**Appendix 11.3**

# GUIDELINES FOR FIXING CO-ORDINATES OF NVS (NATIONAL VEGETATION SURVEY DATABANK) PLOTS USING GPS (GLOBAL POSITIONING SYSTEM).

Larry E. Burrows
Landcare Research
PO Box 69, Lincoln
NEW ZEALAND

Date: July 2000

## CONTENTS

## 1. Introduction

Randomly selected field plot positions were located by GPS (Global Positioning System) during the project. Experiences with GPS use in a hilly, forested, environment in this and other projects have been used to develop some general guidelines for location/relocation of plot sites.

Accurate position co-ordinates are a valuable component of all NVS (Wiser etal. 2001) permanent plot data. They allow more precise spatial analyses as well as simplifying plot relocation and reduction of reliance on difficult-to-maintain and time-consuming line markers.

With the removal of signal-degrading selective availability (SA) from GPS signals on the 1st May 2000 (Announcement from the Office of the Press Secretary to the President of the US) it is now possible to use hand-held GPS to navigate to within a few metres in the field, without subsequent correction processing - what you see on the screen is now almost where you are! The satellite network is also planned to be upgraded by the addition of a further 18 satellites, which will enhance coverage and accuracy in the future. Relocation of permanent plots will be improved and routes taken to relocate them will not need to be strictly linear.

To make best use of this technology requires some knowledge of GPS, GPS receivers, co-ordinate systems, and navigation. This guide is intended to clarify some of those factors in relation to recording co-ordinates of NVS permanent plots, and using recorded positions for relocation.

## 2. How GPS works:

GPS is a network of 32 satellites, or space vehicles (SVs), arranged in a moving web around the globe. At least twenty-four SVs are operational at any one time and the others are spares. SVs are not evenly distributed (there are less towards the north and south poles of the globe), and their relative positions change constantly. Each follows a very precise orbit about every 24 hours and transmits a precise time signal, generated by a set of atomic clocks at <1 second intervals, with a unique code signature to identify the source SV. GPS receivers in line-of-sight collect the time signature, and, knowing which SV it originated from and correcting for known sources of error, convert the signal time into pseudo-distance. Then using the distance information from a number of SVs they solve the spherical triangulation geometry needed to fix a position on the surface of the globe.

Signals are required from three SVs for a two-dimensional fix (x - easting or longitude, and y - northing or latitude co-ordinates), while four are required for three dimensions (x, y, and z - elevation), and a more accurate fix. Elevation can be in either of two forms, HAE - height above ellipsoid (a slightly flattened sphere approximating earth) initially calculated, or corrected to MSL - height above mean sea level or geoid (a theoretical flattened sphere with bumps and bulges more closely approximating earth sea level). The geoid can be above or below the ellipsoid, for example the separation at sea level in Christchurch is +11.12 m, but this difference varies considerably across the country.

By using the distance between 2 positions and the time taken to get between them the GPS receiver will also calculate and display velocity.

If more than 4 satellites are detected receivers automatically select those giving the most precise position using GDOP (see 2.1 below).

Further explanation of GPS can be found at a number of web sites, e.g. http://www.colorado.Edu/geography/gcraft/notes/gps/gps_f.html, http://www.trimble.com/gps/index.htm

**2.1 Precision or accuracy of different GPS models:**

GPS receivers vary in their inherent accuracy due to the way they handle incoming signals, how they correct for a range of known time, orbit, and atmospheric error sources, and interference variables such as multi-pathing.

Multi-pathing is when the signal gets to the receiver by other than a direct route. It has bounced off physical barriers such as buildings, mountains, or trees and may arrive at the receiver at one or more slightly delayed times creating confusion about which is the correct signal. Some more advanced receivers are able to recognise that the first arriving signal, taking the shortest route, is the most correct one. Others don't.

Accuracy also depends on the number of SVs they can 'talk to' at once. GPS receivers are mostly 6, 8, or 12 channels, meaning they can receive up to 6, 8, or 12 SV signals simultaneously. At most times there are between 5 and 9 SVs within sight of New Zealand. If a 6 channel receiver detects 9 SVs it will cycle systematically around them all, but the signal from some SVs will be ~1 or more seconds older than from others, so the calculated position co-ordinates will be less accurate than those from a 12 channel receiver that can receive from all 9 signals contemporaneously.

Precision of co-ordinates is also dependent on SV geometry in the sky. If all receiving SVs are in one sector of the sky then the resulting triangulation will be less precise than if they are spread evenly around the sky. Most receivers can display a measure of this precision as GDOP (Geometric Dilution Of Precision). E.g. PDOP - Position dilution of precision, VDOP - Vertical dilution of precision, HDOP - Height dilution of precision. The smaller the GDOP the better, and anything less than 4.0 is good. Some brands of receiver call the same thing Figure of Merit (FOM), and display it as approximate +/- metres from position. There are always other sources of error beyond those the receiver can identify, and so the displayed measure of precision should always be treated with caution and not be regarded as absolute.

Elevation accuracy is always less precise than x and y co-ordinates, normally ~150% worse, as there are only SVs in the hemisphere <u>above</u> your horizon. To get a more precise fix of altitude would require SVs below you!

Even without selective availability, variation in accuracy from known causes (satellite clock error, orbit fluctuation, ionosphere and troposphere interference, GDOP) can often amount to between 5 and 10 m. Additional unquantified sources such as multi-pathing and receiver noise, can increase error to >15 m. The more difficult the receiving position, the more likelihood of error in some or all signals received.

In summary, accuracy depends on many factors, some of which are unknown by the GPS. Manufacturers of newer model GPS hand-held navigation receivers estimate position accuracy at an open location will be within 15 m 95% of the time, and within 10 m 66% of the time. Greater accuracy than that can be achieved by better reception from more satellites (use a bigger aerial in a better location), using a receiver that recognises multi-pathing, or position averaging (available option on some receivers). But to ensure precision better than ~5 m still requires differential correction, a technique requiring simultaneous collection of position coordinates derived from identical SVs by two receivers, one of which is at a known position. Differential correction is not desribed here, but has been used for fixing positions of NVS plots.

### 2.2 Start-up delay by GPS receivers:

When turned on, GPS receivers often need some time (up to a few minutes) to pick up signal reception from 3 or more SVs. This is due to the faintness of the signal (satellites orbit at 10,900 nautical miles above the earth), and they need to automatically download a new almanac from the first SV contacted. The almanac is emitted by all SVs and tells the receiver which other SVs it should be able to get in touch with at its approximate current position and time. The more often a GPS is used, the quicker it latches onto signals because it has an up-to-date almanac already recorded. Almanacs are automatically downloaded every 12.5 minutes.

### 2.3 Physical obstructions to GPS signals:

The major limitation of GPS in NVS applications is physical signal interference. As GPS requires line-of-sight for signal reception, obstacles such as hills, mountains, or even large rocks can screen off SVs. Further interference by trunks of trees can obscure or reflect the signal from 1 or more SVs. The larger the tree trunks and the taller the canopy the more likely this will be a problem. The leaf canopy itself seems to have little effect on signals, interference is more the result of biomass between the SV and the receiver. Reflected signals result in ‘multi-pathing’ where the GPS receiver picks up the same signal more than once, or some signals take longer to arrive than they should, with resulting degradation of precision. These are common occurrences in environments that NVS plots are found, but with care it is possible to reduce the difficulties.

## 3. Co-ordinate systems:

Co-ordinate systems are global (e.g. Latitude and Longitude in degrees, minutes, seconds, and decimals of seconds), or local (e.g. NZMG in metres). All GPS receivers record global position co-ordinates in WGS84 (World Grid System) and most display them as Latitude/Longitude, which is well known. Global co-ordinates are on curved grids (have a look at a globe), while virtually every country in the world has an independent local grid system for its own mapping purposes. Local systems normally have a squared grid which is irregularly skewed or tapered from global systems. Complex conversion algorithms are available between most common systems, and PC-based GPS data processing software, and many models of receiver, have systems built in. Conversion between systems introduces another source of error.

The New Zealand metric land-based system, as used by NZMS 260 topomaps, is based on the NZ Geodetic 49 Datum and known as the New Zealand Mapping Grid (NZMG). A few models of GPS receivers display NZMG co-ordinates. NZMG to a 1 metre scale requires 7 figure easting and northing co-ordinates (e.g. the satellite dish on the roof of the Godley Building, Landcare, Lincoln, is at NZMG 2467792, 5729528). These full co-ordinate numbers can be found on the margins of NZMS260 topomaps. Commonly, position co-ordinates derived from topomaps consist of a map number along with a 3 figure easting and northing giving a position to a scale of +/- 100m. The above position given in this system would be M36 677 295, and is insufficient for most NVS plot relocation purposes (Table 1).

To record Latitude/Longitude coordinates to 1 m or better requires degrees, minutes, seconds, and decimals of seconds to 2 places. Two decimals of seconds actually gives accuracy to about 0.3 m at the equator. The above position in Latitude/Longitude is 172E 28’ 36.34”E, 43E 38’ 25.87”S (Table 1).

Table 1: Coordinates of the same position using different systems.

| | map | easting | northing |
|---|---|---|---|
| NZMG to 1 m | | 2467792 | 5729528 |
| NZMG 260 3 figure map ref. | M36 | 677 | 295 |
| Latitude/Longitude | | 172E 28' 36.34"E | 43E 38' 25.87"S |

## 4. Recording NVS plot positions:

To make best use of GPS for most NVS plot location and relocation purposes requires position co-ordinates accurate to within a few metres. Co-ordinates are difficult to estimate from topomaps closer than a few tens or hundreds of metres, and even scale-rectified and enlarged aerial photographs on which it is possible to see individual trees are only guaranteed to +/- 15 m by Aerial Mapping Ltd.

The best means of getting accurate plot co-ordinates is to **record them on the plot in the field** using GPS, and store them for future use. Even when navigating to a plot using GPS, it is worth re-recording the plot position and noting recording details on site.

### 4.1 Recording NVS plot positions:

In the field when first trying to pick up SV signals near a plot it is worth doing as much as possible to avoid obstructions. Move into the open, onto a ridge, into a gap, away from large trunks, up a tree etc. Once 'connected' the receiver can hold onto SV reception to some extent, and it can then be moved towards the position needing fixing. Grassland and shrubland ecosystems will be more straight-forward than forested environments, and the bottom of incised topography may be very difficult to get a signal. With fewer SVs towards the south it can mean that a south aspect gully of a high hill may consistently be difficult to get reception.

In forest, sometimes a movement of only a few centimetres will allow reception from enough SVs for a fix. Most brands and models of receivers have a menu option showing 'connected' SVs by number, it is almost always worth going to that screen to confirm that 3 or more satellites have been detected, and to have confidence in the fix check the PDOP of the signal.

Avoid strong magnetic fields such as large powerlines, transmitting cell phones, and electric fences. These fields can cause errors in recorded data or temporarily 'blind' a GPS receiver.

**4.2 Where on the plot:**
Ideally the plot position should be recorded at its centre to give the most likelihood of future relocation. In hill country, with forest, this will often not be possible and so the nearest position with good signal and low PDOP should be selected. Sometimes this may need to be outside the plot. If the recorded position is not at the centre of the plot the horizontal distance and compass bearing to the recorded position from the centre of the plot should be noted along with the co-ordinates so they can be corrected at a later date. If another position not at the centre of the plot is recorded, it is important to note whether the distance and bearing are <u>towards</u> or <u>away</u> from the plot centre.

**4.3 How many positions to record and what to do with them:**
Although one set of position co-ordinates is theoretically sufficient there are enough possibilities for error at forested NVS plot locations to warrant taking a few seconds longer and collecting several sets of positions, which can then be averaged. In practise more than 3 sets at an open location will ensure an accurate fix, while the more difficult the vegetation cover the more positions should be recorded. In tall closed-canopy forest amongst mountains, most of the unquantifiable error sources previously mentioned will be operating (few satellites, poor PDOP, multi-pathing). To ensure a useful fix is taken and to allow for some of the error to be overcome by averaging, prudence and experience suggests at least 20 and up to 100 sets should be recorded if at all possible. It may be easier to spend an extra 2 minutes logging 100 extra positions at 1 second intervals than to get back to the plot site again! Some GPS receivers will allow averaging at the time when recording a set of positions as a 'Waypoint' or 'Mark' - see 3.3.1, and a plot name or label can be added. Alternatively the GPS receiver will assign a waypoint name to the saved data and this can be noted along with the coordinates on the plot sheet.

If several plots are to be visited over a relatively short time, recorded plot positions can be safely stored in the GPS and downloaded at the earliest opportunity back at a base. Otherwise, plot co-ordinates and system (e.g. NZMG) can be noted from the screen onto the plot sheet in the field (remembering that if co-ordinates are in

Latitude/Longitude they should be noted to two decimals). If co-ordinates are in NZMG the full 7 figure easting and northing should be noted on the plot sheet, the receiver type, and whether the position fix is averaged or not. These details will help plot relocation teams in the future to access accuracy associated with the coordinates.

### 4.3.1 What is the difference between Positions and Waypoints?:

Some confusion exists over use of the terms 'position' and 'waypoint' in the GPS context. Single positions recorded by GPS consist of x, y, z, and time co-ordinates and may be part of a point, a line, or a polygon boundary. Raw position data is normally used in survey or mapping applications. Waypoints, or Marks on some model receivers, and used for navigation purposes are created from position fixes at a point where one or more positions are averaged, and a label or name attached. Navigation is normally to, from, or between waypoints. Some surveying- or mapping-oriented GPS receivers need positions to be saved as or converted to waypoints to allow future navigation.

### 4.4 What if I can't get a fix at the plot?:

If insufficient SVs are available for a fix then often a wait for a short while may result in new SVs coming into 'sight' over the horizon. Some brands of GPS software allow 'planning' utilities to be run which will display times of limited SV availability ahead of fieldwork, which helps to identify days or times of day when GPS use will be restricted. Some receivers also display available SVs, their compass direction, and height above horizon which can be used to decide which way to go in the field to pick up more SVs.

There will be times and places for which it will be very difficult to get a fix at a plot. In those instances the best advice is to fix a point at the nearest position for which reception <u>can</u> be achieved, and measure a horizontal range and bearing between them using a tape or hipchain and compass. Co-ordinates for both the nearest point and the plot can be derived and future relocation can be directed towards either. Again, it is very important to note whether the range and bearing are away from or towards the plot.

## 5. Navigation to NVS plot positions using GPS:

Relocation of permanent plots in the field using previously recorded co-ordinates is a relatively straight-forward procedure hampered only by the same signal obstruction limitations discussed above. All GPS co-ordinates are in a horizontal plane so distances given on the screen are slope-corrected.

### 5.1 Directions:

All GPS receivers allow navigation to a previously recorded known Waypoint by use of a distance and bearing screen. The range in metres and bearing in compass degrees (most will allow configuration in True or Magnetic) are displayed and indicate the direction and distance to go. If travelling through forest or other obstructions the signal will come and go, but pausing in clearings or on ridges will allow a check to be made on progress.

### 5.2 Choice of GPS receiver:

With a huge range of options available it is difficult to choose an appropriate GPS off the shelf, but use in relation to NVS plots has some particular requirements which make some models better than others. Compromise will be inevitable. It needs to be rugged and weather-proof with 12 channels and a good aerial to help with reception in difficult circumstances. Models which allow attachment of a larger external aerial will have definite advantages. In general they are relatively power-hungry tools so long battery life is useful. Some models have additional battery packs which give extended life.

Use of GPS models which have data-transferable communications ports allows plot co-ordinates to be loaded from a data file in the office before leaving for the field, or downloaded on return. Many of the lower-priced GPS receivers on the market only allow manual input of waypoints in Latitude/Longitude which may need to be converted from stored NZMG records. Any model which displays NZMG co-ordinates is useful, and it is best if the range and bearing screen displays distance to 0.001 km (1 m). Receivers which display to 0.01 km only get closer in 10 m steps which creates an additional inaccuracy to the position of the operator, over and above the inaccuracy inherent in the original fix being navigated towards and the current position coordinates of the receiver.

Sufficient storage of waypoints is not a problem for most modern receivers, but being able to average multiple positions to create a waypoint in the field is a great advantage which improves precision. Alternatively the receiver would need to be able to store files of recorded positions co-ordinates and have the ability to download files to software which averages positions back in the office. The ability to display available SVs, their bearing and angle above horizon is particularly useful when struggling with few SVs to get a fix.

## 6. SUMMARY

- Accurate position records for NVS plots are extremely valuable for spatial analyses, as well as plot relocation.
- Improved GPS accuracy resulting from removal of selective availability now greatly enhances the use of GPS for recording NVS plot positions and navigating back to them, and should be used at the earliest opportunity to fix plots.
- GPS will become even more useful in the future with planned additions to the satellite network.
- Mountain lands and forests are the most difficult environments in which to use GPS and so users need to be aware of limitations and the best ways to overcome them.
- The best way to get permanent plot co-ordinates is to record them by GPS on the plot in the field.
- If plot co-ordinates cannot be recorded on the plot, co-ordinates should be recorded at the nearest position that satellite reception can be found, and the distance and compass direction between them recorded.
- The best way to relocate a plot is to navigate by range and bearing using a GPS receiver.
- Appropriate GPS receivers to use in the NVS application should be rugged, multi channelled, have a good aerial, be able to upload/download data in the office, have

good battery life, be able to average positions to create waypoints, and display NZMG.

## 7. REFERENCES

Wiser, S.K.; Bellingham, P.J.; Burrows, L.E. 2001: Managing biodiversity information: development of the National Vegetation Survey Databank. New Zealand Journal of Ecology 25(2): 1-18.

**Appendix i: Glossary of abbreviations used in this document:**

| | |
|---|---|
| DOP | Dilution of precision |
| FOM | Figure of Merit |
| GPS | Global Positioning System |
| HAE | Height Above Ellipsoid |
| MSL | Height above Mean Sea Level |
| NVS | National Vegetation Survey Databank |
| NZMG | New Zealand Map Grid |
| SA | Selective Availability |
| SV | Space Vehicle |