of it is taken from materials supplied by various GPS receiver manufacturers and government agencies. There is no warranty, therefore, express or implied, as to the accuracy of any material contained herein.

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Preface

This book is a practical guidebook for anyone who uses, or wants to use, the Global Positioning System —GPS— for backcountry and off-road land navigation. It doesn't presume or require that you have any prior knowledge of GPS, cartography, orienteering, or any other traditional route-finding skills.

You'll find a wide range of topics covered in these pages. From GPS hardware (receivers, compasses, altimeters, etc.) to GPS software (maps, coordinates, bearings, etc.) to GPS skills (trip planning, route finding, map reading, etc.), this book gives you the information you need to get the maximum benefit and pleasure from owning and using the U.S. global positioning system.

That's right, **you** own the global positioning system. The NAVSTAR satellite system was originally developed for the U.S. military and is now operated by the U.S. Department of Defense. This resource is available world-wide to any person with the necessary technology (a receiver) in hand, but the American taxpayer is the ultimate owner of this system.

This book covers an extensive array of GPS-related equipment and information that will allow you to achieve the maximum potential from the GPS system. It is also possible, however, to use a GPS receiver quite effectively by itself. You can decide how you want to use your GPS receiver based on your specific needs. This book will help make your options clear.

In addition to the "how-to" elements of GPS receiver use, you'll also find several useful appendices. They're packed (literally) with actual coordinate data that you can enter into your GPS receiver and use to navigate to specific locations. The highest peak in every county, every state capitol, and all U.S. Interstate/U.S. Highway intersections are listed for easy entry into your GPS receiver's waypoint database.

These precise coordinates have both fun and practical applications. Among other things, they can help you get your GPS receiver locked-in fast, thereby avoiding lengthy "initialization" procedures. All you need to do is select a coordinate you know is within one or two hundred miles of your actual position. They can also make it easy to identify and verify the location of significant landmarks you may encounter during your travels.

Finally, if you don't own a GPS receiver but you are considering buying one, the section on GPS receivers in Chapter 2 and Appendix 4 are for you. They will help you identify relevant GPS receiver features as they relate to your requirements. They will also assist you in selecting the best unit to fit your particular needs.

How To Use This Book

This book is intended to provide you with everything you need to know in order to fully utilize your GPS receiver. All you need to add is a receiver and its operating manual. While it would be flattering to hear that you had read this book cover to cover, only a few readers are likely to be that absorbed by this topic and material. This is a reference book, and you should read the parts that appeal to you.

Every effort has been made to make each chapter a complete stand-alone unit. Some are more important than others. The most important chapters are Chapter 2 and Chapter 6.

Chapter 2 (GPS Hardware) is important because it gives the straight scoop on both the capabilities and the limitations of GPS receivers. Sometimes the manuals that are supplied with GPS receivers fail to acknowledge the shortcomings of this phenomenal technology. The most critical element of this chapter is knowing how and why 2D mode can get you in trouble.

Chapter 6 (GPS Skills) gives you a thorough description of how to get the most value from your GPS receiver by using it wisely and effectively. It also should save you from a considerable amount of trial and error in getting up to speed with GPS. You may need to read all or parts of Chapters 2 to 5 before digging into Chapter 6. If you encounter too many unfamiliar terms and concepts in Chapter 6, then save it for last.

Generous amounts of cross-referencing, a thorough index, and careful organization are intended to make it easy for you to find specific information quickly and easily. Start with the Table of Contents, then try the Index when you need to search for information on a specific topic.

Don't let GPS terminology get in your way — an extensive Glossary of Terms is included at the end of this book. There you'll find definitions for many of the terms that appear in the main text. That's another way to help you deal with the problem of encountering so much new material and terminology. Be aware that the Index does not point to the Glossary of Terms, so if you're looking up a concept, it's probably a good idea to look in both places.

While the side margins help make this an attractive book, they're really there so you can make ample notes to yourself about the topics covered in the text and figures. Remember, this is a reference book. You should be making notes as you go for your own later reference.

The three-level numbering system used for section headings is included to give a clear notion of how the topics are organized ***while you're reading the book***. The first level corresponds to the chapter title, which is also shown on the upper left page header. The second level corresponds to major sections, which are also shown on the upper right page header. The third level corresponds to sub-sections. You can easily see the context for a sub-section by noting the chapter and major section that are printed on the page headers.

A Few Words About Terminology

The advent of GPS for personal navigation has brought with it a baffling array of new terms. Unfortunately, the terminology can quickly become confusing and sometimes is just plain wrong. Among other things, it makes it difficult to communicate some of the concepts presented in this book. In order to eliminate as much potential confusion as possible, the material presented throughout this book conforms to certain semantic "rules." These semantic rules are explained under the next two headings, and they should be considered a framework for the chapters that follow. But please recognize that they only apply to this book, and you can't rely on them beyond these pages.

Locations, Position Fixes, Landmarks, and Waypoints

Coordinates are a fundamental underpinning of the GPS system. Your location on the earth is defined by a pair of coordinates (plus an associated datum). The coordinates that are displayed when your receiver is tracking at least 3 satellites are known as your "position fix." The distinction between your location and your position fix is that your location is the actual physical place that you occupy, while your position fix is the place your GPS receiver says you are at. Under normal circumstances your position fix will most likely be within 100 meters of your actual location. Just remember it this way: location refers to an actual place, position fix refers to coordinates reported by the GPS receiver. They should be close, but only rarely are they identical.

When a position fix is assigned a name and stored in a GPS receiver's memory it is called a "waypoint." A waypoint can also be created by entering coordinate values obtained from a map or some other source (such as the appendices in the back of this book).

Some (but not all) Magellan receivers use the term "landmark" in the place of "waypoint." This book, however, only uses the term waypoint. If your receiver calls a stored position a landmark, just substitute that term in your mind every time you see the term waypoint in this book. They mean the same thing. Remember, a waypoint (or Magellan's landmark) is not a physical location on the ground, but rather the coordinates that approximate that location. This is a subtle, but important, distinction.

Directions, Bearings, Headings, and Azimuths

Directions are among the most important navigational "outputs" of the GPS system. The way you find a location with your GPS receiver is to follow the direction information the receiver provides you. You must first have a waypoint stored that represents the coordinates for the location you wish to find. The receiver then reports the direction from your current position fix to the waypoint you want to find.

Semantic problems arise due to the various terms that are used to describe directions. First the bottom line: In this book (and in most GPS receivers) the term "bearing" is used to describe either the direction from your position to a waypoint, or the direction from one waypoint to another. Bearings are either reported by the GPS receiver or obtained with a protractor and a map. The term "heading" is used to describe the direction you are actually traveling (or if you're standing still, the direction you are facing). Headings are most often obtained with a compass, but they can be obtained with a GPS receiver that is in motion. Again, a somewhat subtle distinction but ever so important.

The use of the term "bearing" in the manner just described is technically incorrect for reasons that are fully explained on page 145. In a nutshell, the correct term for a direction (as reported by a GPS receiver) is an "azimuth." However, this semantic infraction is relatively minor. Since virtually every GPS receiver produced uses the term bearing, it's what we'll use in this book.

Datums

Finally, a few words about a very important concept in the world of GPS — datum. This term is very important to land navigators using GPS for reasons explained beginning on page 44 under the heading "setup parameters." A datum specifies the earth-model (the ellipsoid) and the origin associated with a particular set of coordinates. A datum is needed to properly describe a specific location on earth. ***Without a datum, coordinates are absolutely worthless.***

Even though the datum is often omitted, it is always implied. As you'll see later in this book, it pays to understand which datum (of the many available) you need to use.

Acknowledgments

This book would not have been possible without the help of many great people. First and foremost, thanks go to Diana for supplying the inspiration (and the long weeknights of solitude) that got this project off the ground in the beginning. And to Jack & Penny for occasionally dragging me away from the computer long enough to keep my sanity (and a little color in my cheeks). And certainly to Claire and Maria, for both unintentionally showing me the real value in this technology, and helping me unlock the mystery of 2D mode. A special thanks to Glenn for sharing his knowledge, his GPS World magazines, his surveyor training material, and not one but two rounds of proofing. Steve Stuebner deserves thanks and credit for both his multi-faceted assistance and his inspiration. Steve showed that me that writing a book truly is within reach of the little guy.

There are some wonderful folks in the highly competitive world of consumer GPS receiver manufacturing. Jim White at Magellan, Leann McNabb at Trimble, Bill Wright at Silva Marine, Chad Warford at Lowrance and Steve Featherstone at Garmin were all very helpful and patient. Their generous contribution of their time, the use of their products, and the review of critical sections in this book was of immeasurable value. Thanks also go to their many associates (too many to name) in their respective companies who helped this project along the way.

The technical information and many of the images used throughout this book came from a wide variety of sources. Special thanks to Troy Bunch of the Bureau of Land Management, Alan Gunderson of the U.S. Geological Survey, Dennis Milbert of the National Geodetic Survey, Sheldon Bluestein of the Ada County Assessor's Office, Tom Damiani of Rockwell International, Pirjo Talka of Suunto USA, and Carol Brandt of the U.S. Transportation Department for information they generously supplied. Matthew Heller of Wildflower Productions was kind enough to provide a copy of TOPO! for review.

Proofing books is probably one of the more thankless assignments that anyone can accept, but my deepest thanks go to the many friends and associates who willingly took on that burden. Glenn Bennett, George Brogdan, Doug Colwell, Diana Douglas, Sandy Elliott, Eric Haff, Jack Harrison, Claire Lowrie, Mike Lyons, Bob Meredith, Steve Stuebner, and Scott Williams gave a ton of useful advice and made this a much better product. Nonetheless, it goes without saying that any remaining errors (or fog) are the full responsibility of the author.

And to anyone I overlooked, my sincere apology and heartfelt thanks.

Chapter 1:

Introduction to GPS

The Global Positioning System is easily the most significant development in navigation since the compass. As you'll soon see, GPS is not just about navigation. In just a few years, virtually everyone will rely on this technology in both subtle and dramatic ways.

GPS is not a brand new system. *GPS World*, a monthly magazine devoted exclusively to this amazing technology, is in its ninth year of publication. The first GPS satellites were launched almost 20 years ago, in 1978.

The Global Positioning System is the most significant development in land navigation since the compass.

Trimble, a major manufacturer of handheld GPS receivers, has called GPS "the next utility," suggesting that it will eventually become as commonplace in everyday life as the telephone is today.

Already, GPS is used to keep urban buses on schedule, navigate ships and airplanes, and perform precision surveying. Exciting new uses are emerging in farming, mining, forestry, shipyard operations, inventory control, land management, and many other fields. GPS is being introduced in a vast array of new commercial applications for several simple reasons: it saves time, it saves money, and it even saves lives.

Personal use of GPS on land is just beginning. It won't be long before a GPS receiver is standard equipment for anyone heading into the backcountry for work or play. Again, the reasons are simple: with GPS you can go farther, enjoy your surroundings more, and widen your margin of safety.

1.1 A World Full Of Uses

You probably had very specific uses in mind when you purchased your GPS receiver. Nevertheless, the breadth of potential outdoor recreation uses for GPS is astonishing.

Hunters and fishermen can log their favorite spots then later navigate a successful return trip with ease. Hikers and mountain bikers can explore and "map" new trails, and share their discoveries with other GPS users without resorting to complicated route instructions. River runners can check their location relative to a campsite or a major rapid. Skiers and snowmobilers can venture out into the stark beauty of the winter landscape confident that storms and whiteouts cannot "blind" them and thwart a safe return home. Search and rescue personnel can quickly and accurately identify and locate isolated and remote locations. Whatever your particular outdoor interest, GPS can probably make it safer and more fun than ever before.

The first group to make widespread personal use of GPS were mariners. Magellan introduced the first handheld GPS receivers for nautical use in 1989. They sold for $3,000. In early 1997 a fully functional GPS receiver with interface capabilities (for linking it to auto pilots and other marine electronics) could be obtained for under $200! More sophisticated units that contain extensive map data and color displays are priced under $1,000 and are becoming common in consumer marine applications. Today it's hard to imagine anyone venturing into the open seas (or coastal waters) without a GPS receiver aboard.

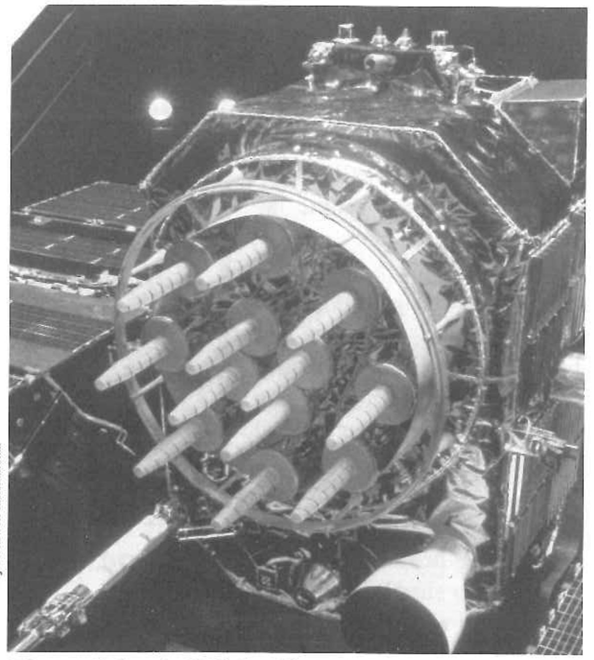
Photo Courtesy Rockwell International

Figure 1-1: *A GPS Satellite Closeup*

GPS is starting to show up in some relatively new areas. Automobile manufacturers are moving toward integrating GPS into the electronics of passenger cars. One recent development is a marriage of GPS and cellular telephone technology that gives the driver one-button emergency transmission capability. The driver simply pushes a "panic" button on the overhead console, and the integrated cellular phone sends an emergency telephone message complete with precise vehicle location information.

Another emerging automotive application is the integration of GPS capabilities with on-board electronic maps. A display panel in the dashboard gives the driver a constantly updated, zoomable map of the vehicle's vicinity, with the position of the vehicle highlighted on the map. When linked with broadcasts of traffic congestion data, the map display will also be able to show the least congested route to a specific destination.

The really good news is you don't have to buy a new GPS equipped car to take immediate advantage of this technology while driving. Most handheld GPS units that are currently available have a cigarette lighter power cord option, making it practical to use your backcountry GPS receiver in your car. In fact, you may find that getting you to the trailhead is one of the most useful secondary applications for your GPS receiver!

Golfers are even finding GPS in use on the links. Recently several golf courses have equipped their golf carts with GPS receivers that give the golfers information on distance to the next hole, and give the course's management real-time information on the flow of golfers through the course. The end result is more golfers are able to use the fairways on a busy day.

...this book can show you why GPS is such a valuable piece of equipment for the outdoor enthusiast.

But let's get back to <u>your</u> use of GPS. This book will provide you with a clear understanding of how to get the most out of this fantastic new navigation tool. If you don't yet have a GPS receiver, this book can show you why it is such a valuable piece of equipment in the outdoors, and assist you in deciding which of the many available receivers is right for you.

A word of caution: This book is ***not*** meant to replace the manual that comes with your GPS receiver. In fact, it is important that you study your manual carefully and learn how to operate the features and functions of your particular GPS receiver. You can do this as you work through the information contained in this book. This book will help you learn how to use your receiver to its fullest, without the need to discover the many and varied capabilities of GPS by yourself.

Besides thoroughly covering how to use GPS technology, this book also provides an extensive amount of actual coordinate data in several appendices. You can use this coordinate data in a variety of different ways. It gives you information that can help you avoid the slow process of "initializing" your GPS receiver when you're in a new location. It can help you identify distant peaks when you're traveling in unfamiliar territory. It can also help you keep track of your progress when your travels extend across the Interstate highways of this land.

So without further ado, let's dig into the workings of the Global Positioning System and see just what it can do for you!

1.2 NAVSTAR — The Satellite System

NAVSTAR is the name of the U.S. government's global positioning system. It is also what your GPS receiver depends on for its operation. GPS receivers are just one part of a three-part system that uses the timing of radio signals to measure distance, velocity, and time. The complete system consists of a **control segment** (the satellite ground stations), a **space segment** (the satellites in orbit), and a **user segment** (the receiver in your hand). Although legend has it that NAVSTAR stands for Navigation Satellite Timing And Ranging, it's really just a word that sounded good to the developers of the system.

The **control segment** is the foundation of the NAVSTAR system. It is a network of ground stations that serve as the central nervous system of the GPS system, constantly providing control information to the individual satellites within the system. The responsibilities of the control segment include tracking satellite positions, keeping the satellites in their proper orbits, and telling the satellites their exact positions and the exact time.

The **space segment** of the NAVSTAR system consists of 24 satellites (plus two spares) in high orbit above the earth. Each satellite orbits the earth once every 12 hours. These

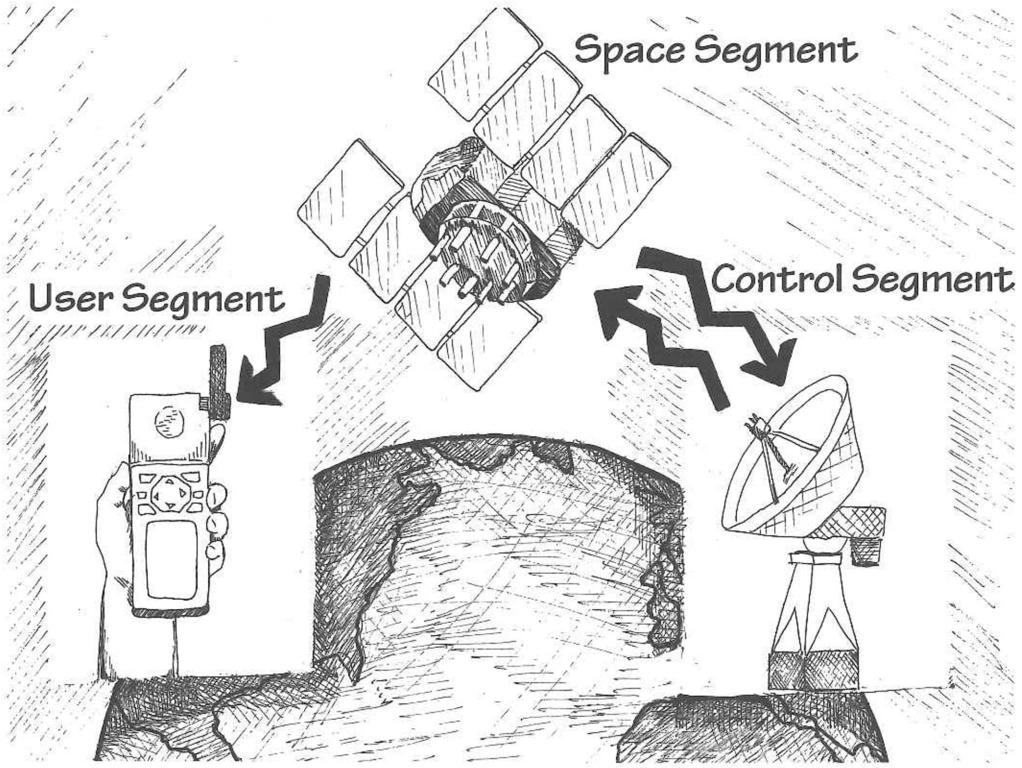

Figure 1-2: GPS System Segments

satellites are located approximately 12,000 miles above the earth's surface, and they each follow one of six orbital paths. Each satellite contains four atomic clocks, and continuously sends radio signals that are used by the GPS receiver to calculate its position.

The **user segment** of the NAVSTAR system is the part you hold in your hand — the receiver. This is where your position is determined. The GPS receiver includes a radio receiver, quartz clock, memory, and a CPU that performs a wide variety of calculations.

The NAVSTAR global positioning system originated in 1973 as the Defense Navigation Satellite System. In 1978 the NAVSTAR 1 through NAVSTAR 4 satellites were launched and became operational. By December 1993 a full constellation of 24 satellites was in orbit and the NAVSTAR system was declared to have reached Initial Operational Capability (IOC). At that point the NAVSTAR system was no longer considered an experimental system.

The satellites used for GPS fall into three categories that relate to their capabilities. Block I satellites were the early models and have all been replaced. Block II and IIR satellites are newer and more advanced. Block II satellites add the means for restricting signals supplied to civilian GPS users, and Block IIR satellites add more accurate atomic clocks and improved orbiting capabilities. Once the satellite constellation consisted entirely of 24 Block II and IIR satellites (i.e., all Block I satellites had been replaced) the system was declared to have reached Full Operational Capability (FOC). That occurred in July 1995.

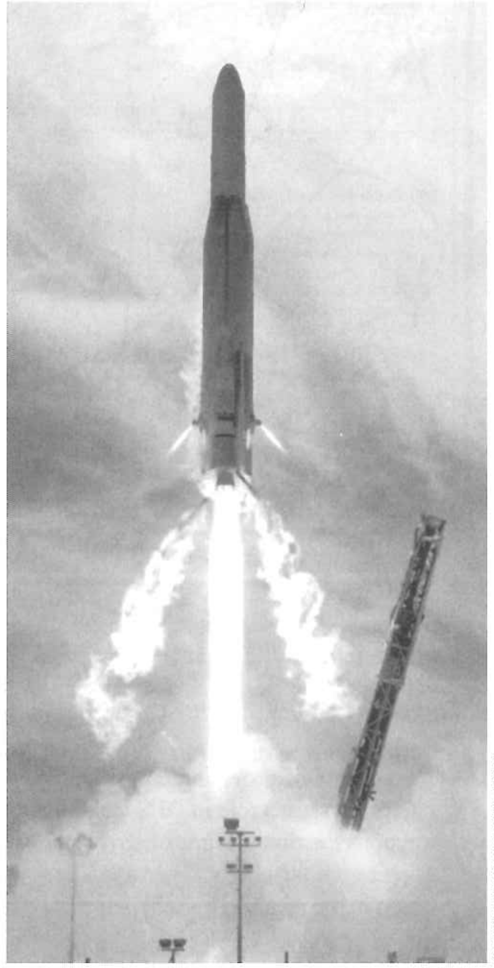

Photo Courtesy Rockwell International

Fig 1-3: Deployment Of GPS Satellite 009

The NAVSTAR system is designed so that any location on earth will have line of sight access to a minimum of six satellites at all times, as long as there is an unobstructed view of the sky from horizon to horizon. It takes at least four satellites for a GPS receiver to obtain a three-dimensional (3D mode) position fix. A 3D mode position fix provides horizontal coordinates *plus* elevation. Most GPS receivers can also provide a two-dimensional (2D mode) position fix when only three satellites are being tracked. A 2D mode position fix only provides horizontal coordinates. ***See page 41 for important warnings about using 2D mode*.**

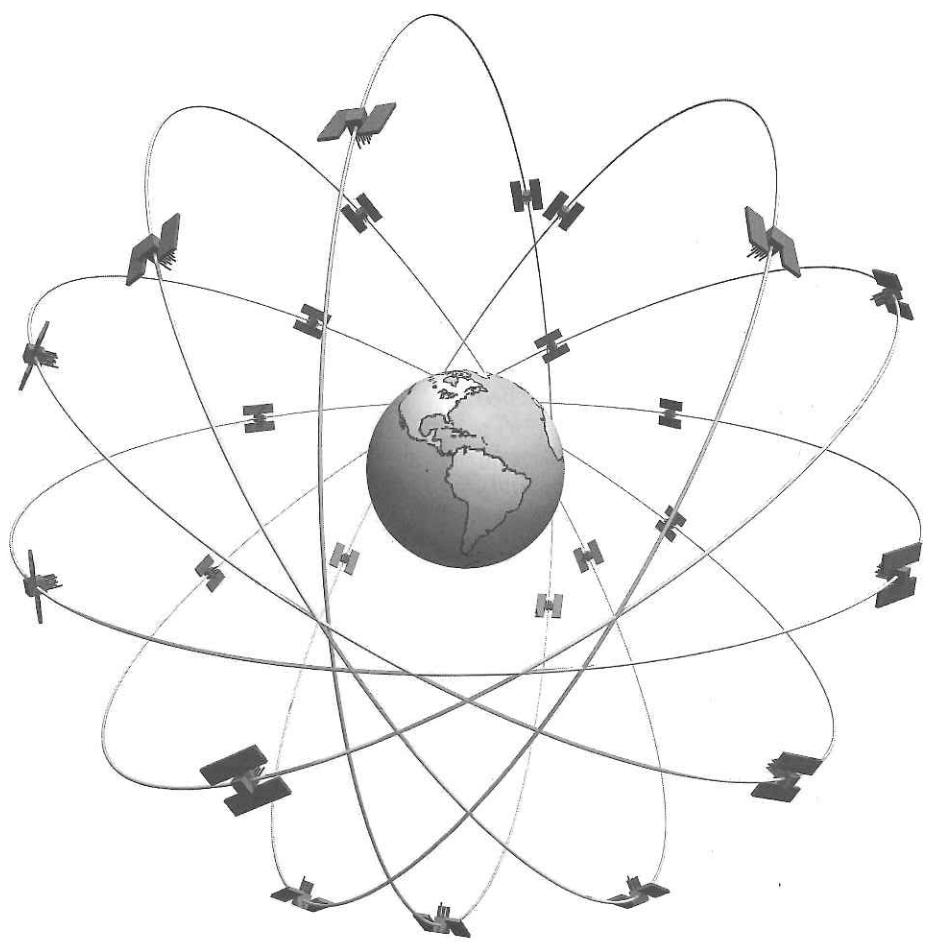

Figure 1-4: GPS Satellite Constellation - The Space Segment

The process of providing a position fix, receiver velocity, and UTC time is the extent of the satellite system's role in GPS technology. Everything else (heading, distance and direction to waypoints, estimated time of arrival, etc.) are calculations performed solely by the GPS receiver using a combination of **[1]** position fixes obtained using the satellites, **[2]** software permanently stored in the receiver, and **[3]** waypoint data that you loaded into the receiver's memory.

1.2.1 How GPS Works

A GPS receiver determines its position by measuring the time it takes radio signals, moving at the speed of light, to travel from each of four GPS satellites to the GPS receiver. This provides the GPS receiver with the data to determine its distance from each of the satellites. A simplified 2-dimensional illustration of this process is shown in Figure 1-5.

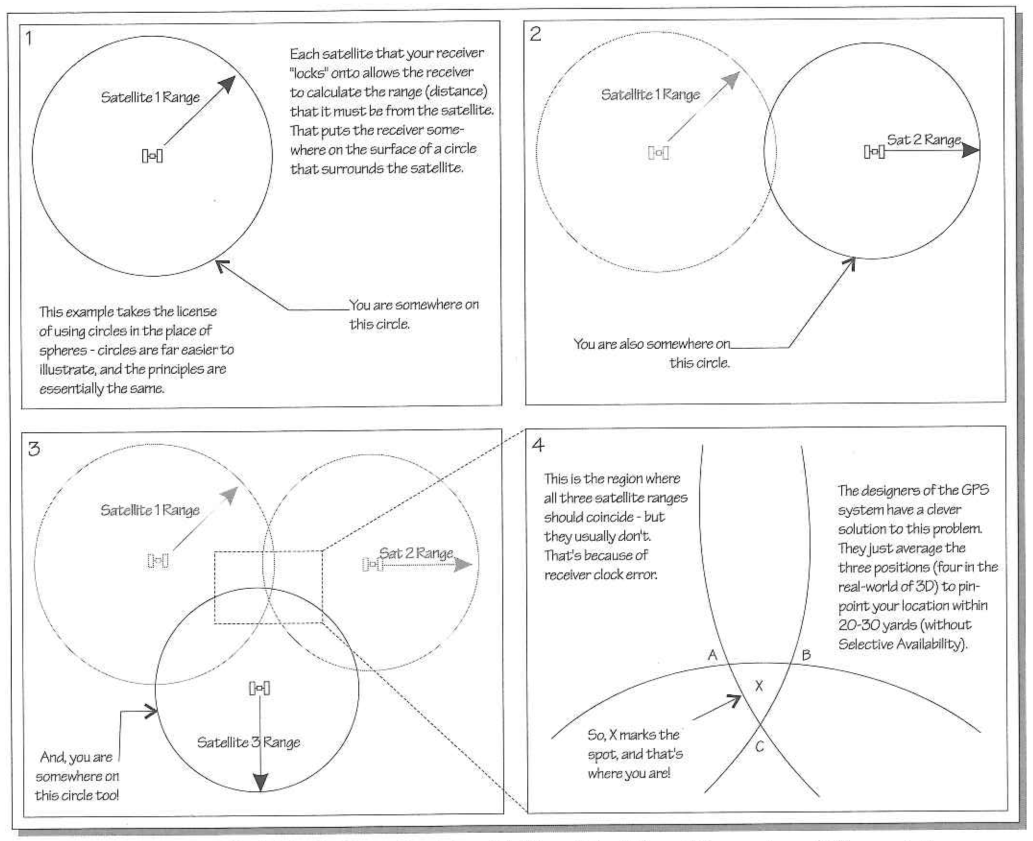

Figure 1-5: How GPS Finds Your Position (A Simplified Two-Dimensional Example)

By knowing the precise location of each satellite (from ephemeris data each satellite sends), the receiver can compute the location of a spherical surface that it must be on. That sphere is centered on the satellite and has a radius equal to the distance from the satellite to the receiver. Add a second satellite and the intersection of these two spheres identifies a circle the receiver must be on. Add a third satellite and the intersection of the circle and the third sphere identifies two points, one of which is the receiver's location. This process is similar to, but slightly different than, triangulation with a compass.

A fourth satellite is required to achieve the level of accuracy offered by the NAVSTAR GPS system. That's because the clock in the handheld GPS receiver is not accurate enough to measure the receiver's distance from each satellite to within a few meters. The fourth satellite provides three more redundant "triangulation" measurements that are averaged and thereby cancel your receiver's time related errors.

To see that the fourth satellite gives three more redundant positions, consider the possible three-way combinations of satellites. Satellites 1-2-3, 1-2-4, 1-3-4, and 2-3-4 each yield a pair of points. One point from each of the four pairs should be the location of the receiver, and therefore the same. Measurement errors related to the receiver's clock, however, result in differences. Fortunately, the receiver's clock error affects all four positions in the same way. This makes it possible to use averaging to eliminate most of the effect of the receiver's clock error. This is the key to how a 10 ounce GPS receiver achieves accuracy (without Selective Availability) of better than 30 meters at least 95 percent of the time.

An interesting by-product of the GPS system is its accurate time... you can't get more clock accuracy than you'll find in your GPS receiver.

Most GPS receivers can operate in 2D mode when they receive signals from only three satellites. Two-dimension mode works by using elevation in place of the fourth satellite. Two-dimension mode requires elevation as an input rather than providing it as an output. This feature has its roots in the marine side of GPS applications, where elevation is not a significant variable. On land it is very risky to rely on a 2D mode position fix because inaccurate elevation data can cause very substantial horizontal position errors. Unfortunately, most GPS receiver manuals don't provide adequate warnings about the hazards of using 2D mode position fixes. AS A PRACTICAL MATTER YOU SHOULD AVOID USING 2D MODE. You need to be very familiar with your receiver so that you know when it is in 2D mode. For more information about this important topic see page 41.

An interesting by-product of the GPS system is its extremely accurate time. The time it takes the GPS radio signals to travel from a satellite to the GPS receiver is measured (by the GPS receiver) in nanoseconds! Although the clock in the GPS receiver is not as accurate as the atomic clocks in the GPS satellites, it is constantly being updated with precise UTC time (Universal Time Coordinated, also known as Greenwich Mean Time) when it is locked onto the satellites. From a practical standpoint, you can't get more accurate time than the time provided by your GPS receiver. Just think, you'll never miss the bus again!

1.2.2 GPS Position Accuracy

An important aspect of the NAVSTAR system is the accuracy of the position fixes it supplies. The primary factors influencing the position accuracy you obtain from your GPS receiver are **[1]** operator error, **[2]** Selective Availability, **[3]** the number and geometry of the satellites being received, **[4]** multipath interference, and **[5]** atmospheric conditions.

GPS error sources are independent of one another and they are cumulative. This means that any reduction in one error source (for example, operator error) improves the overall accuracy of position fixes. Consequently, when you obtain waypoint coordinates from a map, it is definitely worthwhile to be as accurate as possible.

When considering issues of GPS position accuracy, be careful to recognize the distinction between accuracy and precision. They are not the same. Precision means a fine level of

measurement, or high resolution. Accuracy means measuring something close to its true value. A GPS receiver typically shows very precise coordinates, usually to the nearest tenth of a second or thousandth of a minute. That's within 10 feet in terms of ground distance. But the accuracy of civilian GPS receivers is limited to about 100 meters — over 300 feet — when Selective Availability is in use. Without Selective Availability, the accuracy of a typical civilian receiver is within 30 meters — about 100 feet — at least 95 percent of the time. Either way, a GPS receiver usually provides much more precision than accuracy. Now let's take a closer look at the factors behind GPS accuracy.

Operator Error

Mistakes that you make as the operator of a GPS receiver are among the most severe and the most avoidable of the GPS errors. Fortunately, operator errors are not normally a problem when it comes to position fixes. The really big operator errors tend to be related to manual waypoint entry. A good example of this kind of error occurs when you simply enter the wrong coordinates.

The primary mistakes to watch out for when entering coordinate values are having the wrong datum specified, using the wrong zone in the UTM coordinate system, and using the wrong hemisphere (either north/south or east/west) in the latitude/longitude coordinate system. Of course outright keypunch errors can also be quite serious. A good way to prevent really gross errors is to check the distance and direction from a newly entered waypoint to another waypoint or your current position. If the distance is off by hundreds or even thousands of miles (don't laugh, it happens), you probably entered the wrong zone or hemisphere. If it's off by a smaller distance, you probably keyed the wrong numbers.

An easily preventable source of operator error can occur when you read coordinates from a map. Any inaccuracy that occurs when you read coordinate values becomes an addition to the natural and man-made inaccuracy inherent in the receiver itself. Again, it is worthwhile to be as accurate as possible when you obtain coordinate values from a map.

A way that operator errors can affect position fixes is through the display of coordinates. If you haven't set the correct datum for a map you're using, the coordinate values on your receiver's display will not match those of the map. How much error occurs because of using the wrong datum depends on the difference between the datum you are using, and the datum you should be using.

A common datum error in the continental United States is using NAD27 (North American Datum of 1927) in place of NAD83, or vice versa. The amount of error this introduces varies by location, but it is never more than 200 meters in the lower 48 states. Other "wrong" datums can lead to much greater errors, some in excess of a mile.

The only sure way to eliminate operator error is to understand your GPS receiver very thoroughly, be very careful when entering coordinate data and selecting a datum, and check your entered coordinates for reasonableness right after you enter them.

Selective Availability

Selective Availability, or SA, is a man-made form of GPS error that is intentionally introduced by the military operators of the NAVSTAR system. It is intended to deny military adversaries the level of GPS accuracy available to U.S. and allied forces. That goal is accomplished by dithering, or "lying" about, the time and/or location information sent out by each satellite.

Selective Availability is intentionally introduced by the military operators of the NAVSTAR system...to increase the error for civilian users.

The effects of SA impact personal navigation in two ways. One is reduced accuracy of position fixes. The other is distortion in the *speed over ground* and *direction of travel* information displayed by the receiver when it is moving at relatively slow speeds.

The presence of SA increases the horizontal position error of civilian GPS receivers to over 100 meters no more than five percent of the time, and to over 300 meters no more than one-tenth of one percent of the time. Put differently, GPS positioning error from natural and SA sources combined should not exceed 100 meters more than one out of twenty position fixes, and that error should not exceed 300 meters more than one out of one thousand position fixes. In practice, GPS users should experience horizontal accuracy to within 50 meters over half the time, ***even when Selective Availability is turned on***.

Here's how SA impacts speed and direction: If you're walking south at 5 mph, but SA is "going north" at 3 mph, your receiver will erroneously tell you you're going 2 mph. If SA switches to south at 3 mph, your receiver will say you're going 8 mph. If the direction SA is "going" relative to your true direction is lateral, then the direction of travel indicated by your receiver will also be inaccurate. If you are going north at 3 mph, but SA is "going west" at 3 mph, your receiver will tell you it's going northwest at 4.2 mph.

While the presence of Selective Availability is unfortunate, it is not a serious problem for the typical backcountry GPS user. Having a position fix to within 100 meters most of the time (and usually much better than that) is adequate to identify and locate trail junctions, campsites, or other geographic features. The direction of travel distortion caused by SA is not usually a problem, because you should be using a magnetic compass for ground directions.

Selective Availability really impacts civilian GPS use in aviation, marine, ground transportation, and other commercial applications. Precise landings of aircraft in adverse weather, piloting boats and ships through treacherous passages, and locating cars and trucks in urban street grids requires greater accuracy than Selective Availability provides.

Fortunately for these civilian GPS applications, a system known as DGPS (Differential Global Positioning System) has been developed that recaptures the undithered accuracy of the GPS system — and then some. Through the use of ground or satellite based radio beacons, a differential compensated GPS receiver can achieve a level of accuracy ***with SA on*** that far exceeds the accuracy of the same receiver by itself ***with SA off***.

Differential GPS is presently available in most coastal areas of the U.S., but it is not currently relevant to the typical recreational or backcountry GPS land navigator. Although it will work with most handheld personal navigation receivers, differential GPS equipment involves a separate radio receiver that must be electronically connected to the GPS receiver. This adds considerable expense, weight, and bulk. Again, backcountry GPS users can generally get by reasonably well with accuracy at the 100 meter level.

Knowing when your receiver is (and isn't) operating in 3D mode is crucial to safe use of the GPS system... inadvertently using 2D mode can put a position fix off by miles.

Backcountry users may, however, find a way around Selective Availability in the future as the Wide Area Augmentation System (WAAS) is implemented for aviation users. This system is being implemented by the FAA and will provide differential corrections from a network of geostationary satellites. The beauty of WAAS is that it can work through the same channels used for receiving NAVSTAR signals, effectively eliminating the need for separate radio beacon receivers. With luck the system and equipment will be be available by late 1998.

3D Mode

One of the most basic requirements for GPS position accuracy is ***having a lock on at least 4 satellites***. This puts your receiver in 3D mode. Even though the elevation component of a 3D GPS position fix is subject to a large amount of error (about 150 percent of the horizontal error), 3D mode is essential for obtaining a reliable horizontal position fix.

Receiver manuals usually explain 2D mode by saying that when only three satellites are being tracked, the vertical (elevation) component of position is not provided. This implies that 2D horizontal coordinates are reasonably accurate. What the manuals don't tell you is that without very accurate elevation data, the horizontal coordinates provided in 2D mode can be extremely unreliable. In fact, a 2D position fix can easily be off by a distance in excess of a mile!

This issue is of critical importance to backcountry GPS users, and is also discussed on page 41. The good news is that as long as your receiver is tracking at least 4 satellites, its position fixes should be very reliable. In 3D mode you can count on very good accuracy — within the limits discussed elsewhere in this section.

Satellite Geometry

Satellite geometry refers to the position (in the sky) of the satellites your receiver uses to calculate a position fix. This is an important factor in achieving an accurate position fix. Poor satellite geometry can add hundreds of feet to the receiver's position error. The full constellation of 24 satellites generally provides good potential geometry most of the time. Local obstructions (mountains, cliffs, large buildings, trees, etc.) that block satellite signals are much more likely to be causes of poor satellite geometry.

The ideal "geometry" for the satellites your receiver uses to calculate its position is one satellite directly overhead and three other satellites equally spaced around the horizon. Less than ideal geometry occurs when the satellites used to calculate a position fix are clustered overhead, aligned in a straight line, or both. Because of the constantly changing position of the satellites in their orbits and unavoidable obstructions on the ground, it is rare that you will experience ideal geometry. If you experience geometry related problems (or a mysterious inability to get a satellite lock within a few minutes), try waiting for the satellites to change position. That may solve the problem. On some occasions it seems that simply turning the receiver off then right back on can cure a case of "blindness."

How far you are away from ideal geometry is often indicated by a measurement known as Dilution of Precision, or DOP. There are DOP's for the vertical position (elevation), horizontal position (including the north-south and east-west components of horizontal position), time, and various combinations of these components.

PDOP, or Position Dilution of Precision, has all the separate components combined into a single measurement. Larger values indicate reduced accuracy. If your receiver reports DOPs, its manual should indicate acceptable levels of DOP.

Sometimes GPS receiver manufacturers substitute their own indicator of position error (in feet, meters, or an error index) in place of DOP's. The details of these accuracy indicators (and how you interpret them) vary widely depending on the manufacturer and model of receiver. Refer to your receiver's user manual to determine how your receiver supplies satellite geometry related accuracy information.

Multipath Interference

Multipath interference occurs when the radio signal from the satellite bounces off of some object (a building, cliff, etc.) before being "heard" by your receiver. This can lead to errors in the distance the receiver calculates from the satellite(s) whose signal "bounced."

To avoid multipath error stay away from large buildings or cliffs when taking a position fix. Unfortunately, it is very difficult to know when multipath interference is "interfering" with your position fix.

Atmospheric Conditions

Radio signals such as those transmitted by GPS satellites travel at 186,000 miles per second (the speed of light) through space, but they actually slow down as they pass through the earth's atmosphere. An "average" amount of slowing is built into the ranging calculations performed by GPS receivers. Variations in atmospheric conditions (and hence the amount of slowing) are another source of reduced accuracy. Fortunately, the error introduced by variations in atmospheric conditions is only in the range of 5-10 meters.

Nonetheless, this source of reduced accuracy can be minimized by the simultaneous use of a second signal at a different frequency. This is exactly what dual channel "L1/L2" receivers do. Unfortunately, the availability of receivers that process the second signal, known as the P-Code, is limited to U.S. and allied military forces and a few authorized civilian GPS users. The second frequency is also subject to encryption, turning it into what is known as the Y-Code. This encryption is the foundation of anti-spoofing (A-S), a method of securing the precise positioning service (PPS) for military users.

With the "natural" sources of inaccuracy considered (clock error, satellite geometry, and atmospheric conditions), a typical civilian GPS receiver with a good view of the sky should be able to regularly achieve an accuracy of about 30 horizontal meters, and 45 vertical meters. Vertical accuracy is less than horizontal accuracy because of the geometry of the system (all the satellites are limited to a hemisphere). However, this level of system accuracy is before considering the effects of 2D mode, multipath interference, and SA.

1.2.3 GPS Policy Directions

The U.S. Congress commissioned a major study of the NAVSTAR system in 1994. That study was performed by two separate working groups — the National Academy of Public Administration (NAPA) and the National Research Council (NRC) — that examined different aspects of the NAVSTAR system. The study was completed in 1995, and the two separate work groups issued a joint report entitled "The Global Positioning System — Charting The Future."

The NAPA/NRC report made a number of recommendations for improvements to the NAVSTAR system. One of those recommendations was that Selective Availability be permanently turned off, and that another method (known as anti-spoofing) be used to accomplish military security

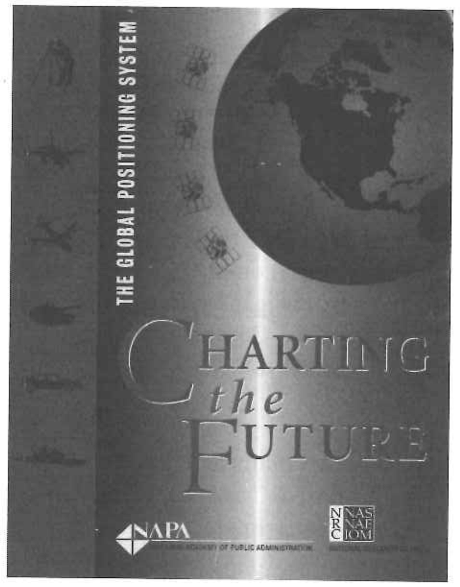

Figure 1-6: NAPA/NRC GPS Study

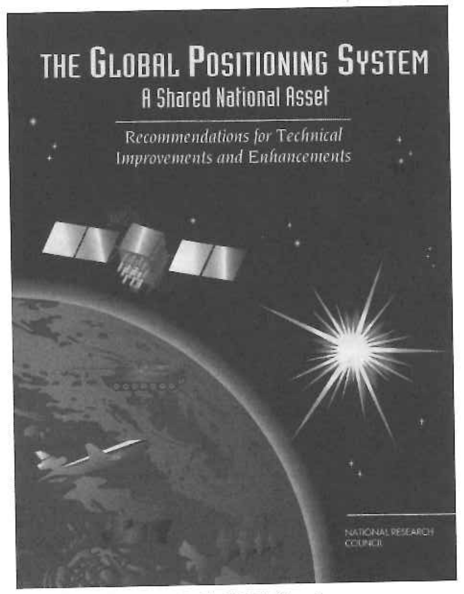

Figure 1-7: *NRC GPS Study*

objectives. The basis of this recommendation was the ineffectiveness of Selective Availability in meeting military objectives, and the constraint that Selective Availability imposes on full commercial development of GPS technology. Interestingly, the NAPA work group was headed by James Schlesinger, former U.S. Secretary of Defense.

The NRC issued a second report in 1995 that reinforced the findings and recommendations in its joint report with NAPA. Both studies recognize the military issues associated with GPS, but emphasize the overwhelming civilian adoption of this technology.

A study by the RAND Corporation issued in early 1996 ("The Global Positioning System—Assessing National Policies") took an opposite approach on the issue of Selective Availability. It recommended that it be left on until political and diplomatic agreements can be put in place to resolve military security concerns. This report appears to be the basis for a White House policy proclamation issued on March 29, 1996 that said, among other things, Selective Availability will be kept active for the next 4 to 10 years.

It remains to be seen how the issue of Selective Availability will actually play out in the near term. Considerable pressure remains to eliminate Selective Availability, and that pressure is mounting. International standards for commercial radio navigation are teetering on the basis of U.S. military policies concerning GPS. Selective Availability and lack of assured access to the basic GPS signals are proving to be stumbling blocks in adopting GPS as the global standard for commercial systems of air, land, and water navigation. Indeed, both Japan and the European Community are exploring development of their own commercial GPS systems.

Another recommendation that came out of both the NAPA/NRC and the RAND GPS studies may be of greater interest to you as a GPS owner. Both studies recommended that basic access to the GPS satellite radio signals should continue to

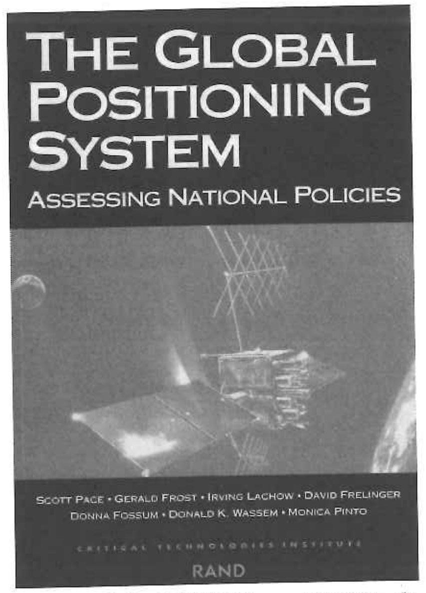

Figure 1-8: *RAND Corp. GPS Study*

be provided free of charge to the public. Already, commercial vendors are emerging in the area of differential GPS services. For a fee, these vendors provide radio signals from reference ground stations that enable GPS receivers to reach accuracy levels below one meter. It is technically feasible for the government to implement a fee system for access to the basic GPS satellite signals themselves. As you can imagine, the commercial GPS industry does not favor such fees.

1.3 GLONASS - Russia's GPS

The United States is not the only country with a functioning GPS system. Russia also has a satellite system similar to the NAVSTAR system. The Russian system is known as GLONASS (Global'naya Navigatsionnaya Sputnikovaya Sistema).

While similar to the NAVSTAR system, GLONASS uses slightly different technology that makes it incompatible with NAVSTAR GPS receivers. There are some specialty GPS receivers on the market, however, that work with both NAVSTAR and GLONASS signals. No handheld receivers that use GLONASS are presently (as of early 1997) sold in the U.S.

An interesting aspect of the GLONASS GPS system is that it does not employ any signal degradation techniques such as NAVSTAR's Selective Availability. Nonetheless, GLONASS is not capable of the level of positioning accuracy offered by NAVSTAR's P-code signal (the second signal that overcomes much of the NAVSTAR system's atmospheric-related inaccuracy). GLONASS does, however, achieve approximately the level of accuracy obtained with NAVSTAR's C/A-code signal without Selective Availability (i.e., if NAVSTAR's SA feature was turned off). In fact, the level of accuracy obtainable today with GLONASS was cited in the aforementioned NAPA/NRC study as one of the reasons that Selective Availability serves no useful purpose and should be turned off.

Chapter 2:

GPS Hardware

Today, one small instrument is all you need to answer that age-old question: Where in the world am I? That instrument is, of course, a GPS receiver. Two other instruments that go hand-in-hand with a GPS receiver are a compass and an altimeter. When combined with a map, these instruments can keep you from ever getting lost again.

Anyone planning to use GPS for backcountry navigation should be familiar with more than just GPS receivers and their readouts. As you'll see, GPS does not eliminate the need for traditional navigation instruments (such as compasses and altimeters) if you want to safely navigate the backcountry. GPS will, however, make backcountry navigation much easier and far more certain. With GPS you'll always know exactly where you are. That adds up to greater peace of mind and more time to spend on the reasons that brought you to the backcountry in the first place.

GPS does not eliminate the need for traditional navigation instruments... but it does make backcountry navigation much easier and safer.

This chapter deals primarily with GPS related hardware. It provides the information you need to select and operate the basic equipment used in satellite-based land navigation. Later chapters explain the fundamentals of GPS related "software" (maps, coordinates, bearings, etc.) in much greater detail.

By dividing the basic tools used for GPS land navigation into "hardware" and "software," this book tries to simplify the process of explaining the various parts of the overall system. The term "hardware" refers to the instruments (GPS receiver, compass, altimeter, etc.) that are used to obtain position fixes, directions, distances, and elevations. The term "software" refers to the information that is processed (maps, coordinates, bearings, etc.) by these instruments. It is not software in the literal (computer program) sense, although computer programs for use with GPS receivers are available and discussed on page 44.

As you can see, GPS related tools include a number of traditional navigation instruments. They are important because they both complement your GPS receiver when it is the centerpiece of your route finding toolkit, and they provide an important backup in the event that the GPS system or your receiver stops functioning.

Additional items of hardware, in the form of map measurement devices and instruments, are very helpful when you work with maps. These map reading aids do on maps what GPS receivers do in the real world — they provide you with precise coordinates.

Figure 2-1: *Three Basic Instruments Of Land Navigation*

2.1 GPS Receivers

Like many newly emerging technologies, GPS is undergoing rapid change. The full satellite constellation (24 orbiting satellites plus 2 spares, all maintained by the U.S. Department of Defense) has only been in place since late 1993, and only became fully operational in 1995. This "space segment" of the NAVSTAR GPS system is likely to remain fairly stable for the foreseeable future.

The "user segment" of the system (the GPS receiver you hold in your hand) is likely to undergo continued rapid change and improvement. New models are being introduced every year. Although ease of use and convenience options are being added, the basic navigation information provided by all GPS receivers remains the same:

[1] Your position in terms of coordinates and elevation,

[2] The direction to any waypoint you specify (or between any two waypoints),

[3] The distance to any waypoint you specify (or between any two waypoints),

[4] Your speed of travel, and

[5] Your direction of travel.

Your ***position,*** the ***direction to a waypoint*** (see page *xiii* in the Preface for the definition of a waypoint), and the ***distance to a waypoint*** are the essential GPS outputs for backcountry land navigators. These outputs can be obtained either while you are standing still or while you are in motion. Your ***speed of travel*** and ***direction of travel*** are non-essential GPS outputs. To obtain them you must be in motion. At low speeds, such as when traveling on foot, horseback, bike, etc., Selective Availability seriously degrades the accuracy of both speed and direction of travel readouts (see page 10 for information about Selective Availability).

The last point is particularly important. ***It is not possible to receive accurate direction of travel information from your GPS receiver if you're not in motion, or if your speed is relatively slow (under 10-15 mph).*** That is why a compass is an invaluable accessory to your GPS receiver.

Besides, using a GPS receiver as a compass consumes a large amount of battery power. Why use your receiver's precious "juice" when a simple magnetic compass can do the job better to begin with?

GPS receivers also provide a wide variety of miscellaneous information that is of limited use to land navigators. Most of this additional information is fairly standard, such as ***estimated time of arrival*** (the time you would arrive at a specified waypoint based on your progress from the last waypoint), ***velocity made good*** (the rate at which you're closing in on a selected waypoint), and ***cross track error*** (the amount of lateral distance you are off of a straight line course between two waypoints).

To a large extent this additional information is a carryover from the nautical origins of today's handheld GPS receivers. While this information can be interesting (and even helpful at times), it is important to recognize its limitations. One limitation, already mentioned, is the inherent imprecision of speed measurements when traveling on foot, horseback, or bike. Another is the fact that land courses, unlike sea or air courses, usually involve uneven terrain that makes it undesirable to rigidly stick to a straight line course. This limits the usefulness of ***cross track error***, and it also casts doubt on the accuracy of ***estimated time of arrival***. Nonetheless, these features are described later in this chapter.

Other more specialized information is found only in particular models or brands of GPS receivers. Examples include the direction and/or time of sunrise and sunset for any date and location you specify; the position of the sun and/or moon (direction and height above the horizon) for any date, time, and location you specify; coordinates expressed as a measurement offset relative to the corner of a map; steering adjustments; and various kinds of graphical displays. Your GPS receiver's manual should indicate the full set of features and information offered by your particular receiver model. Again, many of these

Figure 2-2: *Popular Handheld GPS Receivers*

specialized features have nautical origins. Some, such as sun and moon positions, can be of occasional use to land navigators. Many, such as steering adjustments, anchor drift alarms, and Man Over Board keys, have little practical use in land navigation.

2.1.1 Features of GPS Receivers

For land-based navigators the big GPS changes are small — as in how small GPS receivers are becoming. Popular models are well under 1 pound, and the lightest units are approaching ½ pound. These weights include operating batteries, but exclude a protective case and a spare set of batteries. Another major development is a new generation of parallel channel receivers that offer remarkable sensitivity yet are among the smallest available.

Other changes of benefit to land navigators are in the GPS receiver's internal software and user interface. New and expanded features such as graphic line plots of the user's track, built-in digital maps, one-button route marking on the fly, route inversion capabilities, and multiple route storage capacity extend GPS functionality well beyond simply providing position fixes. You can even make a real-time connection between a GPS receiver and a lap-top or palm-sized computer, thereby giving the GPS receiver a practically unlimited supply of memory. All this is available today in GPS receivers that weigh under 10 ounces!

Each GPS receiver on the market has a unique set of features and characteristics. If you already have a receiver, hopefully it has the right set of features for you. If you are considering buying a receiver, the following feature descriptions should help you identify the inevitable tradeoffs that you'll face when you make your purchase decision.

Above all, the best GPS receiver for your use depends on how you will use it. You'll need to "weigh" the relative importance of the various considerations that apply to your use. A backpacker will probably put a lot of emphasis on weight. A hunter might be more concerned about how rugged a receiver is. A skier may want a receiver that has a low minimum operating temperature and works well with lithium or ni-cad batteries for cold-weather performance. The main issues are laid out in the following paragraphs. You'll find a detailed comparison of various brands and models of GPS receivers in Appendix 4.

Weight

Less is better. It's that simple. Typical weights for handheld receivers range from just over one-half pound to over two pounds. When comparing different units, be sure to factor in a spare set (or sets) of batteries and a protective case. You should allow an average of five minutes of operation for each "fix" you expect to take in the field. Relate this to the rated battery life of the unit to calculate how many sets of batteries you think you'll need. Then add one more set. Don't use "battery-saver mode" run-time specifications to calculate estimated operating time. This mode only saves battery life during continuous operation, not the "on-and-off" operation that is typical during actual field use.

Channels

There are two types of GPS receivers for personal navigation. Multiplexing receivers have 1 to 3 channels, and rapidly cycle through the satellites that are being used to obtain a position fix. Parallel receivers have 5 to 12 channels, so that each satellite that is being used for a position fix has its own separate channel that is continuously being read. Parallel channel receivers can be designed to "over solve" a position, meaning that more than 4 satellites can be used to calculate a position fix. This can provide marginal improvements in position accuracy. The primary benefit of parallel channel receivers is their improved sensitivity and ability to obtain and hold a satellite lock in difficult situations, such as forests or urban environments, where signal obstruction is a problem. Be careful not to confuse the number of satellites that can be tracked at one time with the number of parallel channels. Even one and two channel receivers can track as many as 12 satellites at a time. They just don't track then simultaneously.

Antennas

External antennas (usually quadrifilar helix) are vulnerable to breakage, but are relatively easy and inexpensive to extend for short distances using coaxial cable — say to the windshield of a car or truck. Internal antennas (usually microstrip patch) are protected by the receiver's outer case, but cannot be extended with just a coaxial cable. Most (but not all) models with internal antennas have a connector for adding a remote antenna. This is more costly than a simple external antenna extension cable, but this option does permit much longer extensions of the remote antenna. An extended or remote antenna can make it much easier and more reliable to use your GPS receiver in a vehicle.

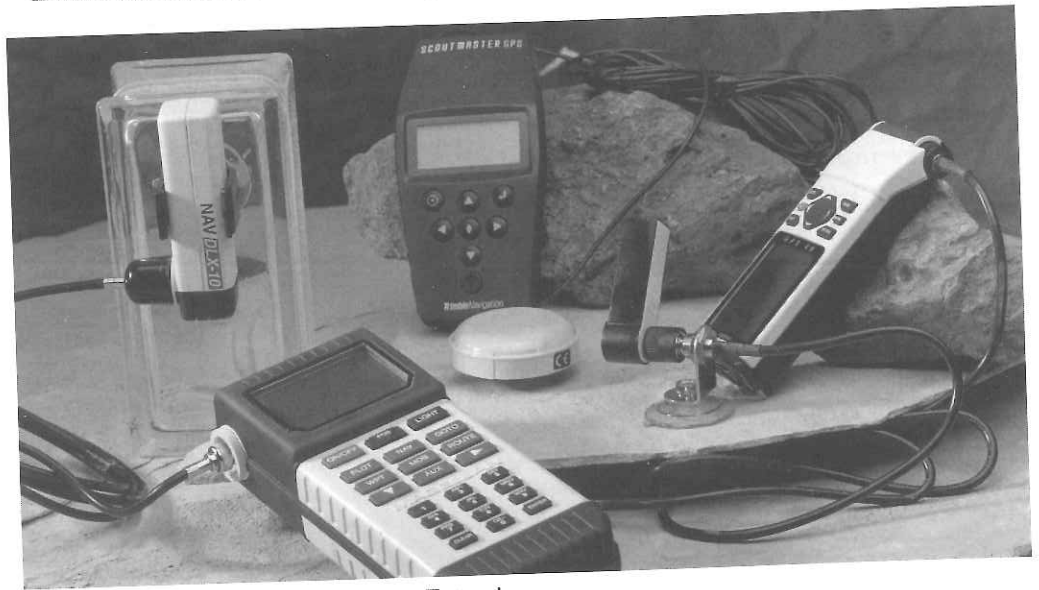

Figure 2-3: GPS Receiver Antenna Extensions

Power Supply

You may want to use an external power supply (camcorder battery, car, etc) to supplement the receiver's internal batteries. A wider range of operating voltage will give you greater flexibility in hooking up your own power supply (such as a video camera battery). Ni-cad or lithium battery capability can be important if the GPS receiver will be used in conditions of extreme cold. It is also important to be aware of how long the unit will operate on a set of batteries. Short battery life means extra batteries and extra weight.

Operating Environment

Two characteristics are important. One is the degree of water resistance. Some units are completely water-proof (they even float), others are water resistant (i.e., they shouldn't be submerged), and others shouldn't be allowed to even get wet. Most personal navigation receivers are at least water resistant (thanks to their nautical origins). The other operating environment characteristic that can be very important is operating temperature range. This is not a limitation of the battery system (although batteries are relevant for low temperature operation), but rather the LCD (liquid crystal display) that provides visual output from the GPS receiver. LCDs have real limits that apply to both their operating range (i.e., a temperature below which the display fades out) and their storage range (i.e., a temperature below which the display can be damaged). If you intend to use a GPS receiver in extreme cold, make sure that it can handle very low temperatures. And try using it with gloves.

Memory

More is better. Unfortunately, there's no standard measurement available. A receiver's memory is reflected in how many waypoints and routes can be stored, the length of descriptive name and memo fields associated with routes and waypoints, and how much track plot data can be stored. In all likelihood you will probably want to supplement any receiver's internal memory with hard copy notes, and possibly a personal computer waypoint management program.

Coordinate Systems

Latitude/longitude is the most common coordinate system. All GPS receivers utilize this system. UTM (Universal Transverse Mercator) is a metric coordinate system that's designed to be easy to use. UTM is a desirable feature, but not all receivers offer this capability. The UPS (Universal Polar Stereographic) coordinate system is a complement to UTM and provides coverage of the polar regions (above latitude 84 north and below latitude 80 south). MGRS (Military Grid Reference System) is a subset of UTM. It is important only if you want to use military maps. A variety of foreign coordinate systems are used in Britain, Ireland, Switzerland, etc. These coordinate systems match the maps

Figure 2-4: *Examples Of GPS Coordinate Systems*

produced in those countries. One company, Trimble Navigation, uses an "Over and Up™" system that gives coordinates in terms of distance from the lower right corner of any map. An enhanced Over and Up™ system from Trimble is referenced to the full set of almost 54,000 USGS 7.5-minute topographic maps. After all is said and done, for North American use latitude/longitude and UTM are the most useful grid systems — all others are "specialized" in one way or another, and relate to special needs.

Map Datums

A datum is part of the reference system that ties the GPS receiver's readouts to a specific map. Some GPS receivers contain well over a hundred different datums to choose from. Most GPS receivers cover the handful of standard North American datums quite well. The need for special datums is mainly an issue for overseas use. Being able to select the correct foreign datum can be important because use of the wrong datum can lead to coordinate "errors" that are quite large — over a mile! A user-defined datum option is a nice feature offered on some models. It can make up for the absence of a specific datum that you may need overseas, but using this feature requires considerable knowledge.

Measurement Units

Metric (meters, kilometers, kilometers per hour), statute (feet, miles, miles per hour), and nautical (nautical miles, knots) are the basic distance-related measurement options. All GPS receivers have these basic measurement systems. Some receivers allow only one

universal setting (pick one system, it applies to everything) while other receivers allow mixing units (distance in kilometers, speed in knots, elevation in feet). Another area of measurement choice is declination offset options — true north, grid north, magnetic north, or a user-specified offset. Measurement options may vary by model and brand of receiver.

Accessories

Remote antennas, antenna extension cables, power and data cables, differential GPS capability, computer interface software, and mounting brackets make up some of the more useful (and specialized) accessories available for lightweight, handheld GPS receivers. Finding a convenient way to mount your GPS receiver on the dashboard of your car can greatly extend its usefulness, and connecting the receiver to your vehicle's power supply can be economical. When selecting a GPS receiver, be sure to compare the availability and cost of any optional accessories you think you may need.

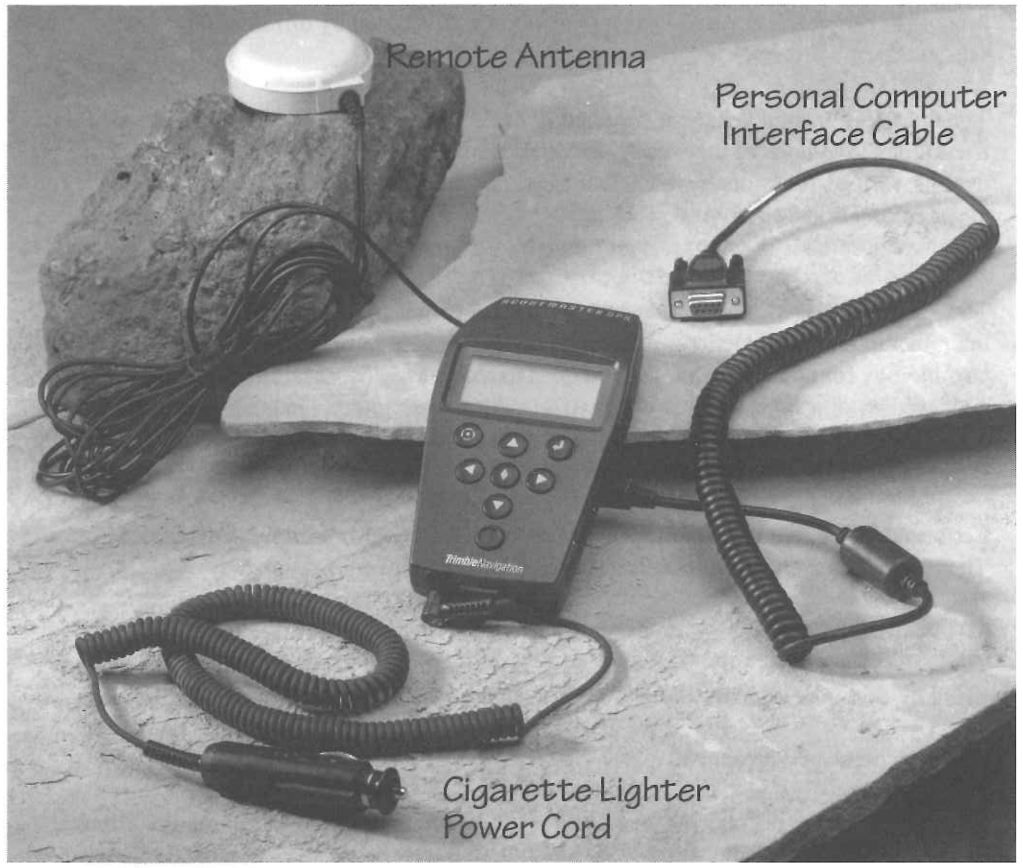

Figure 2-5: *GPS Receiver Accessories*

Bells & Whistles

This area of GPS receiver design is wide-open. Graphic displays, built-in maps, sunset/sunrise time, sunset/sunrise azimuth, satellite signal strength indicators, satellite position maps, battery strength meters, audible alarms, course deviation indicators, anchor drift, and man-over-board buttons are some of the more common "bells and whistles" features. Some of these are carry-over nautical concepts and have little or no practical use for land navigation. Some of the more useful of these miscellaneous features for land navigation include automatic route reversal, a satellite position map, a battery strength meter, and one key waypoint logging. You should identify the features that are important to you and make sure they're available in the receiver you select.

2.1.2 Basic Functions of GPS Receivers

This section's purpose is twofold. First, it is intended to give you an understanding of what the various GPS functions mean to an actual GPS user — you. Second, it is intended to "decode" the various dialects — GPS-speak — that are used by different manufacturers of GPS hardware.

The operating manuals that are supplied with GPS receivers have varying degrees of user friendliness, but none of them really provides a solid underpinning on the topic of *why* you use the various functions of GPS receivers. By dividing basic GPS functions into three general categories, you will be able to get a better perspective on how the various features and display screens in your receiver relate to one another.

The terminology used in the world of GPS can get confusing in a hurry. Different manufacturers (and sometimes different models from the same manufacturer) use different terminology for identical features. You need to recognize this variability to avoid becoming confused. It is a good idea to be familiar with the various names used for a particular feature so that you won't be thrown off course (so to speak) by your friend's Brand X receiver. Think of it as being multilingual.

Let's start by separating the basic functions of GPS receivers into three distinct groups. The main categories of information supplied by GPS receivers are:

[1] Position and waypoint coordinates,

[2] The distance and direction between your position and/or stored waypoints, and

[3] Travel progress reports.

If we divide the items shown on the various display screens of a GPS receiver into these three categories, it will provide you with a better perspective on what your receiver is telling you.

Figure 2-6: *Examples Of The Three Basic Kinds Of Information Supplied By GPS Receivers*

Position and waypoint coordinates refer to the pairs of numbers that represent real-world locations. Coordinates define your current position and coordinates define the stored waypoints that represent all the "memorized" locations that are important to you. Coordinates are what your GPS receiver relies on for virtually everything it does for you.

The distance and direction from your position to a waypoint is the information that you will usually be most interested in — as in: Where am I relative to where I want to be? For example, you may ask your receiver how far and what direction it is to your camp. To use your receiver's distance and direction functions, you must have previously stored the coordinates for the waypoint you are seeking (in this case, your camp).

Travel progress reports tell you how you're doing relative to your travel objectives. Your GPS receiver can give you "travel progress reports" that indicate everything from your speed, to what time you'll arrive at your destination based on your current rate of progress. To use progress report functions you must be in motion, and for some (such as ETA) you must also have a stored waypoint.

There are a variety of other features that various models of GPS receivers have that are of more limited use, especially for backcountry land navigation. "Auxiliary" functions such as anchor drift alarms, sunrise/sunset calculations, moon phase, and track plots are described at the end of this section.

Coordinates (Position Fixes and Waypoints)

Determining your exact position is the most basic function of the GPS system. Your current position can be reported in terms of either angular coordinates (latitude and longitude) or rectangular coordinates (UTM or one of several other rectangular grid systems). All it takes to obtain your current position fix is to be able to "track" at least three or four satellites.

Coordinates can also be associated with locations that you have stored in the memory of your GPS receiver. Stored locations are usually called waypoints or landmarks — it depends on the GPS manufacturer. For simplicity the rest of this book will only refer to waypoints, but you can substitute the term landmark because it means the same thing.

Waypoints are stored coordinates that represent real-world locations that you care about for some reason. One difference between a position fix and a waypoint is the waypoint will have a name. Another is that the coordinate values of a position fix constantly change as you move about (or as Selective Availability "moves" you about), whereas a waypoint's coordinate value remains fixed until you erase it, edit it, or change datums.

A waypoint can be a location you were at 30 seconds ago, or it can be a location on the other side of the earth that you (and your GPS receiver) have never visited. Which leads us straight into the next topic, how to store waypoints.

You can use one of two methods to store a waypoint in your receiver's memory. Waypoints can be stored by using "keystrokes" to enter the coordinate numbers as if you were using a typewriter or a calculator. Waypoints may also be stored by pushing a button (or sequence of buttons) to automatically record the coordinates associated with your current position fix. There are some very important differences between these two methods of entering a waypoint's coordinates.

If you enter a waypoint automatically (that is, you store your current position fix) it does not matter what datum you've specified in the receiver's setup menu. That's because storing your current position fix automatically puts it into the receiver's memory in the WGS84 (World Geodetic System of 1984) datum. WGS84 is the datum that the NAVSTAR satellite system (and your receiver) use for internal processing. When you select a different datum the receiver simply translates the displayed coordinate value from WGS84 to the datum you selected.

Let's say you have selected NAD27 (North American Datum of 1927) as the datum used by your receiver — this is the datum used on most USGS topographic maps. Your current position will be calculated internally based on WGS84, then converted to NAD27 for display. If you change the datum selection to WGS84, the coordinate values that are displayed will change, but the position calculated (or stored) inside the receiver will remain the same. In fact, any time you change the datum that is "active" all you're really doing is shifting the coordinate values that will be displayed for a given position. The position stored in memory will not change.

Position Fix	Stored Waypoint
Based On Real-Time Satellite Tracking	Based On Coordinate Values Entered Into The Receiver's Memory
Represents An Approximation Of The Receiver's Actual Position	Represents Either A Snapshot Of A Position Fix Or User-Supplied Coordinates
Has No Name	Must Have Either A User-Supplied Name Or A Receiver-Generated Name
Constantly Changes As The User's Position Changes (May Change Even When Receiver Is Stationary If Selective Availability Is On)	Once Created, Waypoint Coordinates Do Not Change Unless Edited By User
Is Limited To Locations Actually Occupied By The Receiver	Can Be Specified For Any Location On Earth

Figure 2-7: *Position Fix Vs. Stored Waypoint*

Coordinate systems are handled in a similar way. The receiver's internal coordinate system is ECEF, which is a three-dimensional cartesian coordinate system whose origin is the center of the earth. You never see coordinates displayed in the ECEF system because it is impractical for humans to use. But machines (computers) like it. For more information on the ECEF coordinate system see page 134.

Whenever you see coordinate values displayed on the screen of a GPS receiver they are converted from the ECEF system. Likewise, when you store a position fix its coordinates are displayed in whatever coordinate system you've selected, but it is stored as ECEF coordinates. The receiver uses the appropriate mathematical formula to convert between ECEF and the coordinate values shown on the display.

The bottom line is that a waypoint that was created by storing a position fix will always be accurate (within the limitations associated with satellite geometry, multipath interference, atmospheric conditions, and Selective Availability) at the time it was created.

Now let's look at what happens when you input waypoints manually. This is where you key in the actual numbers that represent the coordinates. When you enter a pair of coordinates the receiver converts the values you enter into WGS84 and ECEF. If you've selected WGS84 as the datum, no datum conversion is done. That's fine if the coordinates are taken from a map (or some other source) that was prepared using WGS84. It is not fine if the coordinates are taken from a map that was prepared using another datum — say NAD27. In this case the coordinate values you enter should be converted inside the receiver, but because you selected WGS84 the receiver thinks they need no datum conversion. The stored waypoint will be "off" by whatever amount of conversion should have been, but was not, applied.

Turning A Position Fix Into A Stored Waypoint

1. Position Receiver In Desired Location
2. Ensure Receiver Is "Locked" Onto Satellites In 3D Mode
3. Perform Keystroke Sequence Required By Your GPS Receiver Model To Store Coordinates That Are Being Displayed
4. Assign Name To Stored Waypoint (Or Let Receiver Assign A Default Name Automatically)

Note: The Current Datum And Coordinate System Settings DO NOT Affect The Stored Waypoint, But They Do Impact The Coordinate Values That Are Displayed

Figure 2-8: Storing Waypoints: Using Your Current Position Fix

That's why it is very important that you have the correct datum specified when you enter a waypoint manually. The wrong datum can yield significant position errors (hundreds of meters), so it pays to be very careful.

Coordinate systems are less likely to be a problem since their differences are usually much more obvious. Generally, it is not too difficult to tell the difference between latitude/longitude and UTM when you're working with coordinates. The important thing to recognize is that regardless of the coordinate system that was active when a waypoint was stored, it is always converted and stored as ECEF. Later, any coordinate system you select for displaying the waypoint will be just as "accurate" as any other coordinate system.

Once you store a waypoint it consists of a name (either the default name your receiver automatically assigned or the one you chose), a coordinate value (stored as ECEF, but displayed according to the coordinate system currently selected), and various other fields of information that vary by model of receiver. Most GPS receivers allow you to edit some or all of the fields associated with a particular waypoint. The other fields of information can include the elevation of the waypoint, the time and date the waypoint was stored, a memo field, etc.

Most GPS receivers also display elevation, but this information is of limited use to backcountry users. That's because the elevation provided by a GPS receiver is considerably less accurate than the horizontal coordinates. In fact, with Selective Availability activated the elevation error range is plus or minus 156 meters. A good barometric altimeter is a far better instrument for obtaining accurate elevation information (see page 55).

Storing A Waypoint Using Coordinates You Supply

1. Obtain Coordinate Values (Latitude/Longitude, Easting/Northing, Etc.) From An External Source (Read From A Map, Appendix Of This Book, Etc.)
2. Set The Receiver's Datum And Coordinate System To Match Those Associated With The Source Of The Coordinates
3. Select Your Receiver's Waypoint Entry Mode, Then Enter The Name And Coordinate Values In The Sequence Required By Your Receiver

Note: The Datum And Coordinate System Settings DO Affect The Stored Waypoint. They Must Be Set Correctly WHEN THE COORDINATE VALUES ARE ENTERED. After That They Can Be Changed Without Impacting The Stored Waypoint, But They Will Impact The Coordinate Values That Are Displayed

Figure 2-9: Storing Waypoints: Using Coordinates You Supply (Keypad Entry)

Now for the bottom line of this section. Without a doubt two of the most important skills you need to develop for backcountry GPS use are:

[1] **Being able to quickly and easily store waypoints based on your current position fix (see Figure 2-8), and**

[2] **Being able to quickly, easily, and accurately store waypoints from coordinate values that you obtain from maps or other sources (see Figure 2-9).**

Consult your receiver's users manual to learn the exact procedures involved, then practice these skills until they are second nature.

In summary, coordinates (both your current position fix and stored waypoints) are the heart of the GPS system. You must understand and be aware of certain parameter settings (the datum and the coordinate system) when working with coordinates. Again, the only exception to this is when you automatically store your current position fix as a waypoint. In this case the datum and coordinate system settings are irrelevant.

Important Note From The Author: As this book was about to go to press, the author encountered a newly-released GPS receiver that did not convert the coordinate values of stored waypoints when different datums were selected. This appears to be a logic error and has been brought to the manufacturer's attention. You may want to verify that your receiver handles waypoints and datums correctly. A check can be performed by comparing the coordinate values of a stored waypoint when different datums are selected. If the values don't change, you may have a logic error in your receiver's firmware.

Distance and Direction (GoTo, Routes, Etc.)

Once you have at least one waypoint stored in your GPS receiver it becomes possible to utilize the functions that give you the distance and direction to stored waypoints. These are the most valuable features of GPS for backcountry land navigators. Distance is a very straightforward item of information, since all you need to worry about are the units of measurement (metric, statute, nautical). Direction, on the other hand, can be quite confusing.

The direction between two locations is usually called a bearing, although it is sometimes called a course, especially in the case of the legs of a route. Just to keep things confusing, some GPS manufacturers call the direction you are actually traveling course over ground. Your actual direction of travel may also be called your heading or your track. The direction you are actually traveling is a much different concept than the direction between waypoints. This will be covered in the next section on travel progress reports (see Figure 2-13).

Usually distance and direction will pertain to the distance and direction from your current position to a stored waypoint. This can be obtained using your receiver's "GoTo" function. Some receivers also have a feature that shows you a list of waypoints along with their distances and directions from your current position fix. It is also possible to select a specific waypoint from among all stored waypoints and see its distance and direction from your current position fix. There are probably a number of different ways your receiver can be "asked" for this information. Consult your receiver's manual for the particular methods available to you.

Figure 2-10: *Examples Of The Basic "GoTo" Screens On Various GPS Receiver Models*

Figure 2-11: *Here Are A Few More Variations Of "GoTo" Screens*

Sometimes it can be handy to have your GPS receiver give you the distance and direction between two stored waypoints. Say you're in camp, but you want to see how far it is from the location you fished at in the morning (where you stored a waypoint) to the peak you climbed in the afternoon (where you also stored a waypoint). This is accomplished by specifying the "from" and "to" waypoints in the particular manner required by your receiver. There may be a dedicated function that does just this, or you may need to specify the waypoints as a leg of a route to "coax" this information out of your receiver. There may be several ways to obtain this type of information. Whatever the method(s), you should learn how to get this type of information from your particular GPS receiver.

You also need to be aware that the distances your receiver calculates between waypoints are straight lines on the surface of the WGS84 ellipsoid — approximately mean sea level. This means you must allow for any extra distance caused by winding trails, plus the extra distance caused by the slope between locations at different elevations. On a 10 degree slope the actual straight-line ground distance will be less than 2 percent more than the GPS receiver indicates. On a 45 degree slope the actual straight-line ground distance will be over 40 percent more than the receiver indicates.

Obtaining distance and direction measurements between stored waypoints can be handy for comparing alternative routes, planning a trip in advance, or just answering interesting trivia questions. In essence, with this function you can obtain the distance and direction between any two points on earth as long as you know their coordinates. Just be aware that the direction provided is along a great circle path (beginning at the "from" waypoint) and not along a rhumb line. See page 146 for an explanation of these terms.

As long as the initial data entry for a particular waypoint was done using the correct datum and coordinate system, it doesn't matter what these parameters are set to when you read the distance and direction information. That's because all position fixes are stored internally as WGS84 ECEF coordinates. You will usually have a choice between metric, statute, and nautical distance measurement units. The one to choose is strictly a matter of your preference.

The direction between two waypoints is a little more tricky, because there are setup parameters that impact the way directions are displayed by your GPS receiver. The most important parameter to be aware of when working with direction is the declination setting. Options can include some or all of the following:

[1] True direction (no offset, 0° referenced to true north),

[2] Grid direction (grid declination as the offset, exact offset value provided by the receiver, 0° referenced to grid north),

[3] Magnetic direction (magnetic declination as the offset, approximate value provided by the receiver, 0° referenced to magnetic north), and

[4] User selected offset (any amount of offset, as specified by the user).

Try not to let all of your receiver's parameter options confuse you. Think of them as providing the flexibility to customize the way your receiver works for you. Some

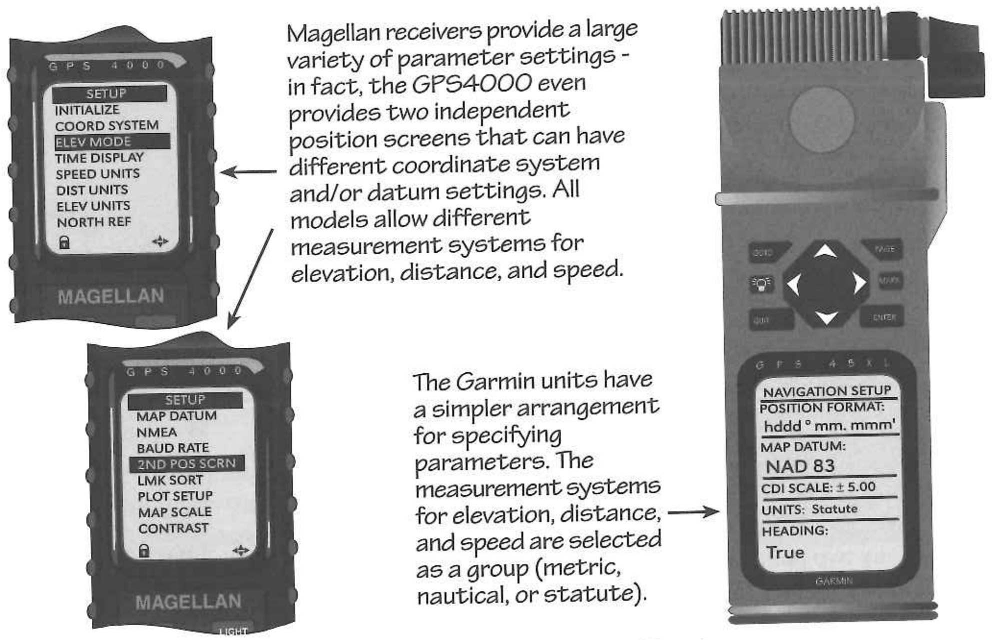

Figure 2-12: Setting The Basic Parameters Used By GPS Receivers

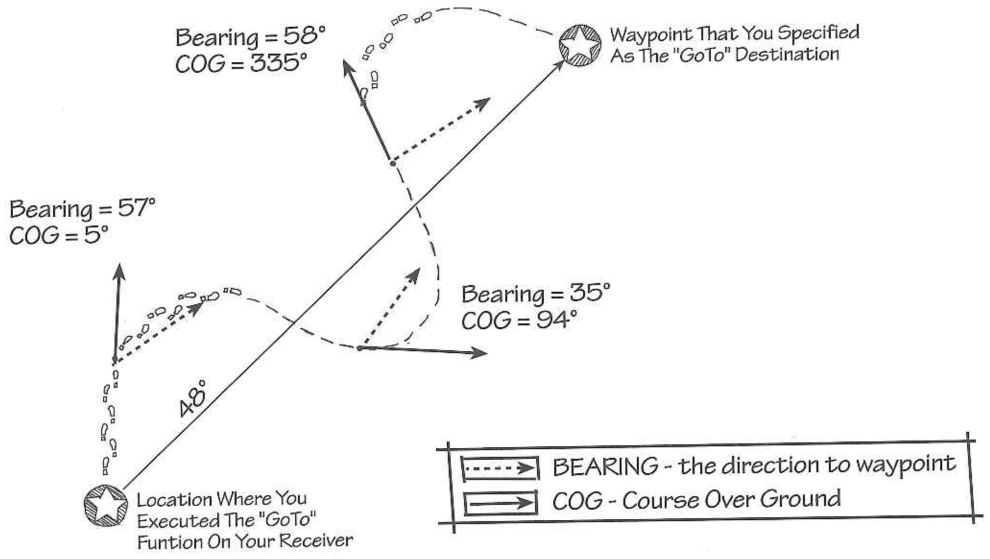

Figure 2-13: COG (Course Over Ground) And Bearing — Two Different Concepts

parameter settings, notably the datum and to a lesser degree the coordinate system, are dictated by the map you're using. Others, such as the declination mode and distance units, should probably be left at a basic setting that works for you, at least until you move up the GPS learning curve.

Try this as a good starting point for the "discretionary" setup parameters: UTM for the coordinate system (unless you prefer to work with a latitude/longitude scale), magnetic headings (unless you have declination adjustment on your compass and prefer true headings), and distance in feet and statute miles (unless you prefer the metric system).

Almost everything mentioned above about distance and direction also applies to routes. Routes are a standard feature of most handheld GPS receivers. A route is a group of waypoints that have been linked into a sequence known as "legs." Legs are just two waypoints (a "from" waypoint and a "to" waypoint) along with the distance and direction between them. Each successive leg in a route starts "from" the prior leg's "to" waypoint. This means a route consisting of "n" legs will have "n+1" waypoints.

Routes are handy because they can simplify the use of GPS. One way they do this is by automatically switching to the next leg as you pass through successive waypoints. Another convenience feature of routes is you can usually reverse them, meaning that you don't need to re-enter waypoints when you want a route that simply backtracks. Not all receivers with routes offer a reverse route feature.

Another feature related to distance and direction found in most handheld GPS receivers is *cross track error* (XTE). It tells you how far you are to the left or right of a course you've set to a waypoint. This function is a carryover from the nautical roots of most handheld GPS receivers. In some receivers it is called *course deviation indicator* (CDI). They're basically the same.

XTE indicates how far and in what direction you have "wandered" away from a straight-line course between two waypoints. That straight-line course is either the current leg of an active route, or it is the course line formed when you last performed a "GoTo" function. In the latter case, each time you perform a "GoTo" function the course line is re-established from the position you are at when you re-execute the "GoTo."

Another feature sometimes associated with XTE is a suggested heading that will get you back to your original straight line course. This suggested heading is usually a compromise between your current straight-line course to the destination waypoint and the shortest distance to the line of the original course.

The purpose of XTE is to keep track of how far you have "wandered" from a straight-line course. The question land navigators must ask themselves is: So what? — does XTE have any relevance? In most cases XTE doesn't really tell you anything particularly useful. It's rare that the course for a backcountry route would be a straight line. If it is, say over featureless plains or tundra, then XTE could be useful (except that once you're off course, you would need a good reason to go back to the original course instead of heading straight for the destination).

In short, the value of XTE to land-based users of GPS is limited. If you are an aviator needing to fly a particular air traffic lane, it matters. If you are a mariner needing to keep

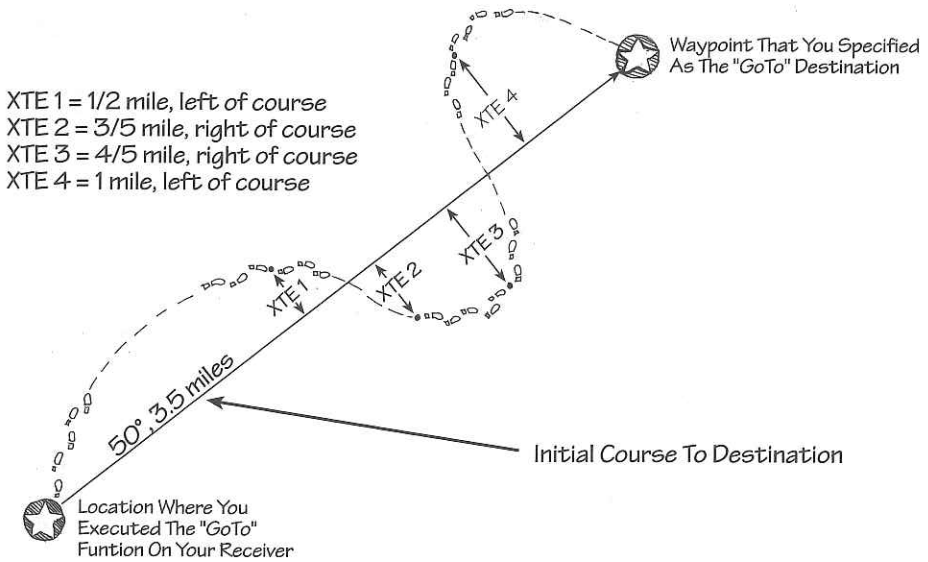

Figure 2-14: *XTE (Cross Track Error); Also Known As CDI (Course Deviation Indicator)*

your boat in a particular shipping lane, it matters. But most overland travel is not through terrain as featureless (or collision-prone) as airspace or the seas. If you're traveling by road or trail, this feature doesn't usually provide much benefit. Even if you're traveling overland off-trail, there will probably be terrain features that make it sensible to intentionally go "off-course."

In the final analysis, there is not much value in XTE for most land applications of GPS. It is a part of the GPS display, however, and you should understand what it is telling you so that it doesn't distract you from the truly beneficial aspects of using GPS for land navigation.

In summary, using the distance and direction capabilities of your GPS receiver can be boiled down to knowing how to do two things. One is knowing how to obtain the distance and direction from your current position to a specified waypoint or list of waypoints. The other is knowing how to obtain the distance and direction between two (or more) stored waypoints.

Progress Reports (SOG, COG, VMG, ETA, TTG, etc)

The final category of basic GPS receiver functions should be called alphabet soup. It includes various indications of your dynamic, or motion related, progress. These functions are of limited value to backcountry land navigators because of both Selective Availability (which ruins the accuracy of motion-related functions at slow speeds) and battery drain (GPS receivers consume a considerable amount of power when operated continuously). These functions can be useful, however, if your GPS receiver is mounted to the handlebar or dashboard of a motorized vehicle and it is hooked up to the vehicle's power supply.

The display of motion-related functions is usually scattered among the static functions described in the previous two sections. Because these dynamic progress indicators are not usually separated (in a display sense) from the coordinate and distance/direction displays, they can make your initial encounter with GPS quite confusing.

There are a wide variety of dynamic-progress related features in today's handheld GPS receivers. Perhaps the most universal, and least confusing, is the "speed" indicator, which is an almost instantaneous readout of your velocity of travel. This measurement is often called *speed over ground* (SOG) for reasons that will soon be clear.

Another motion-related progress indicator is your direction of travel, often called *course over ground* (COG), or heading. It is very important to recognize the difference between this motion-related concept and the direction to a waypoint. If you're not careful, you can mistake one for the other and find yourself off course. See Figure 2-13.

A measure related to both your speed over ground and your destination waypoint is called *velocity made good* (VMG). This is the rate you are "closing" on a destination waypoint (you must have either a route or a "GoTo" active). If you are heading directly toward the waypoint your speed and your VMG will be the same. If you are not headed directly at the waypoint, but your course is within plus or minus 90 degrees of the course straight to the waypoint, then you are getting closer to the waypoint as you move forward. You should recognize that if you stay on a course that doesn't point directly at the destination waypoint you will never actually arrive there. This function is popular among racing sailboat captains, since they usually can't sail straight at an upwind mark. Instead, they tack back and forth. VMG indicates the best combination of boat speed and angle of attack. See Figure 2-15.

Another kind of progress report provided by GPS receivers is the estimated time it will take to reach a particular destination at your current speed and direction of travel. It may be called *estimated time enroute* (ETE), *time to go* (TTG), or some other phrase. This is simply a conversion of the VMG (*velocity made good*) measurement to a time measurement. It is calculated by multiplying VMG times the distance to the destination waypoint. Some receivers give the information as *estimated time of arrival* (ETA), which is just the current time plus ETE. Some receivers even have a screen that gives this information for all remaining legs of the current route.

One characteristic of dynamic progress reports is that you must be moving before there is anything to report. In the case of goal oriented items (such as VMG, ETA, ETE, etc.), you must have a goal (usually established with the "GoTo" function or by activating a route) and you must be moving toward the goal, otherwise the display will be blank. If you find that some or all of the progress report items report a value when you're motionless, that's just Selective Availability making the receiver think it is in motion.

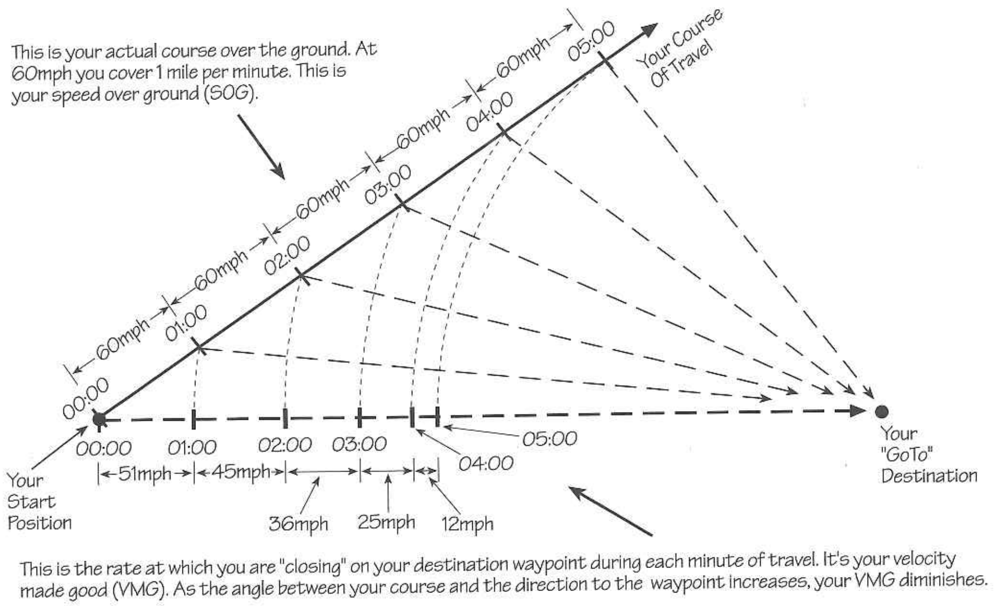

Figure 2-15: Velocity Made Good (VMG) Is The Rate At Which You "Close" On Your Destination

Figure 2-16: Examples Of ETE/TTG And ETA Displays

Selective Availability also limits the accuracy of velocity related measurements at slow speeds. In general, speeds over 10-15 mph are needed to overcome the effects of Selective Availability. Some receivers have the ability to average the position data used to calculate velocity related values. The result is a more stable (but sluggish) display of velocity related items. At slower speeds you need to watch your display for unstable readouts — a sure sign of Selective Availability related problems.

In summary, all GPS receivers provide a variety of travel progress indicators, but those indicators are of limited benefit to backcountry land navigators. One reason is that Selective Availability ruins their accuracy at slow speeds, and the other is the battery drain that accompanies continuous receiver operation.

Miscellaneous GPS Receiver Functions

There are a wide variety of auxiliary functions available with the various models and brands of handheld GPS receivers. Projections of certain events over space and time (sunrise, sunset, moon phase, even satellite positions) allow you to find the status of these events at a particular place and future date of your choice. This can be useful for planning purposes. Graphic plotter screens can show you visually where you've been or where you need to go (to stay on course).

A common auxiliary feature is a display of the exact time of sunrise and sunset for any waypoint and any date you specify. A less common auxiliary feature tells you the exact position (elevation and azimuth) of the sun or moon at any location, date, and time you specify.

Real-time satellite status information (elevation, azimuth, signal strength) can be used to optimize reception in difficult environments such as forests, mountain valleys, urban valleys, etc. Most receivers provide either a table or a graph that shows the position of the satellites currently in the sky and the signal strength of the satellites being tracked.

Graphic plots of waypoints and your track can help you visualize the course you've taken or that you need to take. Graphic "highways" can give you a visual indication of your position relative to a destination waypoint and the course to it. The trouble with these features is that you either need to have your receiver on continuously to use them, or you need to be traveling relatively fast for them to be accurate, or both. This is not likely to be the case unless you are traveling in or on a motor vehicle and the receiver is mounted to the handlebar or dashboard.

Some receivers can average a position reading taken at a fixed position over time, thereby overcoming the effects of Selective Availability. By averaging for at least one hour, the horizontal error range of a position fix can be reduced from 100 meters to 10 meters. This feature overcomes Selective Availability and provides differential GPS accuracy without a differential beacon, but it requires time and patience.

In summary, these miscellaneous features are nice, but they're not essential for backcountry navigation. This is especially true if you are limited to operating on battery power.

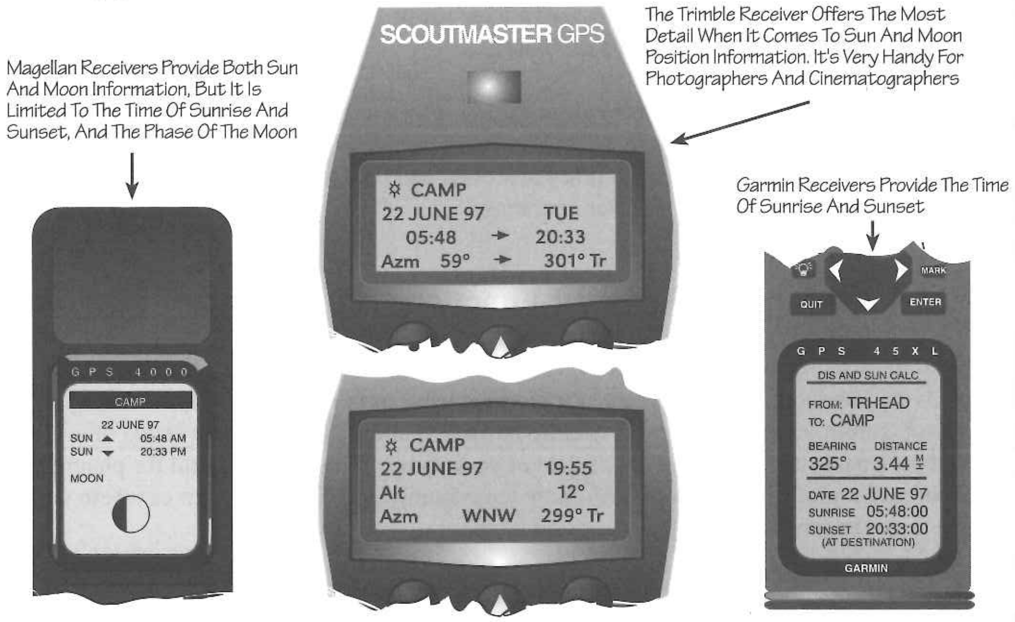

Figure 2-17: Examples Of Some Miscellaneous Information Supplied By GPS Receivers

2.1.3 Limitations of GPS Receivers

When you use a GPS receiver for personal navigation it is important that you understand its limitations and idiosyncrasies.

Line of Sight

A GPS receiver must have a direct line of sight to a satellite in order to receive the satellite's signal. While GPS satellite signals will penetrate glass and light-weight barriers (such as canvas), they will not usually penetrate buildings, forest canopies, or other dense obstacles. This means that you need to be aware of obstructions that may limit the number of satellites you can receive.

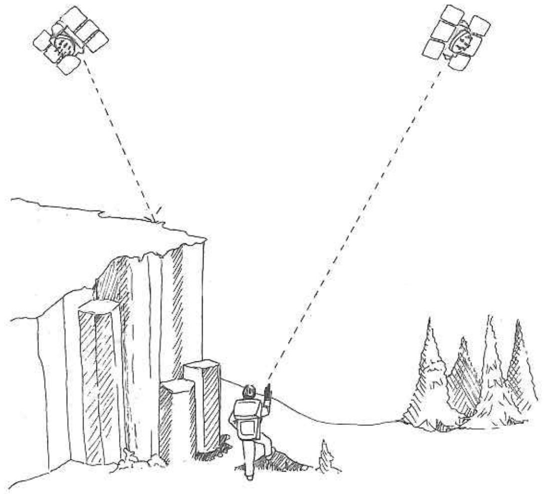

Figure 2-18: Line Of Sight Is Essential

Some GPS receivers have a feature that gives the position of the satellite constellation (azimuth and elevation) in real time. You can use this feature to help you find the best reception location in your vicinity. Since the satellites are in constant motion, sometimes just waiting for their positions to change can improve your reception.

Stale Data

You need to know if the data being displayed on your GPS receiver's screen is based on a current position fix or an old position fix. Receivers indicate this information in a variety of ways. Some receivers show the current satellite lock status on all position and navigation screens. Other receivers require that you either go to a particular screen or decode "hints" to figure this out. It is very important that you understand how your particular receiver indicates whether or not it has a current position fix.

2-D Operating Mode

You need to be aware if your receiver is operating in two-dimensional mode. This happens when your receiver can only track 3 satellites. See page 6 for an explanation of how GPS receivers use satellites to obtain position fixes.

A receiver operating in 2D mode uses the center of the earth as a substitute for a satellite, and it uses elevation in the place of a satellite range. The problem with 2D mode lies in the elevation value.

A GPS receiver not only doesn't calculate elevation in 2D mode, it requires elevation as an input. In most cases if you don't supply an elevation value, the receiver assumes one. Serious position inaccuracies (as in miles of error) can result if the elevation "assumed" by your receiver is wrong. Some receivers default to an elevation of zero. Others may use the last elevation that was actually calculated by the receiver. If the last time you used the receiver was one hour and 2,000 vertical feet ago, you could have a serious problem getting an accurate position fix in 2D mode. As a general rule, two-dimensional position fixes should be avoided.

You may be able to put elevation data into your receiver if you absolutely need a 2D position fix. Try to be as accurate as possible with the elevation you supply the receiver. And be aware that all GPS receivers calculate elevation as height above the ellipsoid, although some use an internal table to convert their elevation readouts to height above the geoid. USGS maps, on the other hand, always give elevation as height above mean sea level, which is height above the geoid.

The geoid is a physical phenomenon that is measured. It is a surface of constant gravity. Where there is ocean it is the surface of the ocean. Where there is land it is where the ocean would be if the land weren't in the way. It is not a "smooth" surface. In a given location, the vertical difference between the surface of the geoid and the surface of the ellipsoid is called geoid/ellipsoid separation. This difference can be substantial—up to 52 meters in the continental United States. Figure 2-20 shows a simulated image of the surface of the geoid across the United States. The ellipsoid, on the other hand, would look like a smooth, featureless beach ball. That means the difference between the surface of the ellipsoid and the surface of the geoid is highly irregular. Receivers that use a table to convert from ellipsoid elevation to geoid elevation are able to get within about 5 meters of the true geoid elevation.

The additional horizontal error that results from inaccurate elevation values in 2D mode can be as much as 5 times the amount of elevation error. This is caused by the geometry of 2D mode (the "4th" pseudo-satellite at the center of the earth, in the opposite hemisphere)

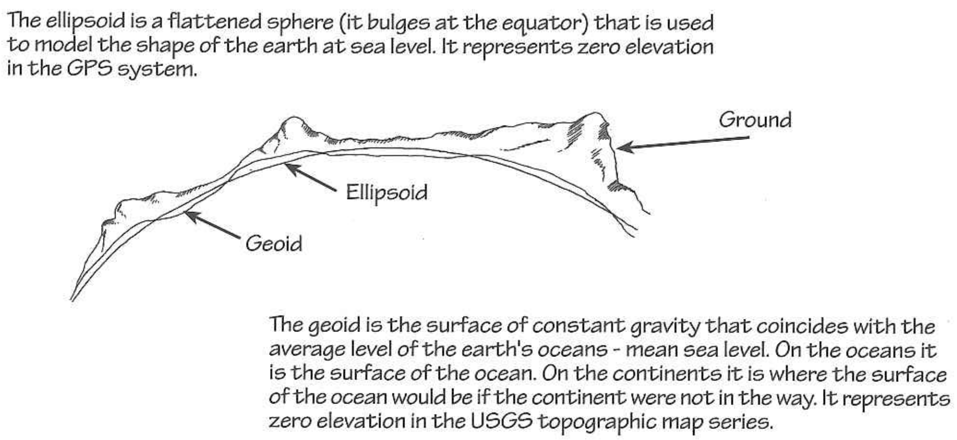

Figure 2-19: The Vertical Distance Between The Geoid And The Ellipsoid Is Variable

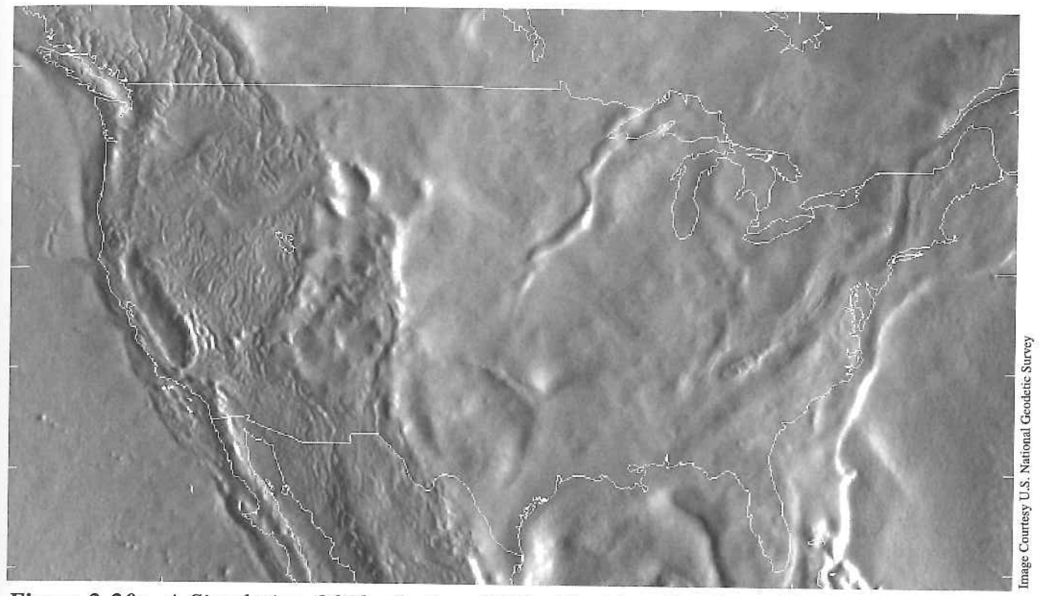

Figure 2-20: A Simulation Of The Surface Of The Geoid — Continental U.S.

and the fact that elevation error does not "average out" with the range errors from the actual satellites. 2D elevation error is from a different source than receiver clock error.

It's Not A Compass

A GPS receiver is not a compass. A GPS receiver cannot tell you the direction it is pointed. It can only tell you the direction it is moving. This capability can be used to simulate a compass in a pinch, but Selective Availability seriously reduces the accuracy at walking speeds. Also, using a GPS receiver as a compass will rapidly deplete its batteries.

This means that you should plan to use a magnetic compass as a part of your GPS tool kit. Only use your GPS receiver as a compass when you need a backup for a lost or broken magnetic compass. (Note: if you use your GPS receiver in a motor vehicle or with some outside source of "unlimited" power, it can serve very effectively as an accurate compass—as long as it is moving at over 10-15 mph.)

Slow Startup

It takes a long time (up to 15 minutes) for a GPS receiver to figure out where it is if it has been moved a long distance (over several hundred miles) since it was last used. You can shorten the process, however, by telling the receiver approximately where it is. This is called initialization. It may also be necessary to enter the date and approximate time if they have been lost from the receiver's memory. Many newer receivers have a list of locations (such as major cities) built-in so that you can initialize the receiver without entering actual coordinate data.

Setup Parameters

It is important that you properly enter certain "critical" parameter settings, especially if you use your GPS receiver with external information derived from maps, compasses, or even coordinate listings (such as those found in the appendices of this book). Without proper settings a GPS receiver cannot give you accurate navigation information.

The most important of these "critical" parameters is the datum associated with the map or coordinate data you're using. Setting the wrong datum can lead to a position error in excess of one mile! See page 78 for more information on datums.

Matching the declination mode setting, or consciously adjusting for it, between the GPS receiver, your compass, and your map is also very important. See page 52 for more information. A failure to match compass and GPS receiver declination modes can lead to heading errors of over 20° in the continental United States. Traveling at 20° off course will put you 1,800 feet (over 1/3 of a mile) wide of an objective that is just one mile away. Even with an error of only 5° you'd get no closer than 460 feet to that objective.

If you used the wrong declination direction (say, east instead of west) the error would be twice the amount of actual declination. A 40° direction error means you would miss an objective that is one mile away by 3,400 feet (almost 2/3 of a mile). In other words, you wouldn't even get close.

The time of day given by the GPS receiver, while very accurate, is stored inside the receiver as *Universal Time Coordinated*, or UTC. To display the correct local time you must set your location's offset from UTC. It's easy to tell if you've done this correctly when you're in civilization — either the local time shown on your receiver is correct, or it is off by exactly one or more hours. In the backcountry it may not be so obvious. By the way, setting the wrong local time offset does not impact position accuracy.

There are other optional parameters you will want to set as a matter of convenience. These convenience settings have no right or wrong values, you just need to be aware of how they are set. The type of coordinate system (usually latitude/longitude or UTM), distance units (metric, statute, nautical), and speed units (km/h, mph, knots) are examples of optional parameters. There may be other optional parameters that apply to your particular GPS receiver.

2.1.4 GPS & Computer Programs

Connecting your GPS receiver to a computer can be a very handy and timesaving feature. GPS receivers designed for personal navigation have two basic types of "links" to personal computers. One is a real-time link that sends a continuous stream of position data from the receiver to the computer. That data is then stored and/or displayed on the computer's screen. If it is displayed, it is done so as points or a path on an electronic map of the surrounding area. This type of computer link is like an extension of the receiver's display

screen and display software. It is similar to the kinds of systems that are starting to appear in the dashboards of cars that are equipped with GPS. It is not likely to be of much use to backcountry GPS users, since it is quite bulky and consumes considerable power.

A second type of link between a GPS receiver and a computer involves using the computer to enter, manage, and store waypoint, route, track, and other data that is used in the GPS receiver. This type of link involves uploading and downloading between the GPS receiver and a PC. The PC becomes an extension of the GPS receiver's keypad and memory. This type of computer link can be very useful for backcountry GPS users, since it allows data entry and storage to be done on a personal computer. That can be much more efficient than using the four scroll keys and limited memory of a typical handheld GPS receiver.

Most current GPS receiver models offer both of these features. Some older receivers can only output data. That means they can be linked to a moving map display, but you can't store waypoints and routes outside the receiver, then upload them at some later time.

You can purchase GPS/PC interface software from the receiver's manufacturer or, in some cases, one of several third-party sources. Delorme Mapping Company and Chicago Precision Mapping both offer GPS mapping software, and even sell a bundled kit that includes a GPS receiver. Wildflower Productions has developed electronic map software (TOPO!) that doesn't yet, but eventually will, communicate directly with GPS receivers. With any 3rd party software, you need to make sure it's compatible with your receiver.

For simple waypoint and route management, it's hard to beat WAYPOINT+, available free on the Internet. This program's main screen and its waypoint list/editing screen are shown in Figure 2-21. As of this writing, it only works with Garmin GPS receivers.

The bottom line for anyone interested in using a personal computer with a GPS receiver is to make sure that the receiver has the interface capabilities you desire (download only or upload and download), and then select a software package that performs the necessary functions. Unless you have a need to do GIS (geographic information systems) or mapping type applications, waypoint/route data management is probably all you really need from the computer interface. Digital maps can also be quite valuable, and they don't need to be linked to the GPS receiver to be of value. See page 103 for more information on digital maps and related software.

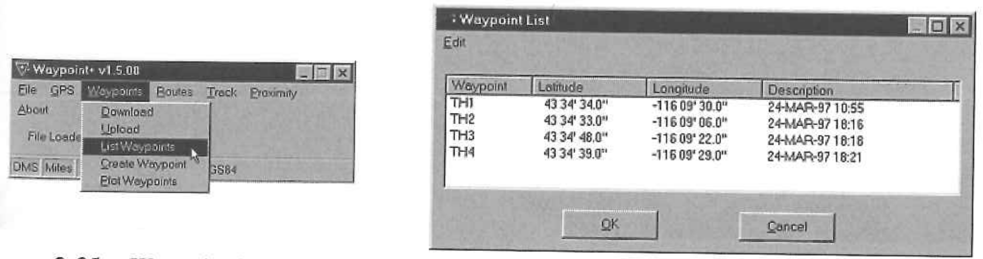

Figure 2-21: *Waypoint Management Software Allows You To Upload And Download Waypoints To A PC — This Is WAYPOINT+ (A Freeware Program Available On The Internet)*