Using Google Earth on World Bank Projects

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Contents

1 Introduction

The World Bank undertakes a variety of projects in different locations in its client countries. To date, the Bank has not taken full advantage of the opportunities offered by spatial referencing of data, *ie* expressing locations in terms of the latitude and longitude. While other referencing may change, for example political boundaries, distance along the road, *etc*., the spatial location stays constant.

Incorporating spatial data into Bank projects therefore offers a number of opportunities to the Bank:

- Data collected over the life of a project, from preparation through supervision to closing, will be consistently referenced making it much easier to confirm the benefits from the project.
- Sophisticated analyses using Geographic Information Systems (GIS) can be executed. For example:
  - The number of people living within a certain distance of an all weather road
  - Access to clinics, education, markets, *etc*.
  - Income distributions.
- Many clients are in the process of collecting spatially referenced data themselves and this could be integrated with Bank data, for example videos of roads.

In 2005 the EAP Innovation Fund approved funding for the development of a 'Spatial Implementation Management System'. The intent was to develop a tool that can be used by Bank Staff in the field during preparation and supervision for recording and monitoring issues. It would also help Bank staff and the clients to clearly document issues; and, optionally, the general public for viewing and reporting issues.

After the project started, Google Earth was released. This free application provides the ideal framework for using spatial data collected on Bank projects since it contains a three-dimensional model of the entire world, which is continually being enhanced and updated. Its .KML files are rapidly becoming an industry standard and are supported by a wide range of applications. The focus of the project therefore shifted into addressing two issues: (i) how to collect data in the field during the Bank's project preparation and supervision activities; and, (ii) how Google Earth can be used to manage and apply these data.

This report presents the final results from the project. It is divided into the following sections:

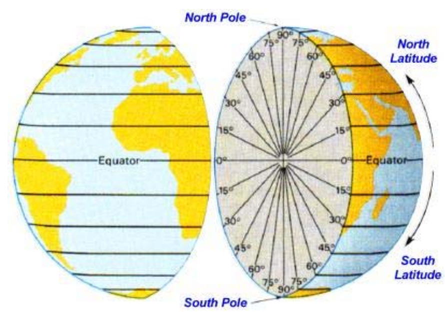
- **Introduction to Spatial Data:** An overview of spatial data and remote sensing;
- **Collecting Spatial Data:** Tools and techniques for collecting spatial data in the field;
- **Using Google Earth to Manage Spatial Data:** Using Google Earth as a data repository and manager; and,
- **Conclusions:** Conclusions and recommendations.

2 Introduction to Spatial Data

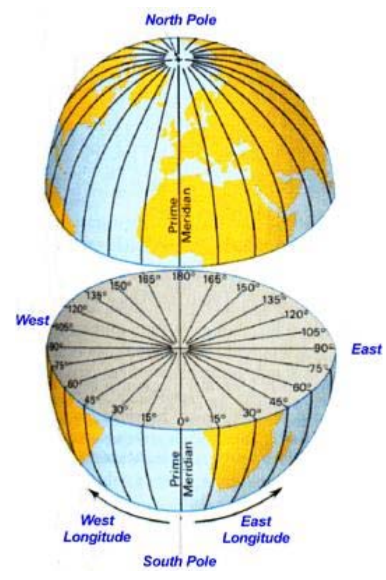
2.1 Introduction

Spatial data (also called geographic data) are data that define a location. With spatial data one can identify where an object is located, its shape, and its relationship to other geographical features. The basis for referencing all spatial data is the latitude and longitude as this is used in the grid system which locates any object on the earth's surface.

Since the earth is roughly a sphere, geometry is used to identify locations. Lines encircling the world east-west are called 'parallels' and are used to measure **latitude**. The latitude is the angular distance from the equator toward either pole, measured in degrees. Any point on the equator has a latitude of zero degrees, written 0^o. The North Pole has a latitude of 90^o north and the South Pole has a latitude of 90^o south. Every other point on the Earth has a latitude somewhere between 0^o and 90^o.



Latitude



Longitude

Source: UNESCO

'Meridians' are lines that extend halfway around the globe from the North Pole to the South Pole. Meridians are counted from the line that passes through Greenwich, in London England. The Greenwich meridian is also known as the 'prime' meridian and has a longitude of 0^o.

Meridians are used to measure **longitude** - that is, the angular distance east or west from the prime meridian. Like latitude, longitude is measured in degrees of a circle. From 0^o at Greenwich to 180^o, the meridian located halfway around the globe from the prime meridian. Between the prime meridian and the 180^o meridian are lines of west longitude (west of the prime meridian) and the lines of east longitude (east of the prime meridian).

The latitude and longitude are expressed in two formats: degrees/minutes/ seconds or decimal degrees. For example:

(40d 26' 21" N, 79d 58' 36" W) or (40.446195, -79.948862)

A full discussion on geographic coordinates and their conversion can be found at: http://en.wikipedia.org/wiki/Geographic_coordinate_conversion.

Since the earth is a sphere, and maps are 'flat', it is necessary to **project** the curved surface of the earth on the plane surface of a map. As can be appreciated, attempting to fit a curved surface onto a flat sheet results in a distortion of the true layout of the Earth's surface The most commonly known projection is the Mercator projection which is shown to the right. The lines of latitude and longitude form equal sized squares, but this leads to a distortion which is amplified as one goes further away from the equator. For example, the Mercator projection shows Greenland larger than Africa when in fact Africa is 13 times larger than Greenland.

There are many different types of projections and they are described in detail at: http://en.wikipedia.org/wiki/Map_projection. The key is to appreciate that when trying to integrate the data with spatial data from other sources, spatial data on a map may be affected by the projection used for the map.

Box 2.1: For More Information

An excellent online training course can be found at:

http://ioc.unesco.org/oceanteacher/resourcekit/Module2/GIS/Module/index.html

Additional training resources are linked to the World Bank's GIS Thematic Group page at:

http://gis.worldbank.org

Spatial data are stored in two formats;

- **Vector data:** point, line and polygon data representing objects. A point is stored as a single x,y (longitude, latitude) coordinate, a line as a pair of x,y coordinates, and a polygon as a set of x,y coordinates, each of which marks a vertex of the polygon; and,
- **Raster data:** data stored in rows and columns of cells, usually images in the form of satellite data, scanned data, and photographs.

There are a variety of techniques available for collecting spatial data:

- **GPS Surveys:** Data are collected using a global positioning system (GPS) receiver;
- **Digitizing:** Existing data, such as maps, are digitized (someone traces the lines) or scanned;
- **Aerial Photographs:** Photo interpretation of aerial photographs, usually stereoscopes, allow data to be captured in two and three dimensions; and,

- **Satellites:** Satellites use different instruments to collect raster data that can be further processed to identify objects and classes of interest, such as land cover.

In the context of this project the focus was on using GPS systems to measure spatial data, and to integrate the data with remote sensing data, such as satellite images, to contextualize the data.

2.2 Principles of GPS Measurement

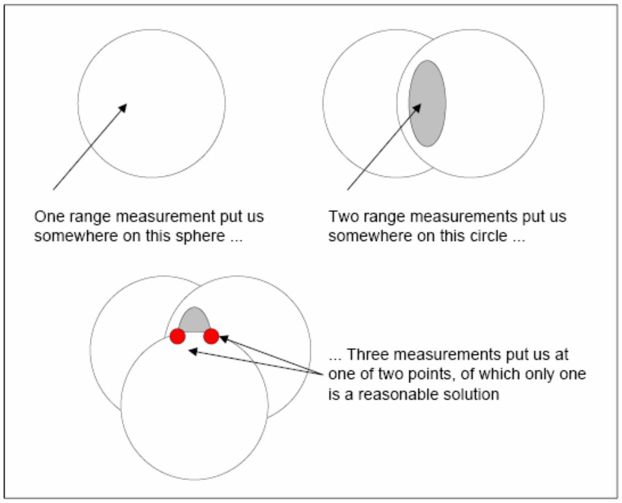
2.2.1 GPS Technology

The Global Positioning System (GPS) is a space-based satellite radio navigation system developed by the U.S. Department of Defense. There are a series of 24 satellites placed in six orbital planes about 20,200 km above the earth's surface. The satellites are in circular orbits with a 12-hour orbital period and inclination angle of 55 degrees. This orientation normally provides a GPS user with a minimum of five satellites in view from any point on Earth at any one time—assuming one has open view of the sky. The EU is in the process of developing Galileo which is their own version of GPS, and this should offer improved accuracy. There is also the Russian Glonass system, which has not been maintained so is not commonly used.

All systems work on a similar principle. Each satellite continuously broadcasts a radio frequency signal. The GPS receiver measures the time required for the GPS signal to travel from the satellite to the receiver antenna. The timing code generated by each satellite is compared to an identical code generated by the receiver. The receiver's code is shifted until it matches the satellite's code. The resulting time shift is multiplied by the speed of light to arrive at the apparent distance from the satellite (called a 'range' measurement).

Since the resulting range measurement contains propagation delays due to atmospheric effects, and satellite and receiver clock errors, it is referred to as a 'pseudorange'. Changes in each of these pseudoranges over a short period of time are also measured and processed by the receiver. These measurements, referred to as 'delta-pseudoranges' are used to compute velocity.

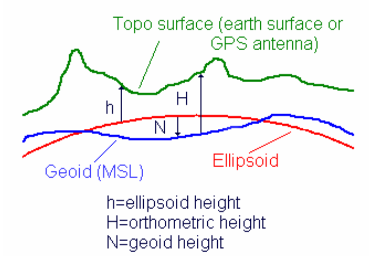
A minimum of four pseudorange measurements are required by the receiver to mathematically determine time and the three components of position (latitude, longitude, and altitude). The figure to the right shows how three satellites are used to establish position. This figure does not include the fourth timing satellite.



After the four range equations are solved, the receiver has estimates of its position and time. Similar equations are then used to calculate velocity using the relative velocities instead of pseudoranges. The position, velocity and time data are generally computed once per second.

2.2.2 The WGS84 Datum

GPS data are collected using what is called the WGS84 (World Geodetic System 1984) 'datum'. Modern cartographers refer to a lumpy, flattened ball called a 'geoid' to measure latitude, longitude, and altitude. The 'Earth Model' and reference points used to prepare a map are collectively called a datum. This is basically a three-dimensional Cartesian coordinate system and an associated ellipsoid, so that WGS84 positions can be described as either x,y,z Cartesian coordinates or latitude, longitude and ellipsoid height coordinates. The origin of the WGS84 datum is the centre of mass of the Earth and it is designed for positioning anywhere on Earth.



While the WGS84 datum is based on the centre of the earth, there are local datums which reflect local conditions and are therefore much more accurate. Errors of 300 m or more can arise if the wrong datum are used so if there are significant differences between GPS data and other information check the which datum was used.

2.2.3 The Accuracy of GPS Measurements

GPS measurements can be very accurate but the accuracy depends on the equipment used. Until 2000 there was a random error in the GPS measurements, called 'Selective Availability' which meant that the 95% confidence interval for the data was +/- 100 m. However, since selective availability has been disabled, the 95% confidence intervals are now on the order of +/- 8 – 10 m. For many applications this is sufficient accuracy, although it must be recognized that 5% of the readings could be significantly worse than 10 m. The latitude and longitude measurements are the most accurate; the height the least.

Survey grade GPS receivers will have sub-meter accuracy whereas consumer grade receivers are typically on the order of 5+ meters. Differential correction can be used to improve the accuracy. This uses data collected at other locations to either post-process the GPS data or transmit a real-time correction signal.

Figure 2.1 illustrates the results of differentially correcting data from a low-cost Trimble Pocket Pathfinder GPS receiver. When compared to the actual position the RMS error with the uncorrected data was in the range of 1.23 – 6.32 m, which compared to a range of 1.05 – 1.58 m for the differentially corrected data. It will be noted, however, that the accuracy varied significantly with both methods over the course of the day as different satellites moved in and out of view.

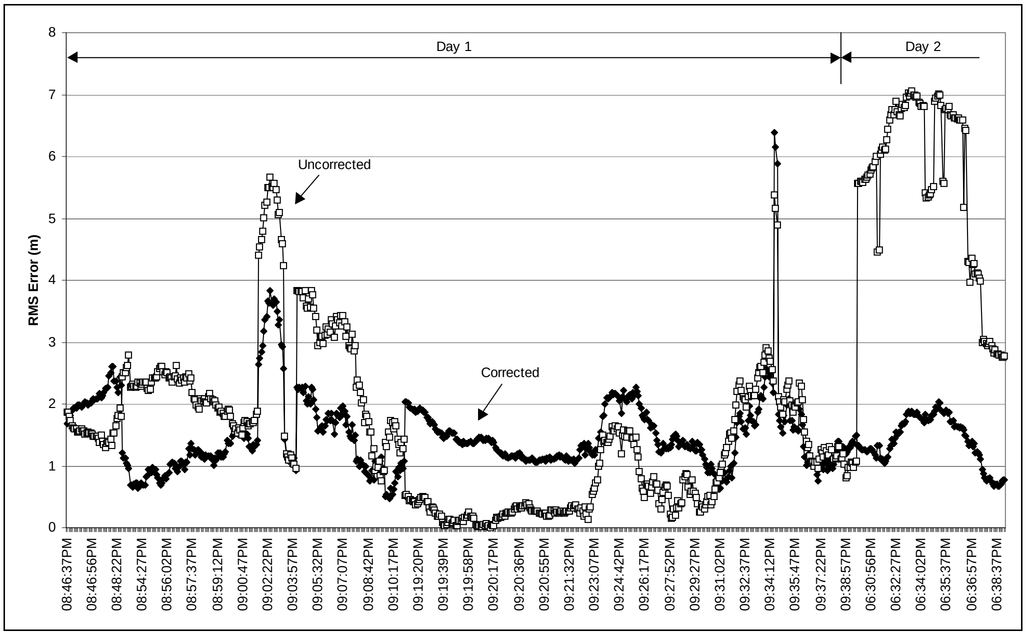


Figure 2.1: Example of Variations in Accuracy Over Time

Figure 2.2 is an example of what can be achieved with a sub-meter GPS receivers, showing the GPS data superimposed on an aerial photograph from Apia, Samoa.

Figure 2.2: GPS Measurements and Aerial Photograph from Apia Samoa

2.3 Satellite Images

2.3.1 Introduction

Satellite images are available from a range of sources with different resolutions. Figure 2.3 from Infoterra (www.infoterra-global.com) shows images at different resolutions, and how data from different sources can be combined to enhance images.

2.3.2 Commercial Sources

There are a variety of commercial sources for satellite data. Different satellites collect different types of data, to different resolutions. Among the sources are:

Satellite	Resolution (m)	Satellite	Resolution (m)
ASTER	15 - 90	Landsat	15 - 30
ENVISAT	10 – 30	Quickbird	0.61 – 2.88
EROS	1.8	Radarsat	8 – 100
ERS	25	SPOT	5 - 20
IKONOS	1-4	TerraSAR-X	1
IRIS	15 - 90		

The cost of images is proportional to the resolution and so there is often a compromise between what is desired and what can be afforded.

Satellites collect data in different bands. These are:

- **Visible Blue:** Designed for water penetration, making it useful for coastal water and lake bathymetry and sediment load mapping. Also useful for differentiation of soil from vegetation, and deciduous from coniferous flora; it is lower for vegetation and coniferous forest.
- **Visible Green:** Measures visible green reflectance peak of vegetation for vigor assessment.
- **Visible Red:** Discriminates between different types of vegetation.
- **Near Infrared:** Identifies healthy vegetation and delineates water bodies. Short wave Infrared: Indicative of vegetation moisture content and soil moisture. Can also identify rocks and hydrothermal altered zones for mineral exploration.
- **Thermal Infrared:** For thermal mapping activities such as heat intensity, vegetation and crop analysis, thermal pollution.

Figure 2.4 shows the different bands collected by different satellites.

By combining information from different satellites and different bands on obtains an enhanced overall image. This can be observed from the images in Figure 2.3 where some examples show combination effects.

The easiest way to obtain satellite data is from a commercial consolidator. They will consider the data requirements, available budget and assemble an appropriate package. It should be noted that it can take several months to acquire the images, depending upon what is required.

Landsat ETM+, 30 meter resolution, false color infra-red.

Landsat 7 ETM+, 15 meter resolution, natural color. merged with the 30 meter color bands.

Landsat 7 ETM+ data merged with 10 meter SPOT Pan black and white data to produce a 10 meter color dataset.

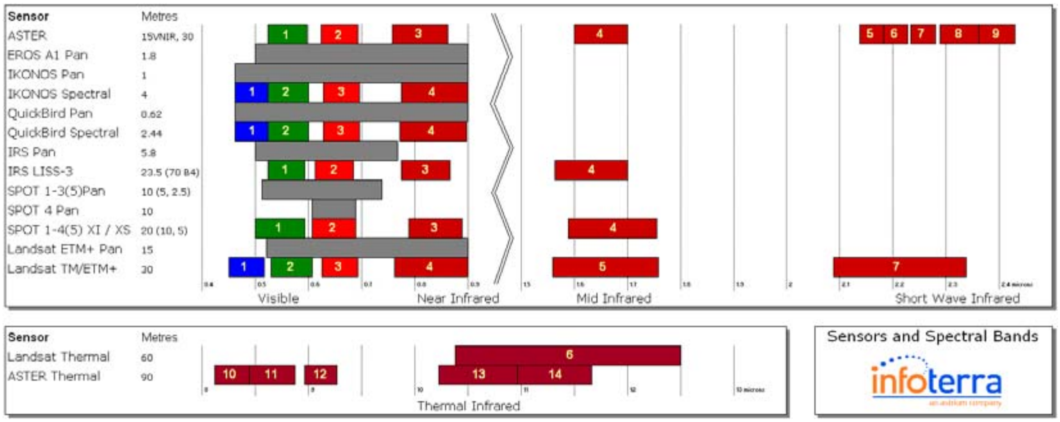
Landsat 7 ETM+ data merged with 6 meter IRS Pan black and white data to produce a 6 meter color dataset.

Ikonos 4 meter natural color image. Can be merged with 1 meter Ikonos Pan data to provide a very high resolution color dataset.

QuickBird 62 centimeter data over the port of Abu Dhabi. This is a merge of the black and white 62cm data with the lower spatial resolution color data.

Source: www.infoterra-global.com

Figure 2.3: Examples of Different Satellite Resolutions



Source: www.infoterra-global.com

Figure 2.4: Satellite Bands

2.3.3 Google Earth

Google Earth (GE) is described at: http://en.wikipedia.org/wiki/Google_Earth. GE is an application which is free to use and is supported by satellite images and a three-dimensional terrain model for the entire world. With accuracies typically of 15 m or better, it is an ideal platform for using spatial data. The features of GE are:

- The data are stored in WGS84 datum which means that it is not necessary to process GPS data prior to loading to GE;
- Resolution generally on the order of 15 m;
- Most data are less than 3 years old. They are sourced from different providers; and,
- High resolutions (1 m or better) available in some areas, such as US cities. More high resolution data is being provided over time.

As an illustration of the different resolutions available in GE, Figure 2.5 contrasts the cities of Wuhan and Beijing. In Wuhan, it is not possible to identify minor roads with any accuracy; in Beijing individual vehicles are visible. Thus, depending upon the requirements additional data may be required beyond that available in GE.

GE is discussed in detail in Section 4.

2.4 Automatic Analysis of Satellite Image Data

There are a variety of automatic analyses that can be done with satellite image data. The industry is rapidly developing as new technologies become available and the cost of satellite images decreases.

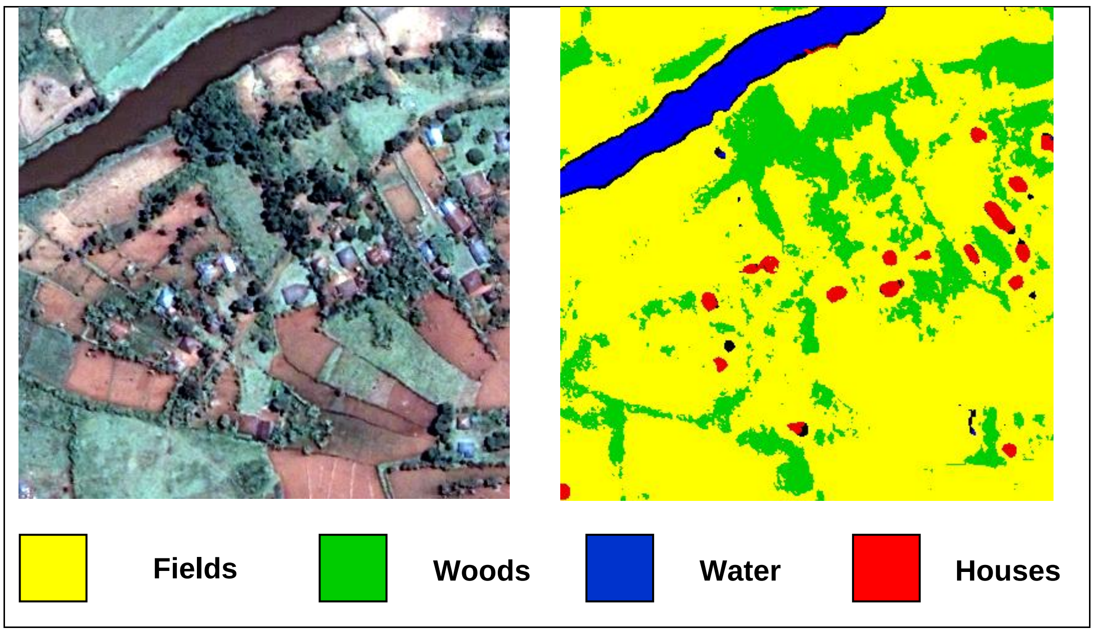
As mentioned earlier, satellites collect data with different bands. Figure 2.6 shows an example how spectral classification can be used to identify features from an image[1].

[1] Presented by Vijay Modi from Columbia University to the World Bank, January, 2006.

Wuhan – 12,052 ft

Beijing – 1,397 ft

Figure 2.5: Comparison of Google Earth Image Resolutions from China



Source: Modi (2006)

Figure 2.6: Example of Spectral Classification

Of interest to many is the location, and extent, of the road network. Under certain circumstances this data can be automatically extracted from images. The left image in Figure 2.7 shows data from an IKONOS satellite that was automatically analyzed to identify road sections based on the pixels[2]. Using this approach, it proved possible to reliably extract road centerlines for an urban area (see the right image).

[2] Finding Road Networks in IKONOS Satellite Imagery. Available for download from http://www.spaceimaging.com/whitepapers_pdfs/2003/Finding%20Road%20Networks%20in%20IKONOS%20Satellite%20Imagery-ASPRS%202003.pdf

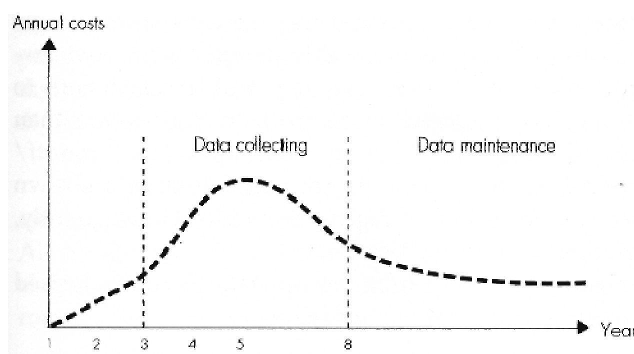
Source: Space Imaging

Figure 2.7: Examples if IKONOS Road Centerline Extraction

Depending upon the type of data of interest, it may be practical to extract it automatically from satellite images. With regard to roads, it is most reliable in urban areas where accuracies of over 85% have been reported. For rural roads, especially unpaved ones, it is much more difficult.

2.5 Issues With Spatial Data

Data are expensive to collect and to maintain once collected. While data costs peak during the data collection period, the data need to be maintained which requires an ongoing commitment and investment (see the figure to the right from UNESCO). For example, about 5% of a country's road network changes each year and unless the data are maintained the network representation will soon become outdated.



There are many sources of GIS data and the tendency is to assume that data provided are 'correct'. However, it has been found more often than not that data have some problems. When using data from other sources it is therefore important to ask a series of questions such as:

- How recently were the data collected?
- Who collected it?
- How accurate are positional and attribute features?
- Does the data seem logical and consistent?
- Is the data relevant to the project at hand?
- If the data were digitized from some source:

    - In what medium was it originally produced?
    - What is the areal distribution of the data?
    - To what map scale was the data digitized?
    - What projection, coordinate system, and datum were used in maps?
- How was the data checked?
- Why was the data compiled?
- What is the reliability of the provider?

As data becomes more widely shared the concept of **metadata** is becoming more important. Metadata describes the history and accuracy of the data set, and there are a variety of metadata standards available. It is important that each dataset has metadata provided for it.

3 Collecting Spatial Data

3.1 Introduction

This section describes the results of tests to collect spatial data in the field. The focus was on how to collect data for project preparation and supervision in a low-cost, simple but effective way. Three approaches were considered:

- Hand-held GPS receivers;
- Personal Digital Assistants; and,
- Digital photography with GPS.
- Each of these are discussed individually after the general data needs are described.

3.2 Data Needs

There are two types of spatial data that are commonly collected:

- **Point data:** This is data pertaining to a single point, such as a building; and,
- **Continuous data:** This is data which is a set of continuous points, such as a road.

In the context of project preparation and supervision, most data will be point data. This is because we are interested in the location of single items (*eg* environmental and social issues). This point data would be collected over the course of the project. Continuous data, on the other hand, is often only collected once, such as when the location of a project road is defined.

An important element of quality control of data collection is to ensure that standard terms are employed. For example, a location with excessive noise could be described as ‘high noise’, ‘bad noise’, or ‘noisy’ by different people. By using drop-down menus when collecting data instead of free-form entry, consistency is guaranteed.

Based on interviews with Bank staff, the list of issues in Table 3.1 was established. When an issue needs to be spatial referenced, the ‘Area’ abbreviation in parentheses () is used with the actual issue, for example:

SE – Air Pollution
SR – Property Replacement
E – Design Issue

In addition to the issues, two other sets of data were identified as required:

- Project ID; and,
- Name of person collecting the data.

Table 3.1: Issues to be Spatially Referenced

Area	Issue
Safeguards – Environment (SE)	Air Pollution Dust Pollution Noise Pollution Property/Land Damage Water Pollution Other
Safeguards – Resettlement (SR)	Compensation Level Completion of House Demolition Completion of Land Acquisition Property Replacement Other
Engineering (E)	Construction Quality Design Issue Safety Issue Other
Inventory (I)	Clinic/Hospital Casting Yard Construction Camp Materials Storage School Other
Other	Other

3.3 Handheld GPS Receivers

There are a variety of different types of GPS receivers on the market, ranging from small handheld consumer units to larger systems which are carried in backpacks. The accuracy of the receivers varies significantly with cost. Using a handheld consumer grade GPS costing on the order of US$ 200 the accuracy is at best 5-10 m; with a US$ 10,000 system such as Starfire the accuracy is at the cm level. The two main companies supplying consumer grade models, which have more than sufficient accuracy for the Bank's needs, are Gamin and Magellan. Google Earth Pro will import data directly from both these units.

The testing was done using a Garmin e-Trex Legend which cost US$ 170. This unit was selected because (i) Garmin is more widely supported by data processing applications than Magellan; (ii) it had the capacity to store a moderate amount of route data; and, (iii) as 12 parallel channel GPS receiver continuously tracks and uses up to 12 satellites to compute and update the position which should give good results.

The Legend was used both in handheld mode and with a special automotive bracket. The latter consists of a suction cup with mounting system for affixing the GPS receiver to the vehicle's window. This was a very effective way of collecting the data when in the field, especially on rough and curvy roads.

The system can store point or continuous data. Point data, called 'Waypoints', are stored by pressing the unit's thumb stick and defining a description of the point. With the e-Trex Legend up to 1,000 waypoints can be stored. The entering of the point data description is somewhat tedious since there is no keyboard to enter the data; each letter must be highlighted and selected.

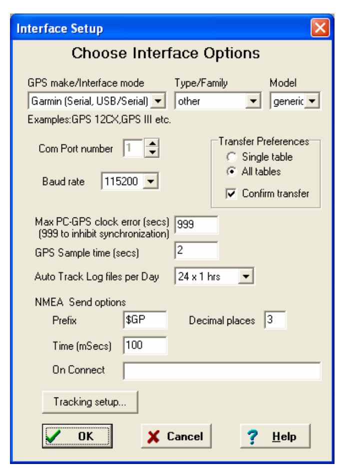
For continuous data the user must define how the data is sampled. The sampling is set under **Main Menu|Tracks|Log Setup**. The default settings are shown to the right. The data can be on a time basis (every *n* seconds) or a distance basis (every *n* meters/miles). For the purpose of testing a distance basis was generally used. With its 8 MB of memory, the Legend can store about 10,000 observations before the data need to be downloaded. This can be used as a guide to the sampling interval when taking continuous measurements.

Box 3.1: Downloading and Converting Data

There are a large number of different GPS receivers on the market with different data formats. The most comprehensive effort for downloading and converting GPS data between different applications is 'GPSBabel' found at:

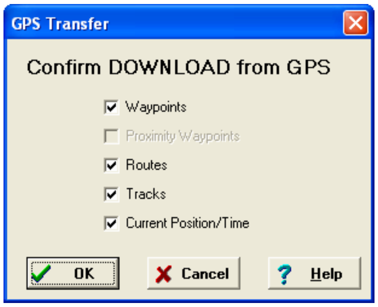
http://www.gpsbabel.org/

If you want to download and process GPS receiver data this is the best place to start looking for solutions.



The Legend has a RS-232 serial cable for downloading the data to the computer. This is potentially a problem as many newer computers do not have an RS-232 port. Google Earth Pro has the facility to import Garmin data, however, it was found that the program GPS Utility (www.gpsu.co.uk), a US$ 55 application was more flexible as it allowed for the data to be manipulated and combined into a individual files.

To interface GPS Utility with the Legend the interface needs to be set up. This is done by selecting **GPS|Setup** and selecting the 'Garmin' as the receiver. Once this is done you select **GPS|Connect** to connect to the receiver. If successful, the software displays the message 'Connected to e-Trex Legend Software Version 3.70' at the bottom of the screen.

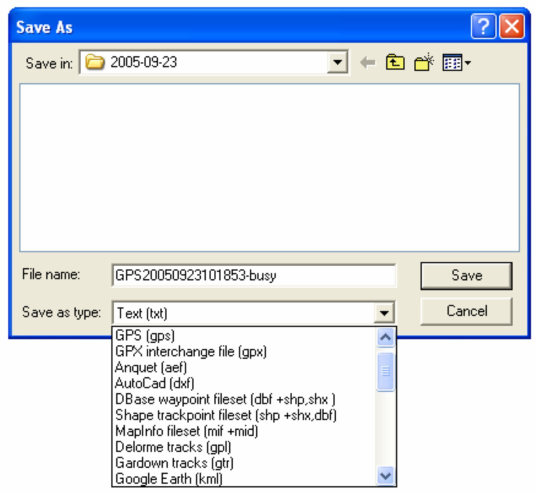


Selecting **GPS|Download All** opens the screen to the left. This allows you to select what data to download. Normally one downloads everything.

Once the data are loaded into GPS Utility they should be checked and any readings not required should be deleted. This is done by using the **Filter** option, or manually selecting records.

The data are then converted to another format by selecting **File|Save As**. The three most useful formats are:

- **GPX Interchange File:** This is a standard file for exchanging GPS data and can be read by many applications;
- **Shape Trackpoint File:** Suitable for being read by ArcGIS; and,
- **Google Earth KML File:** A .KML file which can be read directly by Google Earth.



An alternative approach is to use the free web based program 'GPS Visualizer' (http://www.gpsvisualizer.com/map?form=googleearth). This takes a GPS file and creates a GE .KML file.

Box 3.2: Using the Handheld GPS System in the Field

It was found that the most convenient way of using the units was to leave them turned off until the site was reached. By going to the start of the site, turning the unit on, and then traveling to the end of the site before turning the unit off, a single line was established. During the data processing stage this could be easily identified and saved into a unique file for that section.

The following are the conclusions with respect to using handheld GPS units:

- The units are very simple to use, especially for continuous data collection. With their low cost, they are ideal for using for field data collection.
- The optional protective case should be used with the unit to prevent damage; the car mount is essential when doing field surveys measuring road alignments.
- The batteries last up to about 17 h and, even if replaced, any data in the unit are retained. For extended surveys the optional cable which powers the unit from the cigarette lighter should be used.
- The RS-232 download cable could be a problem since not all computers have an RS-232 port. Other more expensive models have a SD Card for storing data which would be a better approach to use.
- The accuracy of the Legend is equivalent to a PDA with a GPS receiver.
- The time to start the unit and get satellite fixes can be long, well in excess of the 'cold start' time given in the Legend specifications.

3.4 Personal Digital Assistants (PDAs)

3.4.1 Introduction

PDAs are handheld computers. There are essentially two standards of PDA:

- Windows Pocket PC Based; or,
- Palm OS Based.

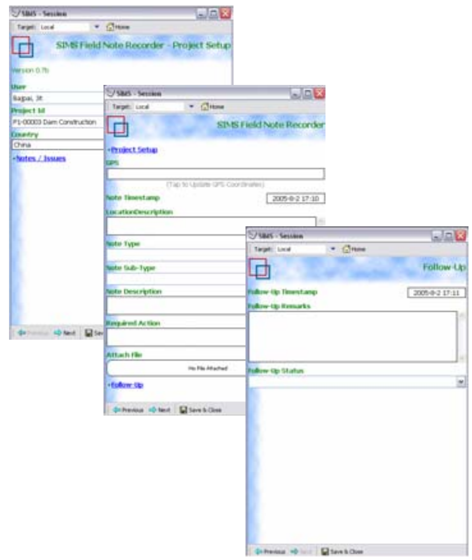
From a functional point of view, there are relatively few differences between the two standards. When it comes to GPS data recording, the Dell Pocket PC systems were considered to be more appropriate since they contained a CF Card slot, which various GPS receivers could be connected to, as well as easy expansion through an SD Card. A Dell Axim X5 was therefore used in the project with a Haicom HI-303S CF Card GPS Receiver. The cost of the PDA with GPS was < US$ 500.

Three approaches were tested for collecting the data:

- A custom application written using 'Pocket PC Creations'. This software allows for the rapid development of data entry forms which will store the spatial data against the user entered data;
- An off-the-shelf applications called 'GPS Dash' and 'Tom Tom Navigator' which could store data continuously; and,
- An off-the-shelf application called GPS2GoolgeEarth which is designed to record data for Google Earth.

3.4.2 Pocket PC Creations

The Pocket PC Creations (PPCC) application was developed using the PPCC environment. This is a very simple to use framework where users can custom create data entry pages, each with customized fields.

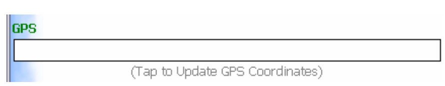


The PPCC Data Entry s split into "Pages". Every new session has a number of pages, which can be navigated to by tapping the "Next" or "Previous" buttons at the bottom of the screen.

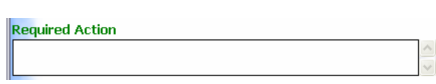
The system was designed with three types of data entry:

- **Drop-Down Lists** which permit selection of choices set up in pre-defined lists as seen below.

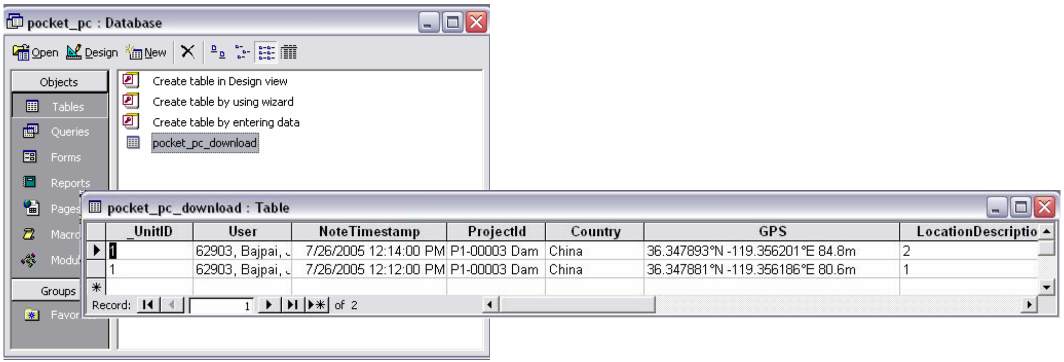
- **GPS Coordinates** which are automatically updated from the GPS (if attached). Tapping on the field should store the current GPS location in SIMS.



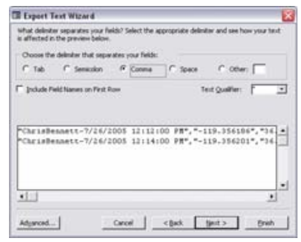
- **Free-Format Data Entry boxes** permit entry of free-format data from the software keyboard on the Pocket PC.



When data are entered the GPS co-ordinates for the record are stored. After the survey, the data are synchronized to a notebook computer and viewed in Microsoft Access.



From Access the data can be exported as a comma delimited file and then imported to a GIS.



The software was found to work fine and it was extremely flexible for customizing to the exact data collection format. The main disadvantages to using it were:

- it could only record point data so if continuous data were required a second system would need to be used; and
- the cost for a large number of licenses would be excessive when compared to other options, even as far as writing a custom application.

The software is ideally suited for proof-of-concept or situations where there are numerous different types of data collection forms to be used since these can be quickly and easily developed.

3.4.3 GPS Data Logging Software

There are a number of GPS data logging programs on the market. These simply record the data transmitted by the GPS receiver into a log file as it is received, usually at 1 s intervals. The files are in NMEA 0183 format which can be processed for importing into a GIS or Google Earth.

Two applications were tested. GPS Dash is a low cost (< US$ 30) application. GPS Log is a program supplied with TomTom Navigator. Both had similar results, the only difference being the interface. Figure 3.1 shows the screens from GPS Dash.

Figure 3.2 shows typical output from a GPS data logging program, here TomTom navigator. After four lines of headers the GPS data there is a series of NMEA strings.

It is necessary to convert the data from any data logging program into a suitable format for reading by a GPS or Google Earth. The program GPS Utility (www.gpsu.co.uk) that was used for downloading the Handheld GPS data was found to be ideal for this task. It is able to read a range of different input file formats and convert the data to a variety of different outputs. An additional benefit was its ability to combine several data logging files into a single file. Figure 3.3 is an example of the .PGL data from Figure 3.2 in GPS Utility.

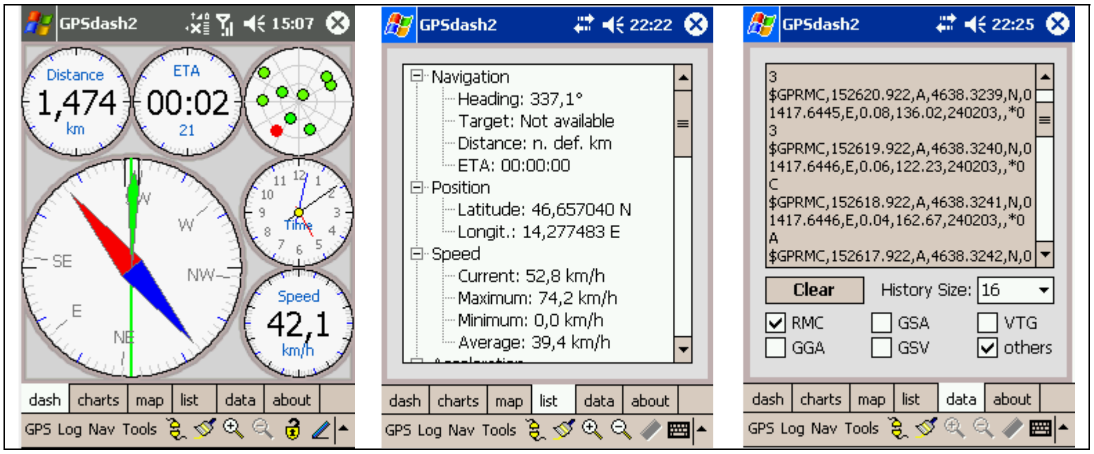
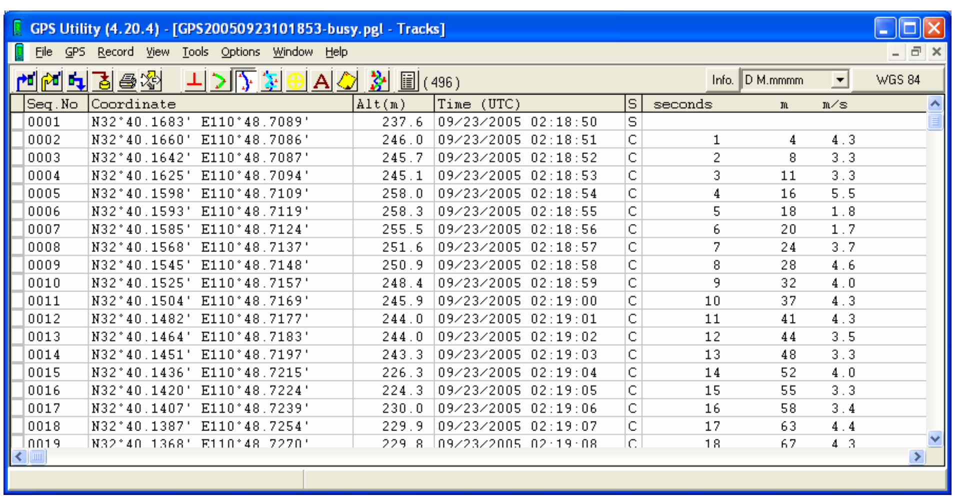


Figure 3.1: Example of GPS Dash Software

```
$PTOM101,PocketPC,Dell Axim X50,2577,4.21*5C
$PTOM102,GPS Engine,378,TomTom Navigator GPS,CF_CARD GENERIC*67
$PTOM103,050923,021853.000,050923,101853.000*37
$PTOM104,\SD Card\GPS Log\GPS20050923101853-busy.pgl*40
GLL,3240.1703,N,11048.7081,E,021849.748,A,A*56
$GPRMC,021849.748,A,3240.1703,N,11048.7081,E,7.43,158.23,230905,,,A*61
$GPVTG,158.23,T,,M,7.43,N,13.8,K,A*3A
$GPGGA,021850.748,3240.1683,N,11048.7089,E,1,06,1.5,237.6,M,,,,0000*0B
$GPGLL,3240.1683,N,11048.7089,E,021850.748,A,A*5F
$GPRMC,021850.748,A,3240.1683,N,11048.7089,E,7.94,164.59,230905,,,A*60
$GPVTG,164.59,T,,M,7.94,N,14.7,K,A*3A
$GPGGA,021851.748,3240.1660,N,11048.7086,E,1,06,1.5,246.0,M,,,,0000*08
$GPGLL,3240.1660,N,11048.7086,E,021851.748,A,A*5C
$GPRMC,021851.748,A,3240.1660,N,11048.7086,E,6.43,160.79,230905,,,A*6E
$GPVTG,160.79,T,,M,6.43,N,11.9,K,A*3C
$GPGGA,021852.748,3240.1642,N,11048.7087,E,1,06,1.5,245.7,M,,,,0000*0E
$GPGLL,3240.1642,N,11048.7087,E,021852.748,A,A*5E
```

Figure 3.2: Example of GPS Data Logging Output



Seq.No	Coordinate	Alt(m)	Time (UTC)	S	seconds	m	m/s
0001	N32°40.1683' E110°48.7089'	237.6	09/23/2005 02:18:50	S			
0002	N32°40.1660' E110°48.7086'	246.0	09/23/2005 02:18:51	C	1	4	4.3
0003	N32°40.1642' E110°48.7087'	245.7	09/23/2005 02:18:52	C	2	8	3.3
0004	N32°40.1625' E110°48.7094'	245.1	09/23/2005 02:18:53	C	3	11	3.3
0005	N32°40.1598' E110°48.7109'	258.0	09/23/2005 02:18:54	C	4	16	5.5
0006	N32°40.1593' E110°48.7119'	258.3	09/23/2005 02:18:55	C	5	18	1.8
0007	N32°40.1585' E110°48.7124'	255.5	09/23/2005 02:18:56	C	6	20	1.7
0008	N32°40.1568' E110°48.7137'	251.6	09/23/2005 02:18:57	C	7	24	3.7
0009	N32°40.1545' E110°48.7148'	250.9	09/23/2005 02:18:58	C	8	28	4.6
0010	N32°40.1525' E110°48.7157'	248.4	09/23/2005 02:18:59	C	9	32	4.0
0011	N32°40.1504' E110°48.7169'	245.9	09/23/2005 02:19:00	C	10	37	4.3
0012	N32°40.1482' E110°48.7177'	244.0	09/23/2005 02:19:01	C	11	41	4.3
0013	N32°40.1464' E110°48.7183'	244.0	09/23/2005 02:19:02	C	12	44	3.5
0014	N32°40.1451' E110°48.7197'	243.3	09/23/2005 02:19:03	C	13	48	3.3
0015	N32°40.1436' E110°48.7215'	226.3	09/23/2005 02:19:04	C	14	52	4.0
0016	N32°40.1420' E110°48.7224'	224.3	09/23/2005 02:19:05	C	15	55	3.3
0017	N32°40.1407' E110°48.7239'	230.0	09/23/2005 02:19:06	C	16	58	3.4
0018	N32°40.1387' E110°48.7254'	229.9	09/23/2005 02:19:07	C	17	63	4.4
0019	N32°40.1368' E110°48.7270'	229.8	09/23/2005 02:19:08	C	18	67	4.3

Figure 3.3: Processing of GPS Data Logging

The two PDA data collection programs were found to work very well. The only major problem was their inability to store point data.

3.4.4 GPS2Google Earth

GPS2Google Earth (www.s-gps.com) is a simple PDA application costing only US$ 19 designed to create Google Earth .KML files. It logs data from the GPS receiver continuously, at user defined sampling intervals (see Figure 3.4), and can also create point data which are called 'Placemarks'. The user can enter a description of the placemark data using the PDA stylus and virtual keyboard. Once data are collected, all data are exported to a .KML file using the export function. There are no options to save the data into other file types.

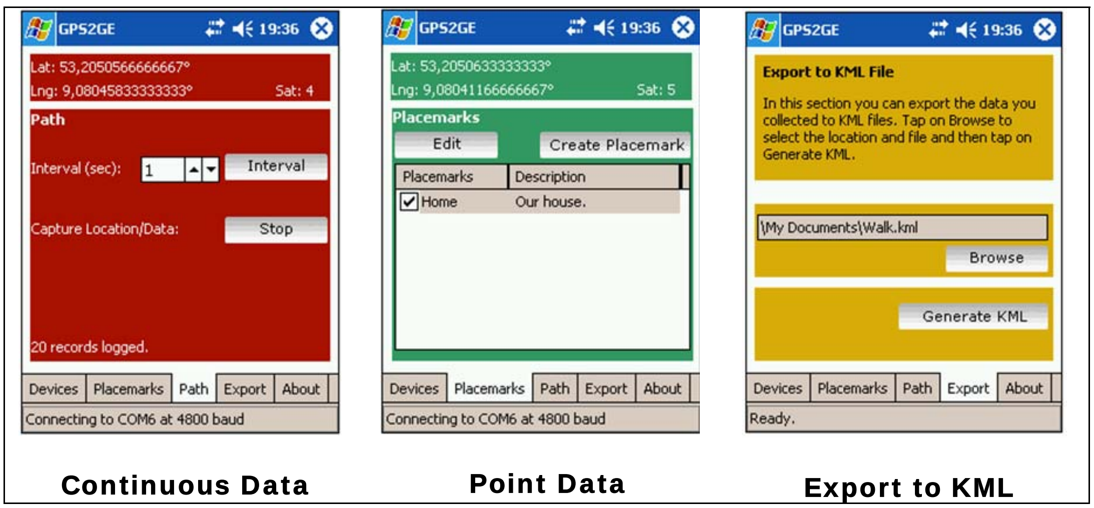


Figure 3.4: GPS2Google Earth Screens

The software was very simple to use and worked well. Both its cost and simplicity are attractive. Some enhancements to the software would make it even better, including:

- The GPS setup must be done every time the software is started. This quickly becomes tedious and is a potential source of problems since new users may not enter the correct data.
- There is no capacity to have drop-down menus for quickly entering descriptions of placemarks and to ensure data consistency.
- It is difficult to manage data when it is stored in a single file. Separate files should be created with a unique date and time stamp representing each time a new session is started.

The above suggestions should not detract from the software. It is a very useful PDA data collection application.

3.4.5 Conclusions on PDA Systems

PDAs are a good way of collecting field data. On the basis of the testing of the different options the following are the conclusions:

- **PPCC:** This application allowed for the rapid development and testing of the concept of GPS data collection. In that regard it was ideal for the project. However, it is not appropriate as a long-term solution for the following reasons:
  - The system is moderately difficult to install and maintain on PDAs and requires a fairly good level of computer skills to get working correctly.
  - It does not allow for the collection of point and continuous data at the same time.
  - The licensing costs of about US$80 per license can become costly if looking at widespread use.
  - It requires Microsoft Access as the back-end database which is an additional cost.
- **GPS Dash / GPS Log:** These applications are low cost, very simple to use and have a good user interface. They record at 1 s intervals the GPS co-ordinates, displaying the number of satellites and other data. They produce an NMEA 0183 output file (usually a .PGL) which is industry standard and can be read by other programs. They are well suited to collecting continuous data, but not for point data.
- **GPS2Google Earth:** This application is low cost, very simple to use and meets the requirements for data collection. It records both point and continuous data so produces both types of files required for data collection. With slight modifications it would be ideal for PDA spatial data collection.

Box 3.3: Using the PDA GPS System in the Field

Due to their relatively short battery life, at least compared to the 17h for a hand-held GPS unit, it is advisable to operate the PDA with an automotive power cable. This ensures that it is continuously recharged. The units should also have a protective case, such as a Rhinoskin, as they are subjected to extreme conditions.

3.5 GPS and Digital Photographs

3.5.1 Introduction

Digital photos, in the form of JPEG (.jpg) files, can be provided with spatial data (latitude, longitude and elevation) in the photograph headers. When imported to a GIS or Google Earth, a marker is placed at the location where the photograph is taken. There are two ways that spatial co-ordinates can be associated with images:

- Linking the image taken with any digital camera to GPS data based on the time when the photo was taken; or,
- Using a camera with an integrated GPS receiver.

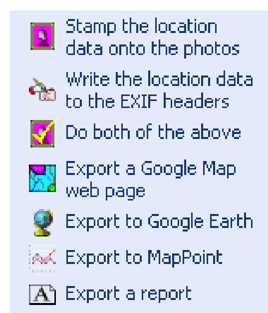
Each of these approaches were tested in the project and the results are described in the following sections.

3.5.2 Linking Digital Photos to a GPS Coordinates

While it is possible to manually insert the latitude and longitude into a .JPG file header, this is not a straight forward process. It would also be cumbersome since one would need to first manually record the spatial location and then insert these data to the header.

It is much easier to use dedicated software to do this, and there are several applications available. For this project the software RoboGeo v 3.0 (www.robogeo.com) was used. This application costs US$ 23 for personal use; US$ 50 for a single commercial license.

The software is very straight forward to use. One selects the folder with the digital photos and then the file which contains the GPS data. The software then assigns the GPS co-ordinates to the photos by matching the time stamps. Figure 3.5 is an example of the RoboGeo output after geo-referencing some images.



Once the images have been geo-referenced you can perform several options. The most useful are to (i) write the location data to the .JPG headers and (ii) to export the data to Google Earth.

With the latter the software creates a Google Earth .KMZ file which is a compressed file containing all the photos. For displaying in Google Earth it was found that a maximum size of 450 pixels gave a good compromise between the size of the image and the available space for displaying. This value is entered during exporting as shown in Figure 3.6.

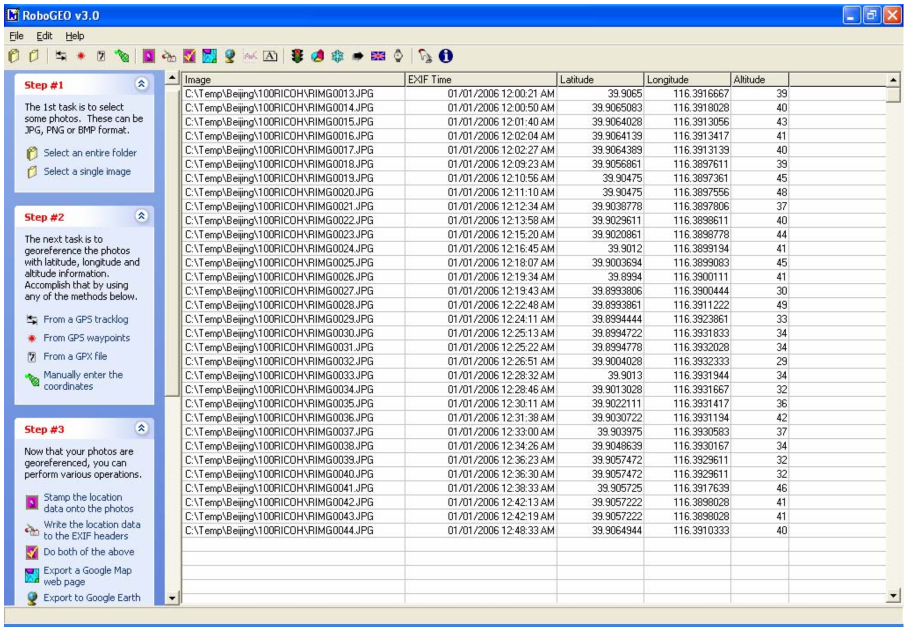


Figure 3.5: Example of RoboGeo after Geo-referencing

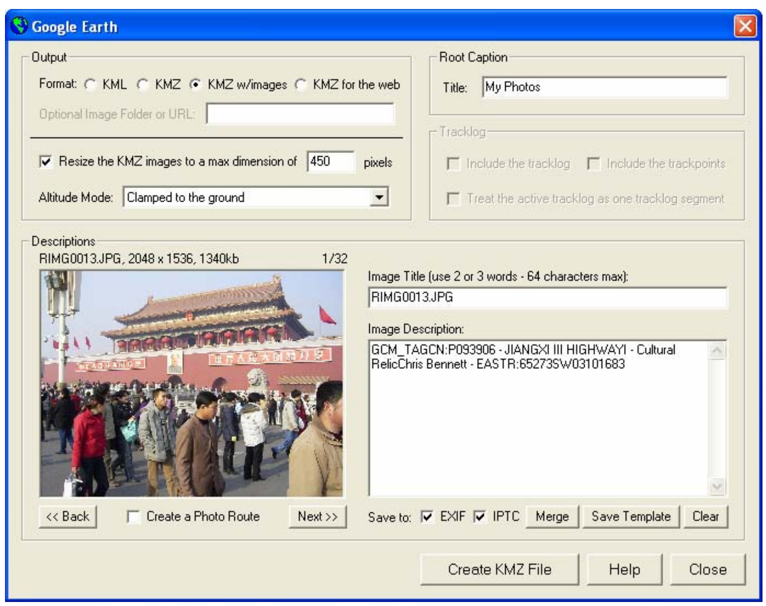


Figure 3.6: Exporting Images to Google Earth

In using the software the following was found:

- It is useful if you have a photo taken at a known location, for example an intersection, which can then be used to test the accuracy of the assignment.

- The key to success is, of course, getting the correct time synchronization between the GPS receiver and the camera. If the camera's time is not set to the same time as the GPS receiver then it is necessary to enter a time offset under 'Specify the camera offset button' . If the time offset is wrong, then many photos will have the same GPS co-ordinates. Having a photo taken at a known location is an easy way to confirm the synchronization.

3.5.3 GPS Enabled Camera

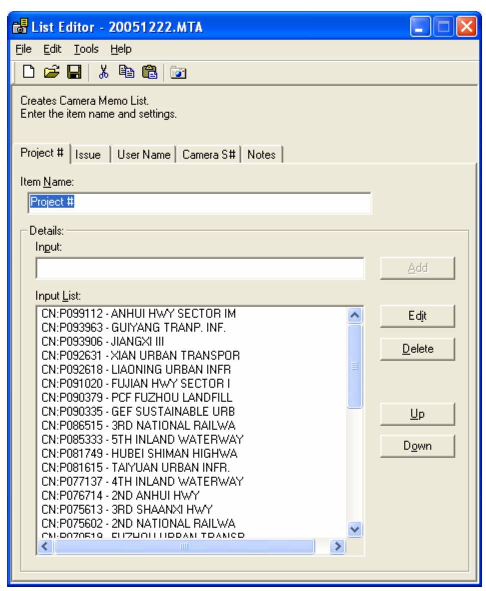
A GPS enabled camera is the most simple way to link digital photographs to spatial co-ordinates. When the photo is taken the spatial co-ordinates are automatically entered into the .JPG header.

The only camera currently available which is GPS enabled is the Ricoh G3-Pro. This camera has a CF card slot so the GPS receiver is attached to the camera in the same way as with the PDA. It is a 3.3 mega-pixel camera which records data on an SD card.

The camera comes with a ruggedized rubber cover which protects it against dropping. It is a very well designed and robust design.

The G3-Pro has an additional feature: it is possible to enter data to be associated with the image. These data are also stored in the header file and can be viewed with the image. Ricoh also provides software to convert the photos and headers into Word, Excel and GE documents.

The user can create up to five different 'Memo' fields to be used with the images. The buttons on the rear of the camera are used to step through the fields and select the appropriate values.



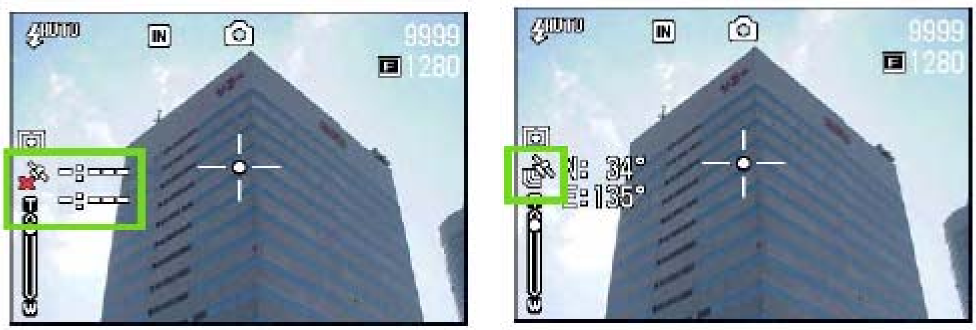
The screen to the right shows the software used to create the file. For this project three memo fields were used:

- Project ID;
- Issue (see Table 3.1); and,
- User Name.

The software creates a formatted text file which resides on the camera's memory card.

For the purpose of testing, the camera was used with a GlobalSate SiRF Star III CF-Card GPS receiver. It was found that this was an excellent unit, with much faster acquisition times than the Haicom CF-Card GPS receiver used with the PDA GPS testing.

When the camera is first turned on it attempts to locate the GPS satellites. The LCD screen on the camera has a display as shown in the left of Figure 3.7. Once there is a GPS fix, the latitude and longitude are shown as in the right of Figure 3.7. When the camera was used in the same general area the time from turning the camera on until a satellite fix was on the order of 10 s, depending on how clear the view was of the sky. In new areas it could take up to one minute or longer. It is therefore advantageous to turn the camera on as soon as possible before taking a photo.



No Satellite Fix **Satellite Fix**

Figure 3.7: Ricoh G3-Pro Screens

The memo field function is very straight forward to use. It is possible to use the same memo field continuously without having to re-enter the data. In field testing it was found that the proposed issues list presented in Table 3.1 worked well and did not need to be supplemented.

The only shortcoming noted with the camera was its inability to record continuous data. It would be very useful if the camera could create a continuous GPS log while it was turned on.

As mentioned earlier, Ricoh provides software which processes the data. It will automatically read the images and create Word, Excel and Google Earth .KMZ files. Unfortunately, there was a problem with the software during the evaluation so it was not possible to test it.

In lieu of the Ricoh software, the program RoboGeo (see Section 3.5.2) was used to read the photos and create a Google Earth .KMZ file (or other GIS format). Figure 3.8 is an example of this for a photograph taken at the entrance to the Forbidden City in Beijing in Google Earth. The image is correctly referenced.

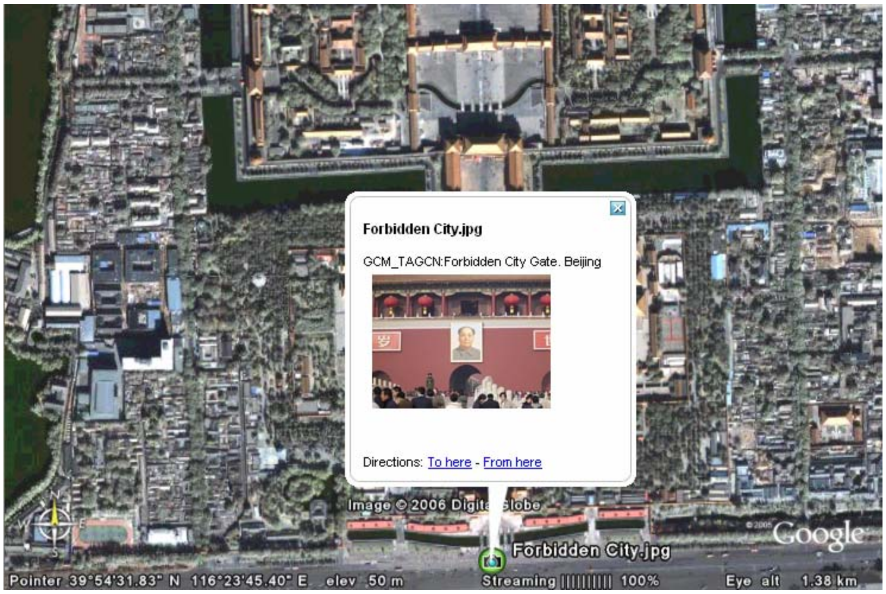


Figure 3.8: Example of GPS Camera Photo in Google Earth

Box 3.4: Using the Ricoh Pro-G3 Camera in the Field
The camera is very well designed and simple to use. The only problem found was that the battery was consumed very quickly. It is therefore advisable to recharge it after each day. Fortunately, the camera is designed to also operate off AA batteries, so these should be carried as a spare. The SD card should have a minimum of 256 MB of storage to save the need to regularly download the data to the computer.

3.5.4 Conclusions on GPS Referenced Digital Photographs

Digital photographs are regularly taken during supervision missions. By recording the GPS co-ordinates where the photos are taken they will be linked to the precise location and can be displayed in a GIS or Google Earth. Over time layers of data can be assembled and reviewed to obtain a time history of the project.

The Ricoh GPS camera is the perfect tool for supervision and project preparation. By automatically geo-referencing the images, all the user needs to do is to download the photos to Google Earth or a GIS.

The alternative is to use a handheld GPS receiver and a regular digital camera, using RoboGeo or similar to geo-reference the images. However, this requires moderate technical skills so is less desirable than the GPS camera.

3.6 Comparison of Accuracy of Different Devices

In order to assess the relative performance of the three different techniques, *ie* handheld GPS, PDA with GPS and the GPS Camera, a test was done wherein the same route was walked with all three units collecting data ate the same time.

The tests were done in Tiananmen square in Beijing. Starting at the NW corner of the square, a complete circuit was made. Every 100 m, as given by the handheld GPS unit, a digital photograph was taken which gave the co-ordinates of the photograph location. The data were processed using GPS Utility and RoboGeo v 3.0 as described earlier, and imported into Google Earth.

Figure 3.9 shows the results of the testing. The following was found:

- There was good agreement between all three systems. The PDA GPS receiver was found to loose satellite lock easier than the other two systems. An example of this problem is at the south end of the photo where there was a loss of satellite in the shadow of the building.
- The distance measurements in Google Earth corresponded to the 100 m measurements of the handheld GPS.
- It will be noted that the measurements are offset by approximately 14 m from the edge of the sidewalk where they were taken. This was found on both sides of the square and is an indication of the differences between the WGS84 datum measurements and the Google Earth co-ordinates.

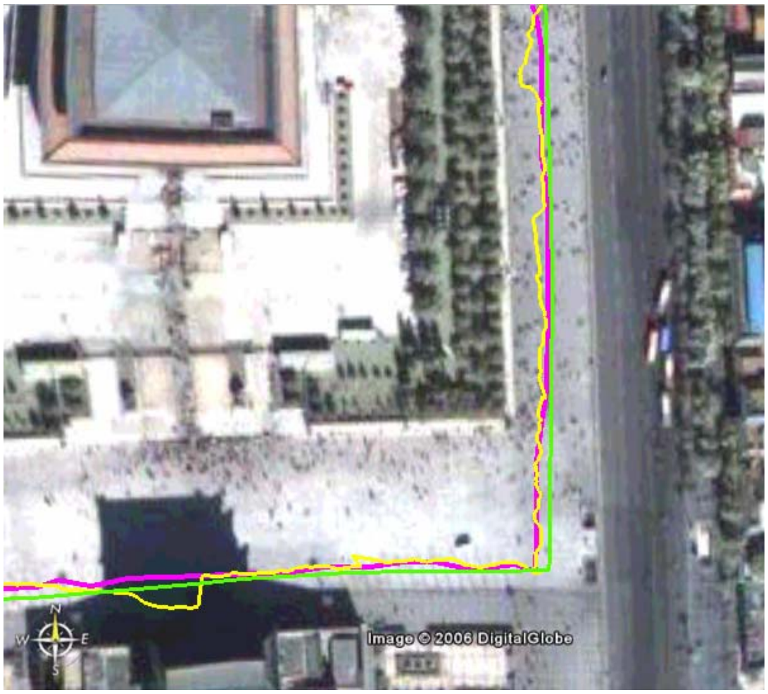


Figure 3.9: Comparison of GPS Devices at Tiananmen Square

3.7 Recommendations

On the basis of the testing of data collection equipment the following are the recommendations:

- The Ricoh G3-Pro camera (about US$ 1000 with all accessories) with embedded GPS is the most simple way to collect spatial data on projects. The memo fields are easy to use and allow each image to be tagged with key information pertaining to the project and the subject of the photo. The list of issues in Table 3.1 proved sufficient in the testing, but could be easily augmented. A maximum of 50 memo items can be used, this is too few for a region with many different projects where the camera would be shared. The only disadvantage of the camera was its inability to record continuous data.
- An alternative to the Ricoh camera is a GPS equipped PDA (about US$ 500 with all accessories) running a simple application such as GPS2Google Earth. Compared to the Ricoh camera, this would require a higher level of technical expertise to operate correctly and transfer data to the computer.
- Handheld GPS units are the least expensive (below US$ 200) way of collecting GPS data. Simple to operate, they can record point and continuous data. The transferring and processing of the data requires a moderate level of technical expertise. It is possible to use a handheld GPS with any digital camera to embed the GPS co-ordinates on the image using software such as RoboGeo.

4 Using Google Earth to Manage Spatial Data

4.1 Introduction

The project adopted Google Earth (GE) (http://earth.google.com) as the framework for managing spatial data. This application has a three dimensional terrain model of the entire world in its database, as well as other attributes such as cities and roads, to different resolution.

There are two versions of GE available:

- Google Earth basic is free to use on any computer; and,
- Google Earth Pro has a license fee of US$ 400 and has enhanced features which allows for data to be manipulated.

The project procured Google Earth Pro with extensions to read GIS files.

This section describes the use of GE on the project and general observations on the software.

Box 4.1: Google Earth vs. Geographic Information Systems (GIS)

Google Earth is not a GIS, rather, it is more of a data visualization tool. A full GIS, such as ArcGIS which the Bank has licenses for, contains a number of tools for manipulating and reporting on spatial data. These tools are not available in Google Earth—the only tool is to measure distances. However, no GIS has available the background images that Google Earth does so for visualizing data there is no better system available, and it is free to use.

In the event that analyses and reporting of spatial data is required, the data should be imported to a GIS and analyzed there. The .KML file format used by Google Earth is rapidly becoming a data standard and it can be converted to GIS formats using a variety of applications, such as GPS Utility (see Section 3.3).

4.2 Google Earth Basics

When started, GE shows the image of the world. Entering an address into the search box at the top left will zoom the image to that address. Figure 4.1 shows the display when zooming in to the World Bank's office in Washington D.C.

The GE controls are at the bottom of the screen, and are as shown in Figure 4.2. The image can also be moved by holding down the mouse button and 'dragging' the image in the appropriate direction.

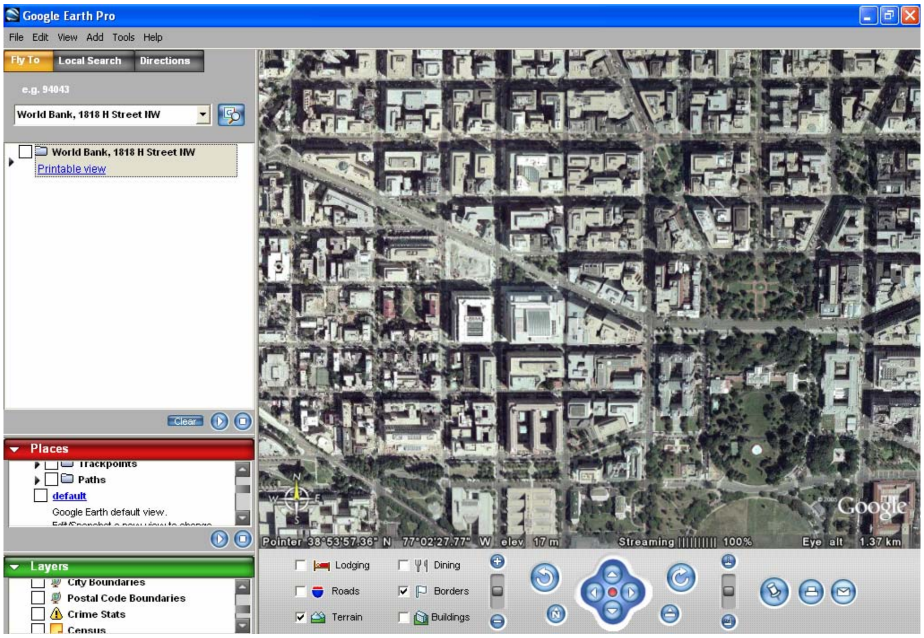


Figure 4.1: Google Earth Opening Screen

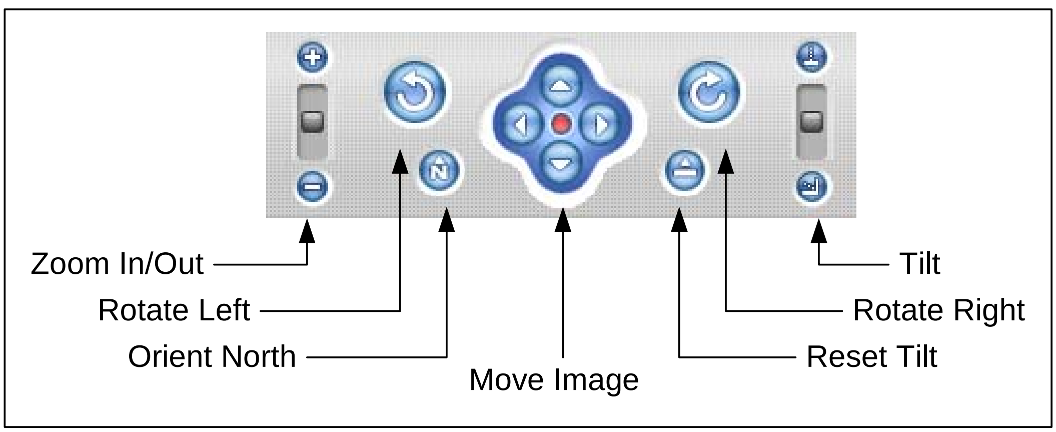


Figure 4.2: Google Earth Controls

The ‘Tilt’ function is a particularly useful feature of GE. GE contains a three-dimensional terrain model for the entire world. Using the Tilt function, one can orient the image so that the surrounding terrain is visible. This helps to contextualize the data based on the local environment.

By default, GE sets the ‘Elevation Exaggeration’, *ie* the vertical elevation scale, to 1, which is 1/3 of the true elevation. To properly visualize the terrain this value should be set to 3 under the **Tools|Options** screen, as shown to the right.

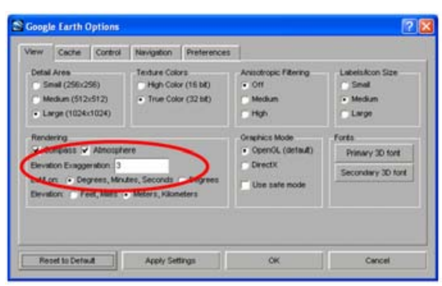


Figure 4.3 and Figure 4.4 show the same image without and with tilt. When tilted, the mountainous terrain that the highway passes through can be observed (this is the Shiman highway project in Hubei, China). In Figure 4.5, the tilted image is rotated to looking in a southern direction.

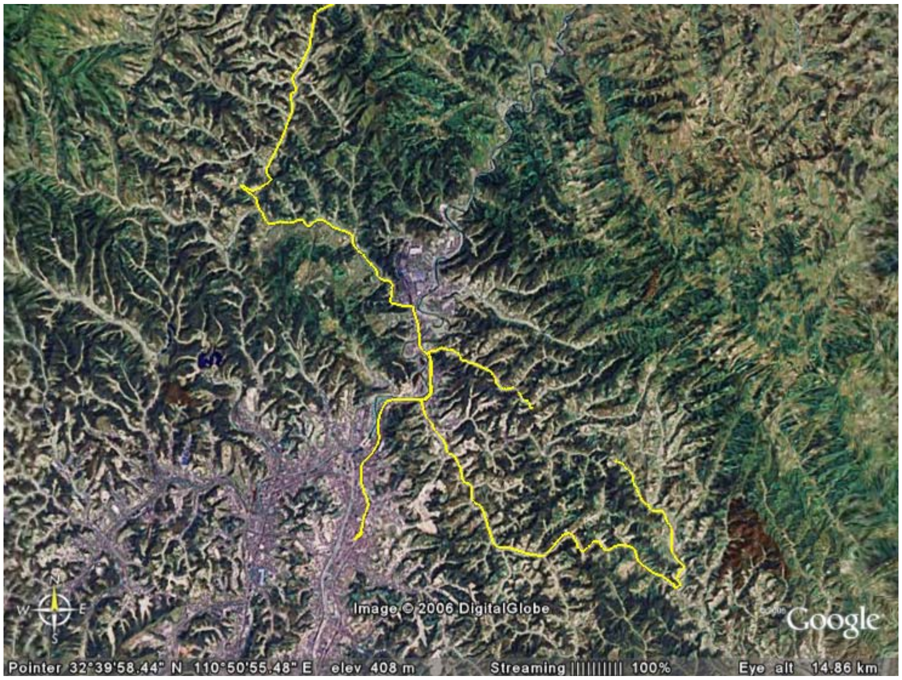


Figure 4.3: Image With No Tilt

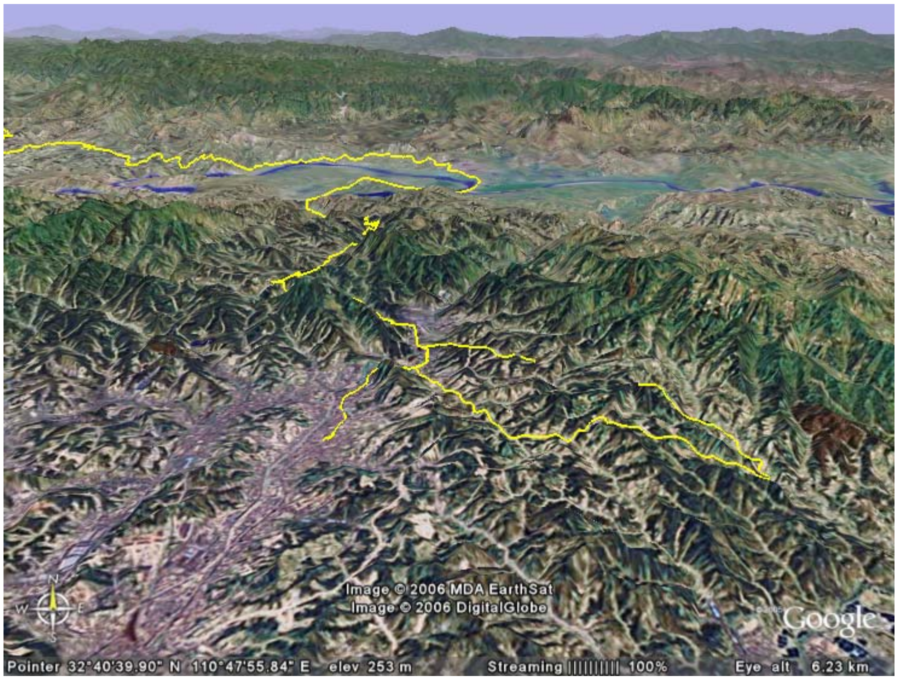


Figure 4.4: Image With Tilt

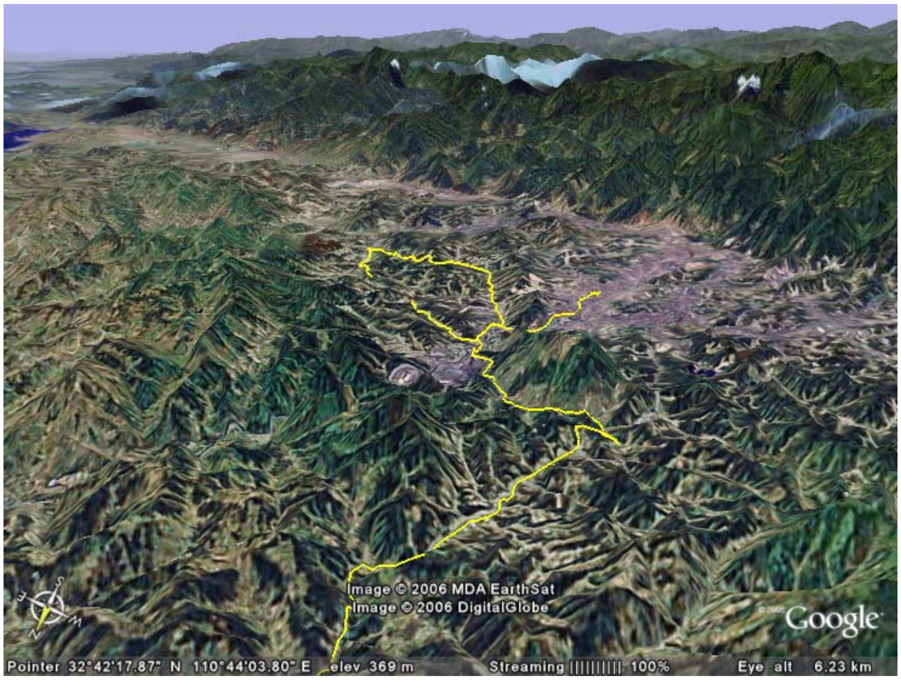
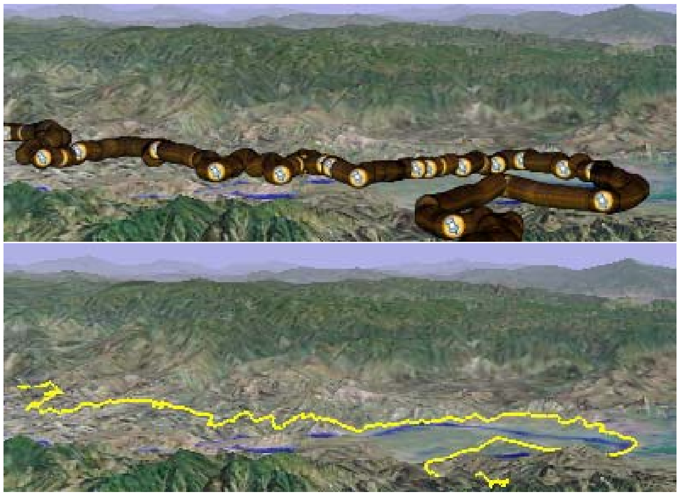


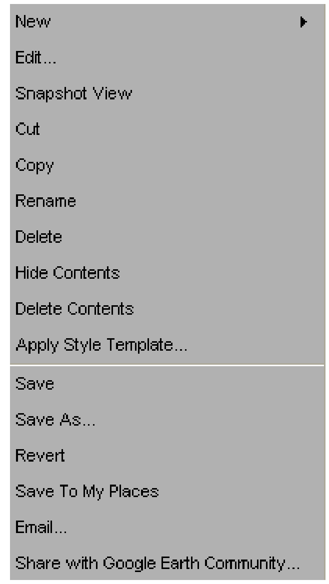
Figure 4.5: Image Rotated

The left hand screen of the GE window lists the places data are available for. When data files are opened or imported they are initially placed under **Temporary Places** (see right). Data are displayed by activating the check box. When there is a horizontal arrow next to the check box, that means that there are sub-layers of data. These sub-layers can be activated or de-activated individually.



Data are often imported as 'Trackpoints' and 'Paths'. Trackpoints are point data; Paths are continuous data.

The image at the top to the left shows data from a GPS imported. Each trackpoint is marked with a symbol. De-activating the 'Trackpoints' layer will show the path, which is shown to the left at the bottom.



There are a variety of options available for formatting the data in GE. This is done by highlighting the layer name and right clicking. The menu to the right will be displayed (Note: some features are only available in GE Pro).

Selecting **Edit** opens the screen for adjusting the properties of the data. The file can be renamed and properties such as the line color and thickness can be set.

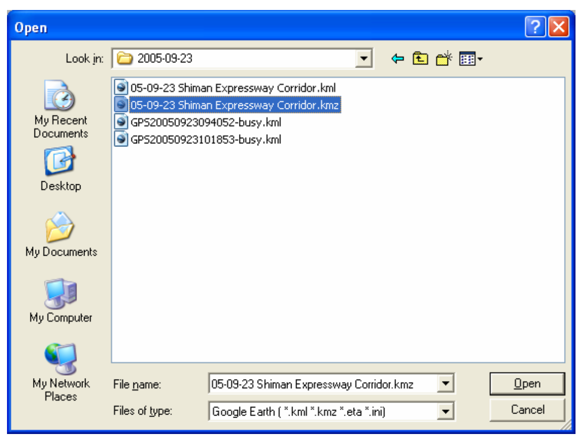
The **Save to My Places** option should be used to save the file permanently in GE. If this is not used, the file and any changes will be deleted when the session closes.

4.3 Importing Data to Google Earth

4.3.1 Introduction

The basic version of GE will only read files in the GE .KML or .KMZ format. These can be created by several programs, such as RoboGeo and GPS Utility. GE Pro can import a variety of files, including GIS (*eg* ESRI Shape, MapInfo .TAB) files, as well as TIF and other images.

4.3.2 GE Files



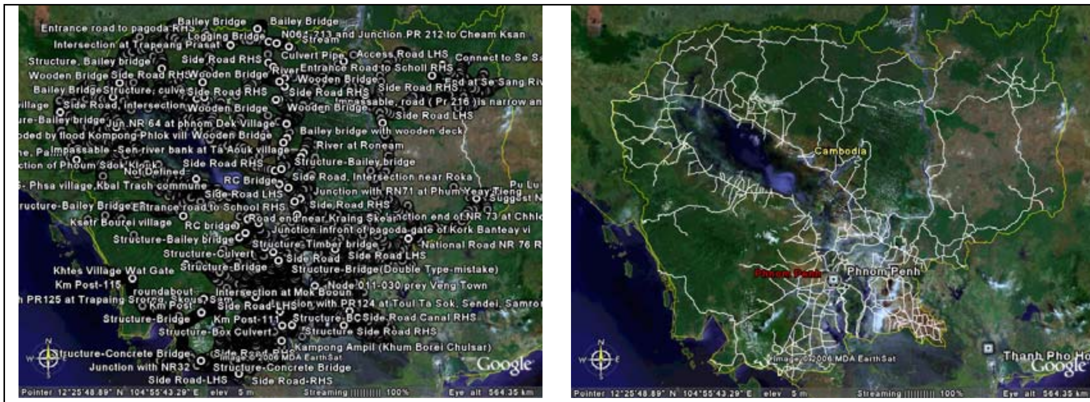
To open GE .KMZ or .KML files, select **File|Open** in GE or GE Pro. Select the file to be opened (see right) and select **Open**. GE will zoom in on the location where the file's data were collected.

4.3.3 GIS Files

To import GIS files select **File|Import** in GE Pro. The screen to the right will be shown. Highlight the files and select **Open**.

If the file is large, a warning message will be displayed indicating that over 2500 features are to be imported. Ignore this message and select **Import All**. The data import screen will be shown, and the import progress displayed. At the end of the import the opportunity to apply a style sheet will be given. Select **No**.

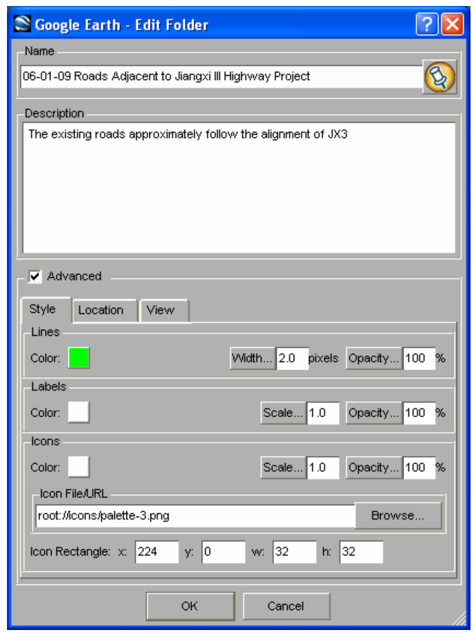
The above is repeated for each of the individual files that are imported. Once the importing is complete the map will zoom to where the data apply. One issue encountered in importing GIS data is shown in Figure 4.6: there can be so much data or labels that the underlying information is obscured. It is therefore necessary to disable some layers by removing the check mark next to their names in the 'Places' box.



All Layers **Some Layers Disabled**

Figure 4.6: Example of Selecting Layers to Display

In order to rapidly locate data in GE it is useful to create a hyperlink to the data that are displayed. This is done by right clicking and selecting **Edit**.



If text are entered as the 'Description', it will be treated as a hyperlink in GE. By clicking on the name, which will now be in bold blue underlined, GE will zoom to the location of the data.

The edit screen also makes it possible to change the attributes of the line, specifically its color and thickness. These options are accessed by selecting the **Advanced** check box.

4.3.4 Image Files

Overview

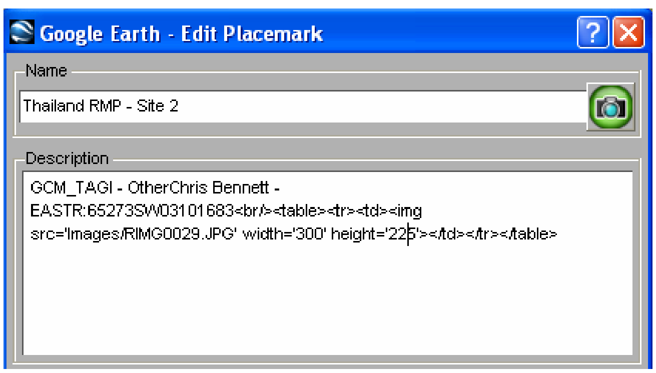
There are two types of images that can be imported to GE:

- Images taken at specific locations representing an attribute of interest, for example a bridge on the road; and,
- Backdrop images, such as aerial photographs showing the terrain in better detail than the GE images.

Attribute Images

Images of attributes taken with a digital camera which have been imported via a .KMZ file (see Section 3.5) will be displayed with an icon of a camera (see right). Clicking on the camera icon or the file name in the 'Places' window will open the image.

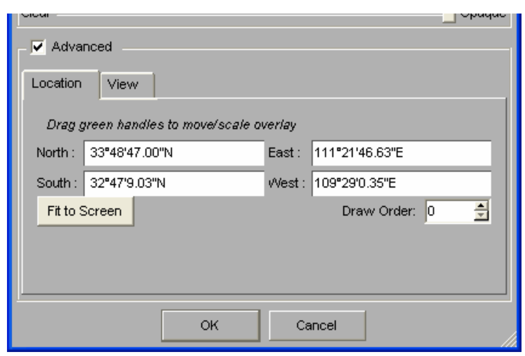
When files are transferred between machines, the location of the image file may be compromised. This is evidenced by the image screen in the GE window displaying only a grey background. When this happens it is necessary to enter the image location manually, or recreate the input file with the new locations.



This is done by selecting the file name in the 'Places' window, right clicking and selecting **Edit**. The window the to the left will be displayed. The location of the file is given by: **Images/RimG0029.JPG**. This should be changed to the new location of the files.

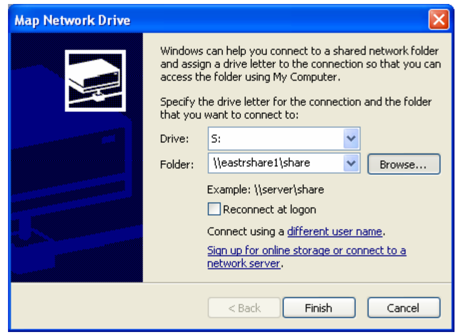
Backdrop Images

When a backdrop image is imported it is necessary to ensure that they have the correct location attributes (*ie* they have been orthorectified). Satellite images are already orthorectified with the data embedded in the file, but some images may not be. Manual orthorectification is done by supplying the co-ordinates of each corner of the image. This is entered by selecting the image, right clicking and selecting the 'Advanced' box. The data can be entered as shown to the right. Alternatively, the image can be manually moved and resized by using the green handles on the image.



4.4 East Asia Pacific Google Network Drive

A network drive has been established to store the GE data for EAP. This drive is accessed as follows:



- Select **My Computer**
- Select **Tools|Map Network Drive**
- In the pop-up window, select the letter "**S**" under "drive:"
- Under "Folder", type in: "**\\eastrshare1\share**" and press **Enter**
- When asked for a password, type in: "**simple123**".

After this, your "My computer" will have an "S" drive which contains the available GE data.

The drive is organized by country, with sub-folders describing the data that are available.

Box 4.2: Sample Data Sets

Sample data sets for using with Google Earth are contained in the folder 'Sample Data'. These are actual files collected during field surveys during the course of this project and include road alignments as well as geo-referenced image files.

Data on the network can loaded directly to GE by using the **Add|Network Link** option in the software. However, this is often slow so it may be better to copy the files directly to your computer.

5 Conclusions and Recommendations

This project has found that using technologies such as a GPS-enabled digital camera, it is very straight forward to spatially reference data collected in the field. By using such tools, it is possible not only to accurately identify where the Bank's projects are, but over time monitor the progress of the project, identify important safeguard issue locations, and perform spatial analyses and reporting.

Data Collection

The Ricoh Pro-G3 camera is ideally suited to collect data. With an embedded GPS and the ability to enter memo fields, it does not require any technical skills to operate. Supplemented by a low-cost hand-held GPS receiver, which could be used to measure road sections, it would be very straight forward to spatially locate our projects and any issues identified.

Applying Spatial Data

The application Google Earth is the ideal framework for integrating and presenting spatial data for the Bank. The basic version is free to use, and this meets the needs of most users. A few licenses for the advanced version (Google Earth Pro) should be procured for those who need to convert GIS data into the Google Earth format.

It would be useful to have ISG include Google Earth as an application that can be installed on the Bank's computers. Currently, it requires a special request.

Satellite Images

There is a range of satellite data available which can complement the data currently in Google Earth. These data can be imported and overlaid on Google Earth. The cost of images varies, some are free while current and very detailed images can be quite expensive.

There are a number of companies which will consolidate satellite image data and prepare a data set to meet a user's specific needs. This is a convenient approach to use.

Data Sharing

Many of the Bank's clients have available spatial data sets. They have proved willing to share them for internal use by the Bank. It would be useful for Bank TTLs to request that clients make available data sets for internal use at the Bank.

Data Policy

With increasing use of spatial data it will be necessary to ensure that metadata standards are followed. These will contain a history of the data, limitations on its use, accuracy, etc.

The Bank also needs to establish:

- **Data Repository:** A central repository for spatial data so that it can be used throughout the Bank.
- **Data Sharing Policy:** A data sharing policy and framework with clear mechanisms for access would allow the Bank, its clients, and various stakeholders to know what kinds of data relevant to their operations might be available and to initiate processes for periodic data sharing.
- **Standards:** Standards which will be applied to data to ensure that it is stored in an appropriate format and to reduce the risk of errors in the data being propagated. Propagated errors increase the inaccuracy of the spatial information and therefore compromise the benefits from using the data.