TAMPEREEN AMMATTIKORKEAKOULU
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Associatie K.U.Leuven

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THESIS

submitted in partial fulfilment of the
requirements for the degree of

MASTER

in

CONSTRUCTION ENGINEERING
OPTION: SURVEYING

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Abstract

This final thesis consists out of two main parts. The theoretical part examines techniques that made mobile GIS reality, techniques that can make mobile GIS more performing and some information on forestry to make the non-expert reader ready for the practical part. We start the theory with basics on PDA's and on the MobileMapper CE. GPS plays a central role in mobile applications; a good understanding of this is from great importance to know what you are doing in the field and how to interpret data like PDOP, DGPS … This makes the next chapter. These techniques made mobile GIS possible. Distributed GIS and Enterprise GIS can make mobile GIS more performing. These are both database-connected ways of working to enable lots of users to work with the same data. The basic information on forestry introduces the reader to the technical terms, techniques and devices used in forestry. This is necessary to know what we're doing in the practical part.

The practical part starts with an overview of all the materials and methods we use to set up the project. This goes till the map document in ArcView. Next step in the project was learning to work with ArcPad, adapting the system to our work and using it in the field. The manual for this, the tests in the fields and the results we booked with the MobileMapper CE and ArcPad are described in last chapters of this thesis.

Acknowledgements

First of all, we like to thank Mr. Luc Boehme, our teacher GIS in the department of Construction of the Catholic Institute for Higher Education in Bruges and Ostend and supervisor in our home polytechnic. He was the stimulus to take this thesis and to go studying at Tampereen Ammatikorkeakoulu (TAMK). Without him, this thesis wouldn't have existed because he bought the MobileMapper CE for us.

We can't forget our supervisor in TAMK, Mrs. Eeva Sundström. She introduced us to the Finish forests and woke our interest to get ArcPad working in the forest management.

We also want to thank our parents, Mr. and Mrs. François – Vernieuwe and Mr. and Mrs. Dejonghe – Hoste. They supported us through our studies, encouraged us to keep working on our final thesis project and most important of all, they gave us the chance to go studying in Finland.

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Jeroen François & Pieter Dejonghe
Tampere – Finland
April 19th, 2006

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Chapter 1 What is mobile GIS? An introduction

1.1 Background

Emerging technologies as the internet, wireless communications and mobile computing have changed the way we think, the way we asses problems and the way we work. So, also Geographic Information Systems have gone mobile by moving GIS from the desktop into the field worker's hands. This poses a few challenging questions. What technologies are best suited to the mobile environment? What are the capabilities of mobile GIS? During this thesis we will provide an overview of these technologies and the capabilities of mobile GIS in a theoretical and practical way.

The vision is to present the user always right information in the right moment at the right place. This sentence says everything about the two major application areas of mobile GIS: field-GIS and Location-based services (LBS). This will be explained later on this chapter.

We mentioned already the move of GIS into fieldworker's hands. They not only get empowered by a new way of collecting data but also with editing and verification. Mobile GIS brings the office in the field to improve productivity, decrease costs and minimize project time. If this is incorporated in an enterprise GIS, a company can even get more advantages of the mobile GIS.

GIS architectures have traditionally focussed on a static environment in which users perform spatial analysis at their workstation. By using mobile GIS this setting can change dramatically. By combining PDA, GPS and wireless internet connections, users are able to access and collect (semi) real-time data.

With this final thesis, we want to examine the acquisition and maintenance of spatial and non-spatial data used in a mobile GIS.

1.2 What is mobile GIS ?

1.2.1 Defining mobile GIS

Describing GIS into a good, comprehensive definition can be very challenging. Many scientists tried to do, but less of them succeeded in defining the total concept of a GIS[1]. Some remarks why this is quite difficult:

- Defining GIS as a Geographical Information System could be to narrow. Maybe that's why Longley (2005) titled his book "Geographical information systems and science". By doing that, he caught much more than only a system. The word science contains those systems, but puts also an accent on research.
- There are so much GIS's, for every field of usage one can build another definition and can put the accent on another part of the GIS.

What's the link of the difficult defining of a GIS with defining a mobile GIS? Well, both have just the same problems as mentioned above. As traditional GIS, mobile GIS is difficult to define, just because of the reasons above, but there is also another issue uniquely for the mobile application: there is a lack of non-ambiguous terminology. This will be explained in the next paragraph. This problem deals with the use of terms like mobile and wearable GIS.

The most conspicuous characteristic of mobile GIS, referred to the characteristics of traditional GIS, is certainly the mobility of the whole GIS-process. This means that hard- and software have to be designed to fit the field workers. This has of course a few implications for the network connecting the components of our GIS. It isn't only hard-wired anymore and we must use technologies like Bluetooth, WiFi or disconnected editing. These will be discussed later on. These two main changes have there impact on technology and generate a few unique properties for mobile applications:

- In a mobile service environment, there will be a plethora of terminals (devices). Services must be able to present themselves on many of these, with consistent functionality and understandable interfaces.
- In the mobile "always on" world, people access services and information independent of location and time.
- Access issues for mobile applications trough wireless technologies.

[1] Boehme, 2005

- In stationary designs, the digital and the physical realms are more or less separated. By contrast, in mobile systems they may be combined. Involving real world data such as geographic position, temperature, time and traffic gives us the chance to have more real time applications.
- Data must be scaled or adapted to fit the mobile devices and their communication protocols. We need content that provides enough level of detail that can be provided through the wireless networks and shown on the mobile computing environment.

We mentioned already about the mobility of hard- and software, but there’s also a possibility of using “mobile data”. We can summarise this type of mobility with the term “distributed GIS”. Because by using a mobile GIS, there’s always a certain mobility of data and distributed data will gain interest, this will be discussed in chapter 4.

Mobile GIS is the expansion of a geographic information system (GIS) from the office into the field. A mobile GIS enables field based personnel to capture, store, update, manipulate, analyse, and display geographic information. Mobile GIS integrates one or more of the following technologies:

- Mobile devices
- Global Positioning Systems (GPS)
- Wireless communications for Internet GIS access

Traditionally, the processes of field data collection and editing have been time consuming and error prone. Geographic data has travelled into the field in the form of paper maps. Field edits were performed using sketches and notes on paper maps and forms. Once back in the office, these field edits were deciphered and manually entered into the GIS database. The result has been that GIS data has often not been as up-to-date or accurate as it could have been.

ESRI's developments in mobile GIS have enabled GIS to be taken into the field as digital maps on compact, mobile computers, providing field access to enterprise geographic information. This enables organizations to add real-time information to their database and applications, speeding up analysis, display, and decision making by using up-to-date, more accurate spatial data.

After all these defining issues, we could say that mobile GIS can be defined as a software/hardware GIS-framework for the access of spatial data and services through mobile devices via wired or wireless networks.

1.2.2 Terminology: mobile, wearable or wireless GIS ?

Mobile GIS can be defined as an integrated software/hardware GIS-framework for the access of spatial data and services through mobile devices via wired or wireless networks. Wireless and wearable GIS are subcategories of mobile GIS technology.

"Wireless GIS" is a subcategory of mobile GIS technology that focuses on the wireless networking capability of mobile GIS services.

Wearable GIS: S. Mann defines a wearable computer as “a small body-worn computer system that is always on and always ready and accessible”[2] .

From the human point of view, he describes wearable computing with the following six attributes:

- Unmonopolising the user’s attention: it does not cut you from the outside world like virtual reality. It is built with the assumption that computing is a secondary activity.
- Unrestrictive to the user: he can do other things while using it.
- Observable by the user: it can get the user’s attention continuously if he desires.
- Controllable by the user: he can have control of it at any time he wishes.
- Attentive to the environment.
- Communicative to others.

Especially the attributes unmonopolising, unrestrictive and controllable are essential for the use of GIS in outdoor applications.

Software for wearable computers has to be developed taking into account these attributes. Traditional GIS are impracticable for wearable computers because they lack of the above attributes of wearable computing, e.g. they monopolize the user’s attention.

Innovative GIS front ends and interaction techniques have to be developed to make use of the geographical information on wearable computers. In the following, we call these next-generation GIS; wearable GIS. With wearable GIS, the user will be able to access on demand geographical information any time at any location.

[2] Mann, 1998

Egenhofer and Kuhn[3] foresee several wearable GIS applications like:

- smart horizons, which allow a user to actually look beyond his or her field of view,
- magic wands, pointing devices to identify geographic objects by pointing to them, and
- smart glasses to augment reality

by superimposing a digital image into the field of view.

With a wearable GIS, the user does not only get access to the geographical data which is locally stored on the system. Such systems must be able to deal with highly distributed data and even distributed GIS functionality.

Advanced computational models are needed to integrate different geographical data sources and to respond in near real time.

1.2.3 Why using ArcPad ?

ArcPad is a mapping tool for working with your GIS data in the field. Field GIS tasks are often quite different from the GIS tasks performed in the office and so the computers are used in these different environments. Desktop computers usually have fast CPU's, large amount of RAM memory and disk space, and large display monitors. In contrast, field computers (PDA's) have relatively slow CPU's and limited RAM and storage capacity. Furthermore, the fieldwork environments ranges from working in bright sunlight to rain to subzero snowy conditions, this compared to the constant temperature and lightning conditions in an office environment. Therefore you need to consider all of these factors before preparing your GIS data for the use in the field with ArcPad.

ArcPad is software for mobile GIS and field mapping applications using handheld and mobile devices. ArcPad provides field-based personnel with the ability to capture, analyse, and display geographic information, without the use of costly and outdated paper map books.

With ArcPad, you can perform reliable, accurate, and validated field data collection. Integrate GPS, rangefinders, and digital cameras into GIS data collection. Share enterprise data with field-workers for updating and decision making. Improve the productivity of GIS data collection. Improve the accuracy of the GIS database and make it more up to date.

[3] Egenhofer, 1998

Here are some key features of ArcPad:

- GIS data collection: possibility to create, edit and display spatial data (points, lines, and polygons), the ability to display a variety of geographic and attribute information (Attribute data is descriptive information about a location and can be edited and collected with ArcPad data collection forms), it supports vector and raster data in a multilayered environment…

ArcPad Tools

Map Navigation	Editing	Display and Query
• Variable and fixed zoom. • Zoom to layer, to visible extent of all layers, and to bookmark. • General pan and pan to selected features. • Center on current GPS position. • Map rotation (manual or automatic based on GPS).	• Edit vertices. • Segmented lines and append to line. • Rotate, move, resize, and scale features. • Snapping. • Offset points and vertices. • Left/Right offset of polylines and polygons. • Linear and radial traverse. • Repeated attributes. • Sketch. • GPS captures: point, vertex, and streaming vertex. • Camera and range-finder support.	• Identify features by attribute. • Display layers by scale dependencies. • Hyperlink to external files: photographs, documents, video, and sound. • Measure distance, radius, and area. • Calculate geographic statistics for selected features such as area and length. • Find features by attribute query. • Find locations by coordinates.

figure 1: Schematic overview of the possible tools in ArcPad

- Integrate external hardware: ArcPad supports field devices, such as GPS receivers, rangefinders, and integrated digital cameras with GIS data collection. Input from these devices is stored within the GIS.

- ArcPad tools for ArcGIS Desktop: ArcPad tools for mobile geodatabase editing allow you to check out your GIS data using ArcGIS Desktop, edit in the field with ArcPad, and post changes back to the central GIS database.

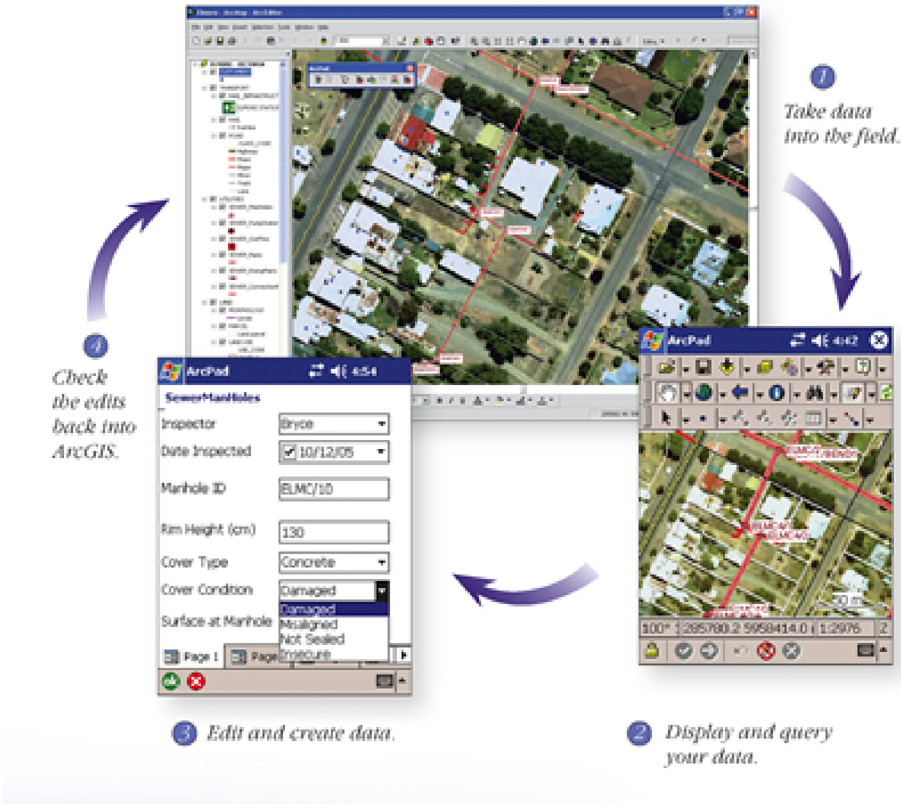

figure 2: Schematic view of the main use of ArcPad - ArcGIS

- Symbology and style sheets: ArcPad enables high-quality mapping on mobile devices through supporting ArcGIS symbology and style sheets.
- Language support: the ArcPad user interface is available in a number of languages, making it easier for mobile GIS workers whose native language is not English.
- ArcPad Application Builder: is the development framework for building custom ArcPad applications for mobile GIS. Effective mobile GIS workers require applications and tools that have been customized for a specific field task or project. ArcPad Application Builder is the development framework for creating custom solutions for mobile GIS applications and tasks.

1.3 Application Areas

There are two major application areas of mobile GIS.

- Field-based GIS: which focuses on GIS data collection, validation and update (spatial and attribute).

- Location-based services (LBS): which focus on business-oriented location management functions, such as navigation, street routing, finding a specific location or tracking a vehicle.

Fire-fighters, police officers, engineering crews, surveyors, utility workers, soldiers, census workers, field biologists, and more use mobile GIS to complete the following tasks:

- field mapping: create, edit, and utilise GIS maps while in the field;
- asset inventories: create and maintain an inventory of asset locations and attribute information;
- asset maintenance: update asset location, condition, and schedule maintenance;
- inspections: maintain digital records and locations of field assets for legal code compliance and ticketing;
- incident reporting: document the location and circumstances of incidents and events for further action or reporting;
- GIS analysis and decision making: perform measuring, buffering, geoprocessing, and other GIS analysis while in the field.

The application areas and industries of mobile GIS can summarised in this scheme:

		Industry			
		Government	**Utility and Infrastructure**	**Environment**	**Public Safety**
Task	**Field Mapping**	• Recording Building Footprints • Right of Way Mapping • Base Mapping	• Centerline Review and Mapping • Facility Mapping	• Forrest Boundary Mapping • Trail Mapping • Geochemical Mapping • Volcanic Deposit Mapping • Wetlands Delineation	• 911 Address Mapping • Minefield Mapping • Military Fieldwork and Mapping
	Asset Inventory	• Street Sign Inventory • Municipal Assets Inventory (GASB34) • Tree Survey • Census Data Collection • Housing Condition Survey • Cemetery Inventory	• Recording Installations • Storm Water Inlet Inventory • Storage Tank Mapping	• Toxic Inventory • Mineral Exploration • Vegetation Survey • Wetland Survey • Archaeological Site Survey	• Aerial Survey • Fire Perimeter Mapping
	Asset Maintenance	• Road Condition Survey • Street Light Survey • Patient Registration	• Power Pole Maintenance • New Equipment Installation • Pavement Condition Assessment	• Crop Management • Vacant Land Condition Management • Timber Harvest Management • Drainage System Management	• Locating Buried Infrastructure • Recording Avalanche Observations • Facility Maintenance Survey
	Inspections	• Road Pavement Management • Code Enforcement • Health Inspection • Housing Condition • Water Rights Enforcement	• Meter Reading • Septic System Inspection • Documentation • Compliance Monitoring • Dam Safety Inspection	• Habitat Studies • Weed Abatement • Well Sampling • Wildfire Sightings	• Damage Inspection • Tracking Violations • Street Sign Inspection • Flood Risk Assessment
	Incident Reporting	• West Nile Virus Incidents • Public Nuisance Surveys	• Locating Outages • Regulatory Compliance	• Animal Migration Tracking • Oil Spill Assessment • Radioactive Contamination Tracking	• Property Damage Assessment • Accident Reporting

figure 3: Schematic summary of the application areas of mobile GIS (ESRI ®)

1.4 Mobile GIS in Forestry

The new generation of compact PDA's and GPS receivers incorporate GIS into the palm of your hands and into the forest, this gives clearly more value for the forest planners.

The use of GIS in forestry is quite obvious (and deeper explained in the chapter about Forestry), but also Mobile GIS is used more and more in Forestry. Roughly, Mobile GIS is more specific for Forestry in some fields like: timber, stand & forest management in general, forest planning & protection, fire management, ecology, waterways and even urban forestry…

When you think about Mobile GIS in forestry, you can think about some applications that are quite obvious, such as defining and finding back the borders of the forests (jurisdictional) and the compartments (tree attributes), pointing some sample plots,… These properties are linked to the georeferenced position.

But the thing that makes it the most interesting is the possibility to complete and change the data, which is georeferenced (linked to the sample points). By having this opportunity, the person who is making the forest samples is able to fill in the data in the database in the PDA immediately, instead of filling in listings by hand and copy that to the pc later on. In fact he can pass one step in the project, a step that takes a lot of time. So the use of these mobile devices saves time (and money). Afterwards it's also possible to track back where you have walked and taken the sample plots. You can also import that information into ArcGIS, directly on the map or aerial image, so you have a visual of the situation.

The use of the PDA – GPS evades also the use of large, unhandy paper maps to see where the compartments are. Also possible errors of positioning are evaded by the accuracy of the GPS. Questions like "in which compartment am I?" belong to the past (sometimes it's not easy to know your exact location in the forest).

Apart from the direct advantages, there are some possibilities incorporated by GIS in general, more likely the larger cases, such as the overall forest planning of an area, including harvesting, log production, growth, death, thinning, reforestation,…
Here we will point out the two most important:

1. Timber Management

   GIS-based spatial modelling allows managers to maintain stand information to meet shifting market demands. It also provides the appropriate records for contract administration and fiscal accounting generated by harvest activities. Logging engineers can develop solutions that best fit harvest designs to topography and stand objectives.

   Application areas include:
   - Logging Engineering
   - Harvest Scheduling
   - Contract Administration

2. Logging Engineering

   - Harvest Scheduling
   - Contract Administration
   - Stand Management

   GIS provides a means to track all the elements of forest prescriptions and schedules for a multitude of stand activities. In the field, Mobile GIS gives you the tools for accurate inventory control and management.

   Application areas include:

- reforestation;
- stand tending;
- thinning and
- silvicultural prescriptions.

1.5 Motivation for research in mobile geographic information systems

There are some different reasons and motivations why we chose this subject for the final thesis. First of all in Belgium we are in Industrial Engineering in Construction, with an option for surveying (in the last year), so we have courses about GIS in our home institute. The real start was when our teacher (Mr. Luc Boehme) in our home institute started talking about the MobileMapper. He said he was interested to use this device, as part of the didactic material for the students and to get on with time.

The school didn't want to buy this device just to have it, so our teacher asked around if somebody was interested in writing a final thesis about this device, because the school wanted to buy the MobileMapper when it would be used in a thesis. We reacted on his call.

The main reason for that was our interest for GPS and GIS in general. Pieter's interest went out mostly to GIS and the informatical part, while Jeroen's interest mostly was about GPS receivers and the practical part, so in fact we would complete each other in this project. When we got the thesis subject we didn't know about the practical part here in Finland, but we could start with reading about (mobile) GIS, PDA's and so on. When we heard here in Finland that it the thesis would deal with Forestry, we needed to inform about it, but we saw no problems, because we both like being outdoors.

At last we liked the thought of helping and providing both our home institute in Ostend (Belgium) as well as TAMK in Tampere (here in Finland) with some valuable information for the future, because these types of devices get more and more spread around.

For Belgium our work and research had mostly to do with the MobileMapper, the use of it and the use of ArcPad – ArcGIS, so there was a kind of manual how to use it and what the performance is. For Finland, our thesis was also quite important, because they want to change their own Tforest database into ArcGIS/ArcCatalog, and this in the whole of Finland. They are also looking for PDA's to incorporate in their forest management system. So with our information we hope they have an idea about what to do in the future.

1.6 Aims of the thesis

The aim of this thesis is ambiguous. When we got the subject of our thesis back in Belgium, the main aim was to test the PDA – GPS and the software. The reason therefore was the more upcoming use of GPS receivers and PDA's in GIS and surveying in general. There are already some professional surveyors which use PDA/GPS (this mostly in city environments), so it's a good idea to get students to know this "new" technology, because it gets more and more spread around.

Testing the PDA and GPS consisted of different parts. The main thing to test was the GPS receiver. This included testing the accuracy of the receiver. It's one of the recent GPS receivers, it's made by a good brand and it's equipped with WAAS/EGNOS – DGPS – post-processing possibilities, so theoretically it shouldn't be a problem. But as you know reality differs from theory, that's why some field testing is necessary. The second thing that needs to be tested is the new ESRI software: ArcPad, which is a smaller version of ArcGIS, specially designed for the use on PDA's (less possibilities, but the basics remain the same). Also the link between PDA and pc (ArcPad – ArcGIS) is important. Most important thing in the software-hardware part is the connection and the ease of use of everything.

In Finland we got more information about the thesis, because we have to finish the thesis here. We got to know that the thesis should deal about Forestry, something that is very important in Finland and other Scandinavian countries (the forested area in Finland is about 75%), but in Belgium people never heard about that… so that made it also more interesting for us. Before we could start we needed to inform about forestry.

The reason for the thesis here was the use of the PDA – GPS receiver and the use of ArcPad and ArcGIS in forestry. Today they use some PDA's in forestry, but none of them linked with a GPS receiver. They only use the PDA here to correct and complete the compartment data, so for them it's a new idea, maybe with some options for the future… So the use of the PDA and the accuracy of the GPS receiver (even under dense tree canopy) were an important point for them. But the most important aim here was the use of ArcGIS. Now they are using a Finnish made forest program, named Tforest.

Within the near future they want to change everything in the whole of Finland from the Tforest database to ArcGIS, because this is a more universal program, so in this case we looked at the opportunities for the conversion and the ease of use. In fact we are doing some research work before they start the conversion; we check the possibilities of the combination PDA - GPS and ArcPad - ArcGIS.

We hope that we can give some valuable information, here in Finland for their conversion to ArcGIS as well as in Belgium for the use of the PDA - GPS and ArcPad - ArcGIS.

1.7 Contents of the thesis

1.7.1 Backbone

According to Longley (2005), GIS contains six parts (figure 4). These six parts will be the basic structure of our final thesis. The main piece in a GIS today is a network. This can be the internet, an intranet or whatever network one could imagine. This is the most fundamental part without which no rapid communication or sharing of digital information could occur. This network connects the five other parts and will also form the backbone of our thesis.

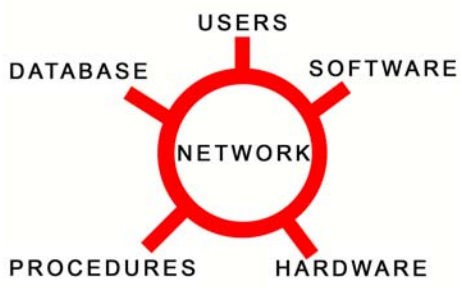

figure 4: the six components of a GIS

The network doesn't function only as a backbone but it's also of great importance for the positioning system of the MobileMapper CE. This uses GPS to get an accurate absolute position. These techniques will be discussed in chapter 3.

The second piece of the GIS anatomy is the user’s hardware. This is the device that enables the user to interact by directly carrying out GIS operations. Traditionally this device sat on an office desktop, but due to the introduction of mobile GIS today's user has much more freedom. We will examine these devices and take a closer look at the MobileMapper CE from Thales Navigation in chapter two. In the language of the network, the user's device is the client, connected trough a network to a server that can probably handle many other clients simultaneously.

The third piece of our GIS anatomy is the software that runs locally in the user's machine. For our thesis we use ArcGIS as server application and ArcPad as client application.

The fourth piece of the anatomy is the database, which consists of a digital representation of selected aspects of some specific area of the Earth's surface, built to serve some problem solving or scientific purpose. The whole process of database design won't be discussed in this thesis. We focus on the use of ArcPad and the MobileMapper. So data collection and data quality are more of importance here. We examine the new way of collecting data by GPS-enabled PDA and link this to some issues in data quality and maintenance of data.

During the whole text, we have tried to focus on the use of mobile GIS through the theoretical study. In chapters 8 to 10 we bring the first chapters together in order to bring the theory in practice.

During chapter 10, we reintroduce chapter 6 to see where we can improve our application and to examine what we can say about accuracy and quality. At last we finish our final thesis with a view on what could be possible with mobile GIS in future and a conclusion on our work with the MobileMapper CE.

1.7.2 Overview of the chapters

In this part we want to give a little overview of the different chapters, why we describe them and the links between the chapters.

The thesis exists of two main parts; the first it the theoretical part with necessary background information and the second is the practical part, with the test, results, further possible developments and finally the conclusion.

After this introduction, we start with a little description of PDA's in general and the MobileMapper CE specific, because this is the most important piece of hardware we use (next to the pc, the only hardware). Also because the PDA/GPS configuration is one of the things that has to be tested.

A logical consequence of the PDA is the link with GPS, which is the second chapter. In this chapter the system and working of GPS is explained, starting with the satellites, ground stations, going over the electronic components and the different kinds of signals, to the accuracy, possible errors and ways to improve the accuracy. With this background of GPS, you can understand more of the whole concept and the use of GPS receivers in this field of work and in GIS.

The next two chapters deal with some database techniques. When the project becomes bigger and bigger, the amount of data will get bigger and bigger, so more advanced techniques must be incorporated in order to be able to have a well organised and maintainable database that is open for several users at the same time. That's why we write one chapter about distributed GIS or the use of data on several servers and a chapter on enterprise GIS or data use within an organisation.

Without collecting data, there can't be data on the server. To produce quality data, one has to follow some basic rules and you have to think about how to improve the quality of you data. That's why we added the chapter on data collection.

Because the thesis deals with forestry and we didn't know anything about it, we had to get informed about that subject. After reading some texts, we summarised the most important things down to a chapter about forestry. It deals with forestry in Finland, forest planning & management in general, forest measuring, GIS and remote sensing in forestry and aerial images. This is the last chapter in the theoretical part.

The chapter about methods and materials concerns all types of data, materials and methods we use. This is in fact the basis for our project. A good understanding of the different data types and methods is a key word in the setup of the fieldwork. That's why we will describe this in detail.

The next chapter is a Field manual for ArcPad. This part is basically the description how you get the data, maps, images and other from ArcGIS (pc) to ArcPad (PDA). In fact this is a kind of step-for-step guideline to install everything for the practical work in the field. Also the problems we had are described.

Another thing that has to be incorporated in our thesis is of course the results of the field tests, which we wrote down in the following chapter. We describe the way how we work in the field, step-for-step and also the issues we have while accomplishing the tests in the forest.

Next chapter is the one that holds all the results of our field work and summarises some issues and good points in the work with ArcPad.

After this practical part we will tell something more about the future of mobile GIS, and in special the possible further developments with the MobileMapper CE, such as ESRI's Application Builder.
We will finish our final thesis with a conclusion on the whole project.

Chapter 2 PDA

2.1 What is a PDA

PDA is the abbreviation of ‘Personal Digital Assistant’. In fact it is a small handheld computer that combines computer, telephone, fax and internet functions.

The development of the PDA started back in the nineties, first as a gadget but not long thereafter business people discovered the power of the little machine. The idea is simple; easy data management combined with telephone and internet connection.

Two kinds of PDA’s exist: those with a keyboard and those with a touch screen, mostly operated with a stylus (pen).

The PDA is a personal, wearable organiser and is repulsing its paper pastor bit by bit. It incorporates a maximum of functions, such as: address book, agenda and telephone list. But most of the PDA’s offer more applications, such as: spreadsheets, memo pad, calculator, task list, clock, games,… There are some which incorporate GPS navigation, camera or cell phone. Most of the PDA’s have connections to wireless Internet and an email manager.

figure 5: Examples of different kind of PDA’s

What makes it so attractive is the possibility to exchange data between PDA and PC, for example automatic synchronisation of memo pad, new incoming emails, ... so changes made on the PC will automatically being updated on the PDA and the other way around. Most PDA are linked to the PC with an USB-cable, but nowadays wireless applications are possible (like Bluetooth or Infrared).

2.2 Hardware

PDA's are in fact very similar to desktop-pc's; they have a processor and a memory. Input occurs by a small keyboard or a touch screen. Output is by a small flat screen, which in some cases is very good quality. Noteworthy is that there is no hard disk as in a normal PC, but instead the PDA uses an alternative memory, sometimes partly combined with the RAM-memory. Of course the different parts aren't the standard parts you find in a desktop PC, hereby some explanation.

2.2.1 The processor

PDA-processors are built differently from desktop processors, because of mobility, durability and lifespan are important. Thereby the processors in a PDA aren't as fast as those in a desktop PC, top of the line PDA have a clock speed of more than 600MHz.

2.2.2 The memory

Considering RAM-memory, the PDA has a lot less than PC's: 64-128 MB is standard. This explains why specific software has to be designed for these devices.

When you open a PDA, you normally won't see a hard disk, because all data is saved on memory chips. In most of the times it is possible to expand the memory of your PDA, by means of the so called 'Flash' memories. Some of the newest have a shock resistant hard disk.

2.2.3 The screen

It's obvious that a handheld device can't be equipped with a 17 or 19 inch screen.
The size, the number of colours they can render and the number of pixels depends on the model. Values between 160 x 160 with 16 grey values and 640 x 240 with 65536 colours are most common.

2.2.4 The input

The PDA has a hardware and/or a software keyboard. During development of PDA's, designers need to find the right relation between simplicity of input and the space the keyboard will take up. Normally these are simplified keyboards; no numeric or function keys.

2.3 Software

2.3.1 Operation systems

Microsoft is always trying to get the biggest share on the market, so with PDA's it's nothing different. The war of the operation systems is expanded to the world of small computers. At this moment the biggest part of the PDA's is equipped with the 'Symbian' operating system. Microsoft's 'Windows CE' has the other share in the operating systems.

2.3.1.1 Symbian

Symbian is the operation system with the biggest share, mostly because it hasn't got high system requirements so designers can make a good system without very powerful hardware. Another thing that makes it one of the best operation systems is the compatibility with other operation systems and PDA's.

2.3.1.2 Windows CE

When Microsoft started producing Windows CE, a lot of companies intended to join by developing hard- and software. The first PDA's working with Windows CE had a lot of shortcomings; the operation system wasn't to the point and it was non economical hardware, it was too expensive. A lot of companies quit the cooperation with Microsoft.

Many people consider Microsoft's decision to copy the 'look and feel' of the traditional Windows environment as the cause of the errors the system contains. That's why Windows CE is simply to complex for PDA's. Microsoft's solution was to develop two different versions of CE: 'Handheld PC' for PDA's with a keyboard and 'Pocket PC' for PDA's without a keyboard.

The MobileMapper CE uses Microsoft Windows CE .NET 4.2 as operation system.

figure 6: Screenshot of the start menu of the MobileMapper CE

2.4 MobileMapper CE

The PDA's we use in our experiments is the 'MobileMapper CE', made by Thales Navigation.

figure 7: Thales MobileMapper CE

Hereafter a little description of the PDA and some specifications, important for this thesis.

2.4.1 Mobile Mapping platform

The MobileMapper CE has an open-platform design operated by Microsoft's Windows CE, which supports Windows CE software for GIS and other mobile mapping applications.

The MobileMapper CE offers features like sub-meter GPS positioning, integrated Bluetooth wireless technology, removable SD memory card, touch screen, field replaceable all day runtime battery and built-in alphanumeric keypad.

figure 8: Built-in alphanumeric keypad with backlight

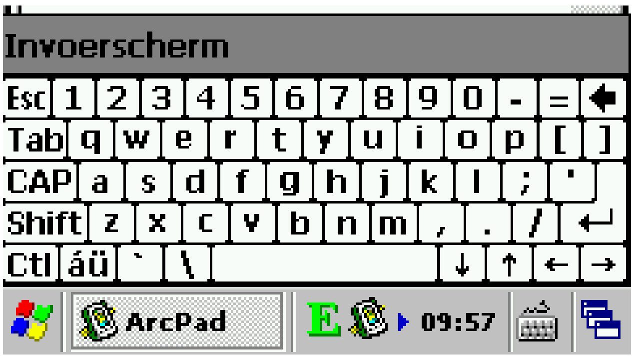

figure 9: Easy to use input keyboard on the touch screen

2.5 High performance GPS

The simple all-in-one design of MobileMapper CE allows you to focus on the task instead of the configuration of the device. It has fully integrated 14-channel GPS receiver and offers real time sub-meter position accuracy through WAAS/EGNOS or post-processing differential corrections.

MobileMapper CE GPS technology provides multipath mitigation to overcome the environmental challenges in ‘urban canyons’ and dense foliage.

2.6 Rugged and waterproof

Designed for extreme outdoor and industrial environments, the MobileMapper CE offers professionals the rugged features they need without sacrificing size, weight or affordability.
Fully submersible in one meter of water, the MobileMapper CE is waterproof in accordance with the IEC-529 IPX7 standard. It is also tested to withstand accidental drops on concrete from 1,5 meters and has an operational temperature range from -10° to +60° C.

figure 10: Rugged and waterproof

The MobileMapper CE affords even the most demanding user’s peace of mind in extreme field conditions.

2.7 High performance-to-price ratio

MobileMapper CE offers best-in-class performance for the price with user-friendly features and dedicated support from Thales Navigation. With so many integrated features in a highly shock resistant and waterproof device, MobileMapper CE is the next generation mobile mapping tool built to survive the hazards of professional fieldwork. MobileMapper CE - the features and performance you demand at the price you want.

2.8 Specifications

2.8.1 System features

- Microsoft Windows CE .NET 4.2
- ARM920T processor
- 64 MB SD RAM, 128 Flash Memory
- Removable SD card
- Colour display
- Touch screen
- Removable, rechargeable battery
- Integrated alphanumeric keyboard
- Rugged design and waterproof
- Integrated Bluetooth
- Built-in speaker and microphone

2.8.2 GPS

- Sub-meter accuracy
- 14 parallel channels with integrated WAAS/EGNOS
- External antenna connector

2.8.3 Software

- GPS utilities – initialisation, setup, mission planning and configuration
- Bluetooth manager

- Microsoft Word, Excel, Image Viewer, WordPad, Internet Explorer, Windows Media Player, Inbox and ActiveSync
- Software Development Kit & GPS Application Programming Interface

2.8.4 Standard accessories

- A/C adaptor
- Removable, rechargeable lithium-ion battery
- 32 MB SD memory card
- USB data cable
- Stylus pens

2.8.5 GPS characteristics

- DGPS position accuracy: sub-meter (RMS)
- 14 parallel channels (L1 code and carrier phase)
- Integrated real-time DGPS: WAAS or EGNOS

2.8.6 User Interface

- Full colour TFT liquid crystal display (LCD) with backlight
- 320 x 240 resolution with 262144 colours
- Resistive touch panel
- Keyboard with backlight: 18 buttons
- Battery life with GPS on: 8 hours
- Operating temperature -10° to + 60° C
- Shock resistant: 1,5 m drop to concrete
- Waterproof: IEC-529 IPX7 standard (depth of 1m)

Chapter 3 The GPS System

3.1 What is GPS?

GPS is the abbreviation of “Global Positioning System”. The system was invented and is still operated by the Department of Defence (DoD) of the United States of America. Initially the system was designed to enlarge the military possibilities (i.e. the exact location where a missile has to strike…), but it didn’t take a long time to develop the system for civilian use.

3.2 Parts of the GPS System

The GPS System consists of three segments: the satellites in the sky, the control stations on earth and the GPS receiver, operated by the user. Now we are going to take a closer look at those segments.

3.2.1 The satellites

The system consists of 27 satellites (24 active and 3 ‘spare’), also known as NAVSTAR-satellites (Navigation by Satellite Timing and Ranging). These satellites are rotating in six different routes with each 4 satellites around the earth. The angle between these routes and the equator is 55°.

figure 11: The routes of the satellites

The routes are calculated in such a way that every GPS receiver can receive can receive at least four satellites at every moment of the day, so the positioning will be accurate. The satellites rotate at a height of 22240 km above the earth surface at a velocity of 12950 km/h, so their circulation time is about twelve hours (they circle around the earth twice a day)

3.2.2 The Control Stations

There are five control stations on earth (a.k.a. Ground Stations or Control Segments). These stations are monitoring the satellites and control their ‘health’ (possible damage, electrical problems) as well as their exact position.

There is one Master Control Station that is collecting data from the other four Ground Stations. The Master Control Station is responsible for the entire preservation of the monitoring of the place- and signal data. It calculates every position or error in the atomic clock, for each satellite individually, based on the information from the Monitor Stations. It sends the signals back to Monitor Stations, which send the corrected data to the satellite.

The Monitor Stations control the exact height, position, velocity and “health” of the rotating satellites, they also take care that the errors in the orbital routes and the atomic clock are minimal. Occasional errors can be evaded. These check-ups are accomplished twice a day, when the satellites are in the visual of the Monitoring Stations.

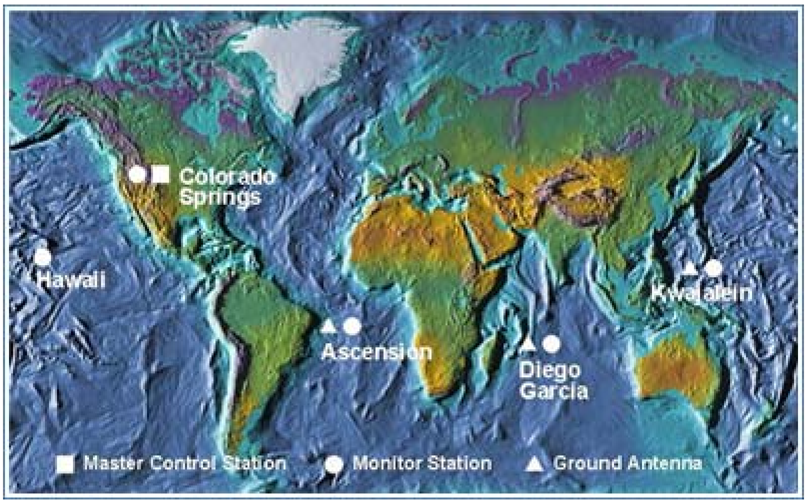

figure 12: Position of the Monitor Stations

3.2.3 The Receiver

The GPS receiver is in fact a special kind of radio receiver, which has been developed to receive the signals emitted by the satellites and to calculate the exact position with this information. The receivers differ in size, possibilities and price (which is mostly linked to the accuracy of the receiver). Most receivers can receive data from four or more satellites and switch between satellites during surveying.

There is a difference between civilian and military receivers, because the latter ones use encrypted data, so only the desired authoritative sources can use these signals.

3.3 Triangulation

The basics of the GPS system is in fact simple triangulation. The task of the GPS receiver is to localise four or more satellites, to calculate the distance to these satellites and use this data to calculate its own position. The difficulty here is that the triangulation is three-dimensional instead of two-dimensional, therefore a little explanation.

3.3.1 Two-dimensional

When you know for example that you are at a distance x from place A, you can be everywhere on the circle with radius x, so you don’t know your exact position.

Now when you know you are also at a distance y from place B, you know you have to be at the intersection of these two circles. But there are two intersections, so you still don’t know the exact position.

A third circle can solve the problem, because this one can eliminate one of the intersections of the first two circles. So when you know you are at a distance z from place C, this circle will intersect at one of the two points. Distances to other places will give even more accurate information.

3.3.2 Three-dimensional

Three-dimensional triangulation is initially not very different from two-dimensional, but might be a little harder to imagine. Imagine the radiuses from the example above are not in a surface but are three-dimensional, so we get three spheres instead of three circles.

When you know the distance to satellite A (i.e. 20000 km), your position will be somewhere in space on a sphere with radius 20000 km. (Figure 13)

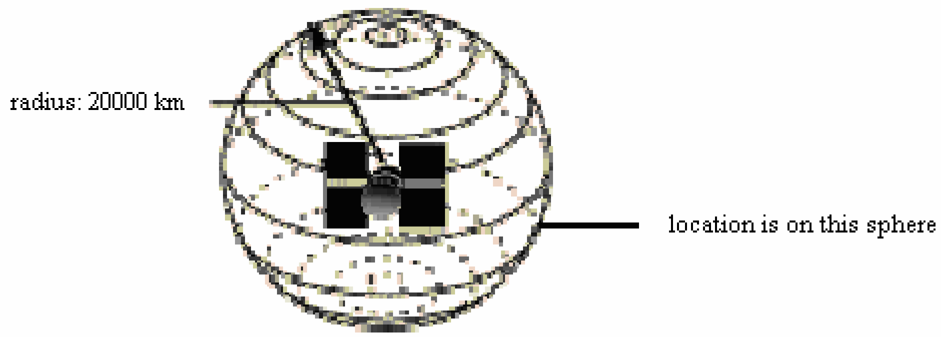

figure 13

Subsequently we calculate the distance to a second satellite B en we find a distance from 23000km. Thereby we know that our position is not only on the surface of the first sphere, but also on the surface of the sphere with centre satellite B and a radius of 23000km. The possible location is one of the intersecting points of these two spheres. These points are located on a circle which is the profile of the two spheres. (figure 14)

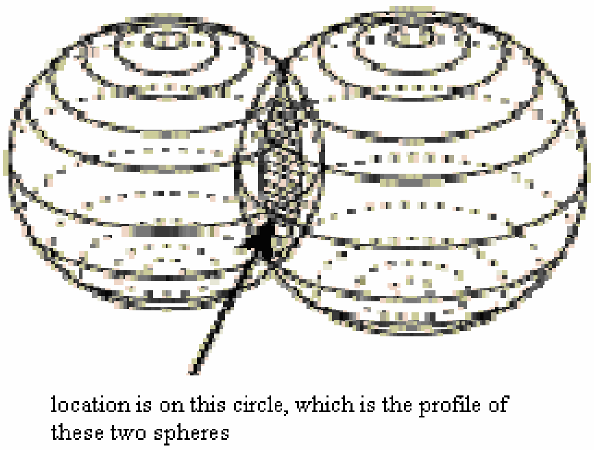

figure 14

When we achieve a third measurement, we know the distance z to a third satellite C (i.e. 18000km). This sphere will intersect the circular profile of the other two spheres at two points. Now the possible locations are limited to these two points. (figure 15)

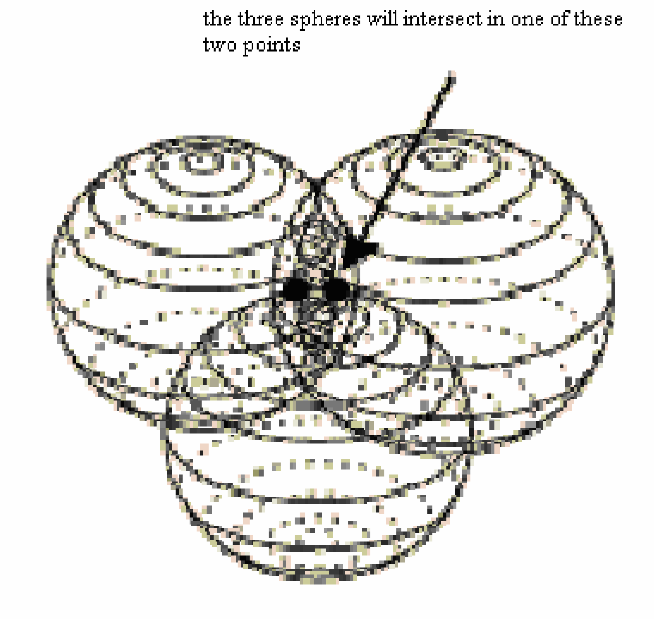

figure 15

To know on which of the two points we are located, the earth surface can act as a fourth sphere (one of the points is located in space, the other on the earth surface) or we can make a measurement to a fourth satellite, which will both intersect at one of the points. More satellites will improve the position accuracy.

3.4 Measuring distances

We talk about measuring distances from earth to the satellites that are moving in an orbital route around the earth, but it is not that simple, and it needs some explanation.

3.4.1 Mathematical idea

The idea behind the GPS system is measuring how long it takes for a signal, emitted by the satellite, to reach the receiver. In fact it is based on a simple equation (figure 16):

Velocity x Time = Distance

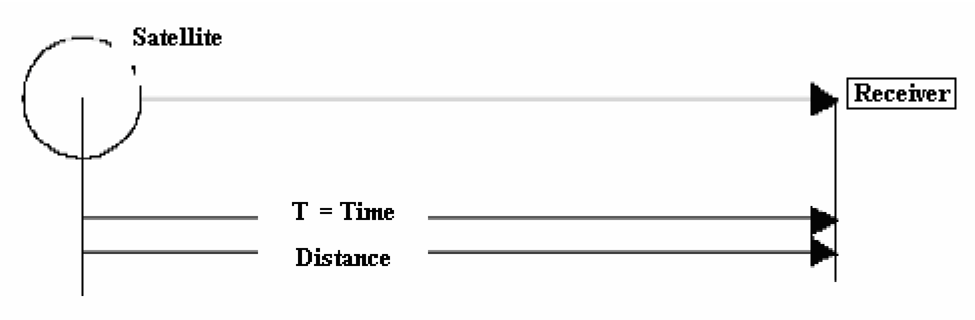

figure 16

In the case of the GPS system we are measuring radio signals, from which the velocity is the speed of light, about 300000 km/s, which makes measuring time not easy.

First of all the times are very short; when a satellite is above the receiver, it would take approximately only 0,06 seconds, which will make ultra precise time measuring necessary. The satellite as well as the receiver need a clock that can be synchronised on the nanosecond. An error of one thousand of a second causes an error of almost 200 meters.

To achieve this level of accuracy both the receiver and the satellite should be equipped with an atomic clock. But only the satellites are equipped with atomic clocks, not the receivers, because it would make the receivers unaffordable. The GPS system uses a normal quartz-clock but with a smart system that is very accurate too.

We can represent this idea in a simple way; imagine we have very precise clocks at our disposal. Now both the satellite and the receiver can send out the same signal at exactly the same time. When the signal should be able to reach us here on earth, we would hear two versions of that signal, they wouldn’t sound simultaneous. The signal from the satellite would have a little delay, because it has to travel the distance to earth.

When we want to see the delay of the signal from the satellite, we can delay the signal emitted by the receiver so the signals would sound simultaneous. Now we know that then delay is equal to the time the signal needs to reach us from out of space.
When we multiply this time by the velocity of light (300000 km/s), we have the distance from the satellite to the earth surface. This is the basic explanation of how it works.

We can abstract this in a few lines:

- The distance to the satellite is determined by measuring how long it takes for a radio signal to reach the earth.
- To make this measurement, we assume that both satellite and receiver generate the same signal at exactly the same moment.
- By comparing the delay of the signal emitted by the satellite, we can calculate how long it takes to reach us.
- When we multiply this by the speed of light we get the exact distance.

The signal that is used by the GPS system is not a simple radio signal, but a complicated signal which is called the “Pseudo Random Code”, explained in the next part.

3.5 Pseudo Random Code

The Pseudo Random Code is a fundamental part of the GPS system. Fiscally spoken it is just a very complicated digital code, in fact an order of ‘on’ and ‘off’ signals, also known as ‘0’ and ‘1’ signals.

The signal is so complicated that it resembles electrical noise, hence the name “Pseudo Random”. There are a few different reasons for this complexity. First of all, the complexity of the pattern prevents that accidentally another signal is picked up. The complexity of the pattern is that high that it’s almost impossible that there exists a similar signal.

Every satellite has also its own Pseudo Random Code, so the receiver wouldn’t accidentally pick up a signal from another satellite, and all satellites can use the same frequency without disturbing each other.

But there is another reason for the complexity of the Pseudo Random Code, and that is to make the GPS system economical. These codes make it possible to amplify the signals, whereby it stays possible to make our GPS receivers quite compact, so we don’t need big antennas to receive the signals.

We forgot one thing, we acknowledged that both the satellite and the receiver start sending out their codes at exactly the same moment, but how everything is synchronised?

3.6 GPS signals in detail

3.6.1 Carrier signals

Each satellite has an oscillator and emits carrier signals in two frequencies, named L1 and L2. On the carrier signal L1 there is a user code (C/A code) and a precision code (P-code) modulated, together with information about navigation. The carrier signal L2 contains the P-code and further information concerning synchronisation, route data and atmospherical corrections.

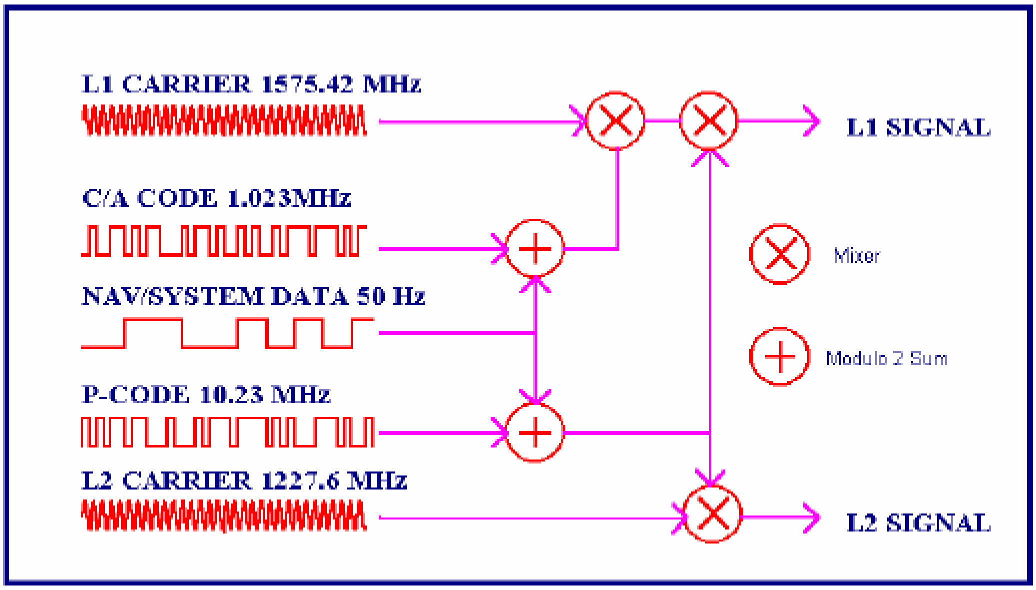

figure 17: Summary of the GPS signals

3.6.2 Pseudo Random Codes

The first Pseudo Random Code is called the C/A-code (Course/Acquisition) and is modulated on the L1 code, and is the base for civilian GPS navigation. A low-frequent signal is added to the L1 code, and gives information about the route of the satellite, the clock corrections en the system status of the satellite.

The second Pseudo Random Code is called the P-code (Precise) and is modulated on the L1 as well as on the L2. This code is destined for military use en can be converted in a secret code en is than called Y-code, so possible enemies can't decode the signal.

Component	Frequency (MHz)	
Fundamental frequency	f_0	$= 10.23$
Carrier L1	$154\ f_0$	$= 1\,575.42$ ($\hat{=}$ 19.0 cm)
Carrier L2	$120\ f_0$	$= 1\,227.60$ ($\hat{=}$ 24.4 cm)
P-code	f_0	$= 10.23$
C/A-code	$f_0/10$	$= 1.023$
W-code	$f_0/20$	$= 0.5115$
Navigation message	$f_0/204\,600$	$= 50 \cdot 10^{-6}$

Parameter	C/A-code	P-code
Chipping rate	$1.023 \cdot 10^6$ bits per second	$10.23 \cdot 10^6$ bits per second
Chip length	≈ 300 m	≈ 30 m
Repetition rate	Millisecond	One week
Code type	37 unique codes	37 one-week segments
Properties	Easy to acquire	More accurate

figure 18: Frequencies and parameters of the signals

3.6.3 Code-Phase GPS vs. Carrier-Phase GPS

These terms refer to the specific signal we use to measure time. By making use of the GPS Carrier Signal frequency we can strongly improve the accuracy of the GPS system. The idea is simple, but it needs some more explanation.

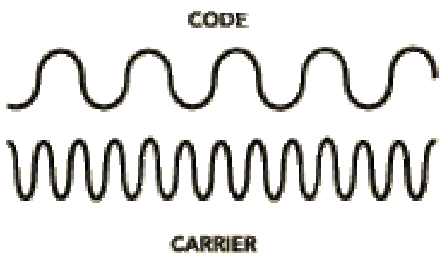

figure 19: Code frequency vs. Carrier frequency

As we described above, the GPS system calculates the time it takes for the signal (Pseudo Random Code) to reach the earth. Therefore the signal, emitted by the receiver is being retarded until both signals are synchronised. The time of delay equals the time the signal needs to cover the distance.

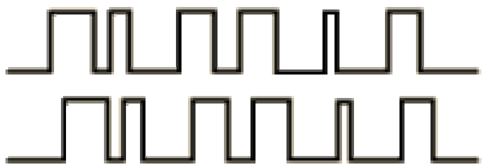

figure 20: Delay of the signal

The problem is that the bits (different cycles) from the Pseudo Random Code are very broad, even if they are synchronised and that there is a certain space. Let us look at the next figure:

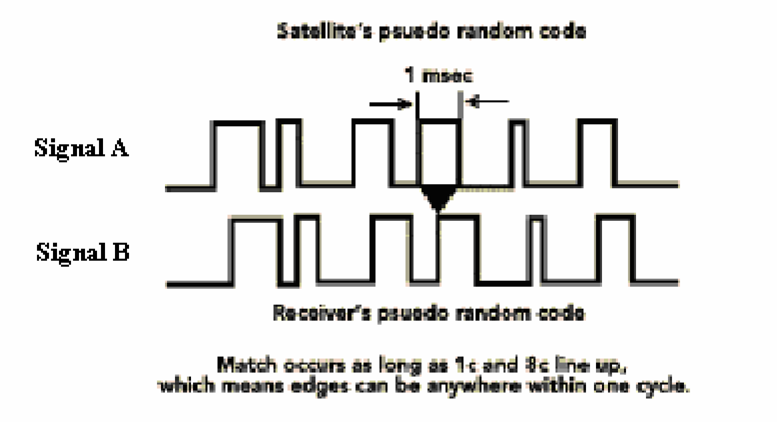

figure 21: Match of the signals

When you compare both signals it seems that they are analogous; when signal A is ‘1’ signal B is ‘1’ and when signal A is ‘0’ signal B is also ‘0’. But as you can see both signals are not perfectly in phase, notice signal B is slightly in front of signal B. In fact you can move signal A almost half a cycle and the two signals will still correspond. (see figure 21 above)

This is the problem with Code-Phase GPS. It compares the Pseudo Random Codes, which have as width of the cycle almost one microsecond. When signals travel at the speed of light, it will conduct to an error of about 300m, which is unacceptable.

3.6.4 3.6.4 A higher frequency

The receivers start receiving and recognizing the Pseudo Random Code and commute to measurements based on the carrier wave for this Pseudo Random Code. The frequency of the carrier wave is much higher so these waves are much closer together subsequently it is far more accurate (see figure 22).

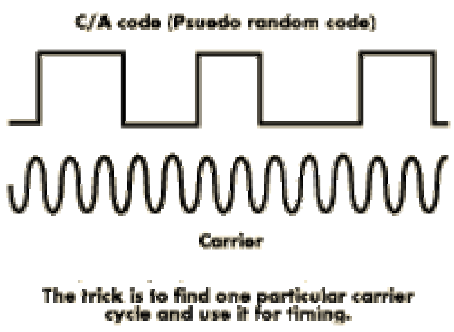

figure 22: A higher frequency of the carrier wave

We can compare the design to a normal radio receiver. The music we hear is a modulation in the carrier frequency. GPS works similar, the Pseudo Random Code has a bit rate of about 1 MHz, but the carrier frequency has a cycle of more than one GHz (Gigahertz), which is more than thousand times as fast. By taking the velocity of light, the GPS signal has a wavelength of about twenty centimetres so the carrier frequency can serve as a much more accurate referential than the Pseudo Random Code itself.

3.6.5 Receiving the right wave

In essence this method ensures that the exact amount of carrier wave cycles between the satellite and the receiver are being counted. But the carrier frequency is very hard to count because it is a very uniform signal, every signal resembles another.

On the other hand, the Pseudo Random Code is made very complex to make it easier to know in which cycle you are, but it is less accurate. So the trick with the Carrier-Phase GPS (most accurate) is to use the Code-Phase techniques to get close and then we only need to consider a few wavelengths of the carrier frequency to see what the end of our measurement is.

3.7 Exact time measurement

As mentioned before, exact time measurement is important. In a satellite we get this by the very accurate atomic clock, but in the receiver it is a simple quartz clock. Some explanation is necessary.

When the clocks in the receivers were accurate, all the measured distances would intersect in one point. With non-accurate clocks there would be a fault in the measuring, it wouldn’t intersect in one point when we handed out a fourth measurement (as a control). The receiver’s computer will notice the clock isn’t synchronised with universal time.

Because every small aberration from the universal time would influence our measurements, the receiver will look for a correction factor. This correction will set the atomic clock back to universal time, and so you have the accuracy of an atomic clock in the palm of your hand.

As a result of this every decent GPS receiver needs at least four channels to hand out four measurements (distance to at least four satellites) at one time. With the Pseudo Random Code as a fixed time signal and this little trick to perfectly synchronise the receiver with universal time, we have every factor to calculate the exact distance to the satellite in space.

In this case we consider that we know the exact position of these satellites, but how do we know where these satellites are, rotating around the earth.

3.8 Exact position of the satellites

The satellites circle at a height of about 22240 km above the earth surface, and this is even an advantage, because there is no atmosphere whereby the satellite will describe a simple mathematical route.

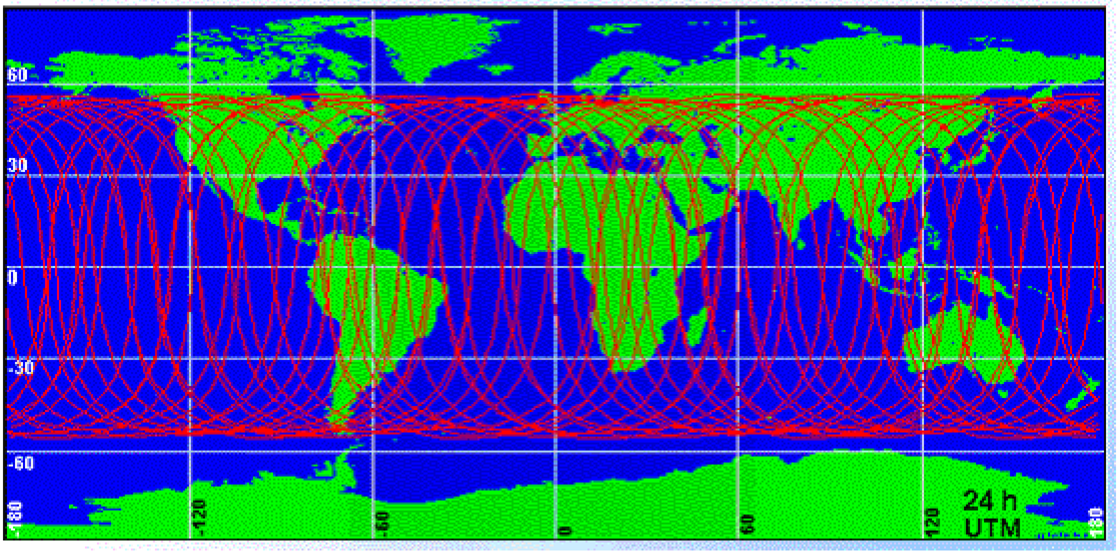

figure 23: Satellite routes projected on the earth surface

The satellites are launched into exact position by the Department Of Defence (USA). Every GPS receiver has a logbook containing the perfect routes of the satellites, so the receiver knows where every satellite is at any moment.

To make everything accurate there is a permanent monitoring of the satellites by the Department Of Defence, which contains, exact location, height and velocity. The errors which are corrected are called ephemerical errors, because they influence the route of the satellite (or ephemeris) and are caused by gravitational attraction from both moon and sun and by pressure from solar radiation on the satellites.

When the correction is made, the information is send back to the satellite which will take notice and use it in the time signals it sends.

3.9 Possible errors in GPS signals

Despite all the electronics and solutions to improve the accuracy of the GPS system, there are some factors which influence the signals and thus make the system less accurate. Here a little summary of possible errors and their solutions:

- One of the basic information we took for granted during this whole explanation, is in fact not fully true. We told that we calculate the distance to the satellite by multiplying the time of travelling by the velocity of light, but this velocity is only constant in a vacuum. GPS signals pass through the loaded particles of the ionosphere and through the vapour particles in the troposphere and will hereby be slowed down. This causes the same sort of aberration as incorrect clocks.

  There are a few ways to decrease these errors. We can predict what the average retardation would be on a given day. Therefore the GPS system uses a built-in model and so part of the error will be corrected. But everybody knows that atmospheric conditions are rarely equal.

  Another way of correcting these atmosphere related errors is to compare the relative velocity of two different signals. This “Dual Frequency” measurement is quite complicated and only possible with advanced receivers. Further explanation about this would lead us too far in the subject of electronics.

- The problems for GPS signals don’t stop when they reach the earth surface. Those signals do pass clouds, glass and plastic, but are reflected by massive objects such as large buildings and mountains. Because of this reflection the signal will travel a longer way before it reaches the receiver hereby causing an error.

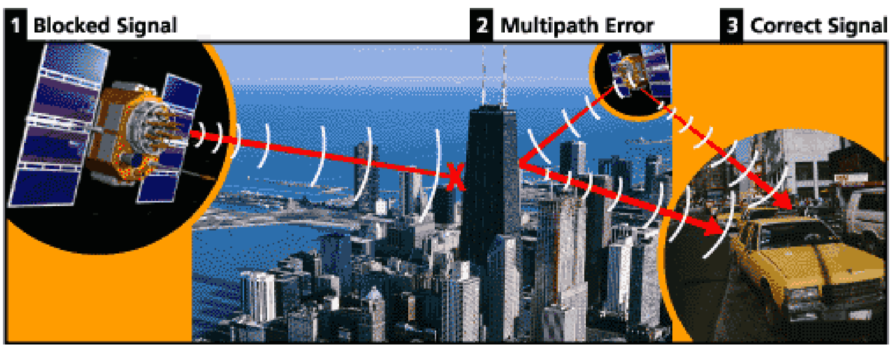

figure 24: Multipath error

These kinds of errors are called “Signal Multipath Errors”. Good receivers use sophisticated techniques to minimalise this problem, but again this is more related to electronics than the surveying applications of the GPS system.

- The satellites are sophisticated and use very exact atomic clocks, but miniscule discrepations can still occur, which is translated into very little errors in time measuring.
- Although the positions of the satellites are constantly being controlled, they cannot be monitored every second. So little errors in the route of the satellite can occur (called epimeric errors).
- Most of the time there are more satellites ‘visible’ to the receiver than strictly necessary to calculate the position. The receiver picks out the best signals or uses more signals for correction and so a more accurate positioning. Open terrains are best; forests, densely built and mountainous areas can decrease the ‘visibility’. Also under dense tree canopy there may be some problems, which could give some problems in our case (use of GPS in forestry). Electrical interference can also cause some errors in positioning; the receiver won’t work indoors, under ground level or under water.
- Also the geometry of the satellites takes a part. This resembles the relative position of the satellites at a certain moment (positions of the satellites in relation to each other and the receiver).

  Point Dilution of Precision, or PDOP, is a general indicator of the accuracy of a GPS measurement as determined by satellite geometry. Low PDOP values are reported by a receiver when satellites are widely spaced in the sky above the user. The best possible satellite geometry, one that gives the lowest PDOP, can be found when one satellite is directly overhead and the remaining three satellites are equally spaced around the horizon. High PDOP’s occur when satellites are close together or when they form a line in the sky. Only in very rare cases are satellites arranged in a configuration that prevents the receiver from obtaining a position.

Most of these problems can be decreased by using “Differential Global Positioning System”.

3.10 Differential Global Positioning System

Differential Global Positioning System (DGPS) works by placing a high-performing GPS receiver (referential station) in an exactly known place. Because the receiver knows it exact position, it is able to define the errors in the signals emitted by the satellites.

This is accomplished by measuring the distances to the satellite by means of the received signals and comparing these to the real actual measurements, calculated out of the known position of the satellite and the referential station.

The difference between the measured and the calculated distance is the global error. This information concerning the error is encoded in a correction message and is sent to the GPS user. The degree of accuracy is obtained by the quality of the receiver and is less than half a meter.
Accuracy with DGPS is estimated about 3-5 meters.

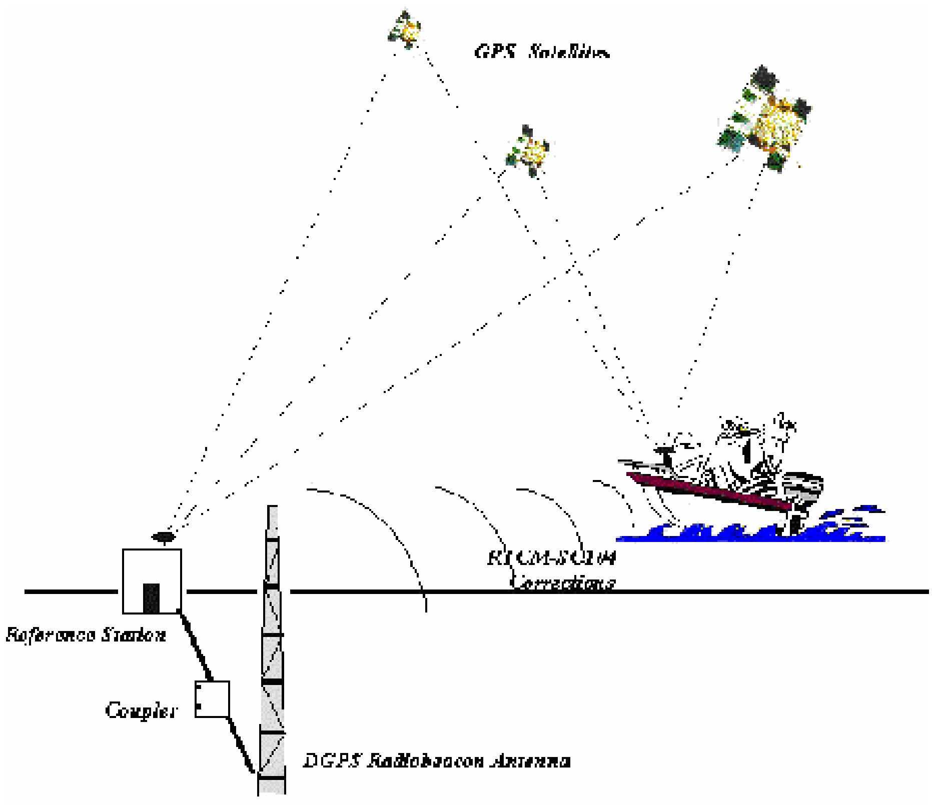

figure 25: Basic sketch of the DGPS system

3.10.1 Referential stations

The referential stations know the exact position of their antenna (obtained from standard surveying) and they calculate the distance to the satellite so they know what the measured distance should be. It measures its distance to the satellite by making use of the received signals, just as a normal receiver does. Now the measured distance is subtracted from the calculated (= exact) distance, and the result is the error on this distance. This information is sent to the user and not to the satellite. In fact it is a kind of real-time correction of the signals.

3.10.2 Radio transmitter

The radio transmitter is an amplifier that is connected to the antenna. The modulated signal is amplified and is sent to the antenna. The transmitter has an output of 250-1000 Watt and makes use of the 300 KHz frequency. The amplified signal is now sent to all DGPS receivers via the antenna, for ‘real-time’ position corrections.

3.10.3 DGPS receivers

The DGPS receiver decodes the signal received from the referential station. This information is used in the positioning to make a more accurate positioning.

Also post-processing differential corrections are possible and are even more accurate.
Disadvantages of post-processing are: no real time corrections, takes more work and time

3.11 Possible GPS errors

Here is a small list with some possible GPS errors, and the differences between normal standard GPS receivers and those with Deferential GPS. You can clearly see that there is a big improvement in accuracy between the two, only the multipath errors can’t be corrected by DGPS.

Maximum errors (meter)	Standard GPS	Differential GPS
Satellite Clock	1.5	0
Errors in the route	2.5	0
Ionosphere	5.0	0.4
Troposphere	0.5	0.2
Noise	0.3	0.3
Multipath errors	0.6	0.6

figure 26: Maximum errors for Standard GPS and DGPS

3.12 WAAS/EGNOS

Receivers equipped with WAAS/EGNOS will make even more accurate measurements possible. WAAS is the abbreviation of 'Wide Area Augmentation System' (USA) and EGNOS is 'European Geostationary Navigation Overlay System' (Europe). Both are based on a network of ground stations (with an exact known location) and satellites. Hereby most of the errors due to the atmosphere are eliminated. It doesn't need any form of subscription or extra receivers.

You can compare this system with the differential GPS system, but here the corrections of the ground stations are first sent to the geostationary satellites, which send the corrected information to the user on earth. Each receiver which supports WAAS/EGNOS can make use of these corrections. Accuracy with WAAS/EGNOS is less than 3 meters.

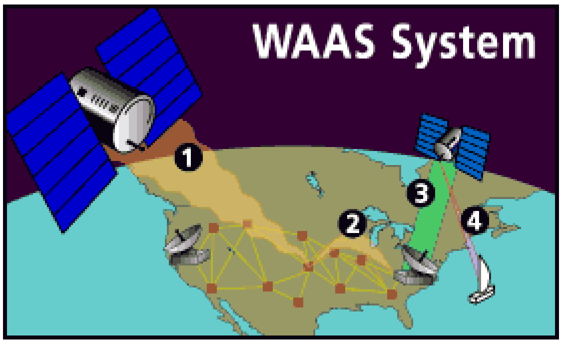

figure 27: WAAS system

Chapter 4 A new way of working with GIS

Until recently, the only way we could use GIS to solve a problem was to assemble all of the necessary pieces in one place, on a user's desktop. But recent advances now allow all of the parts – the data and the software – to be accessed remotely, and allow the user to move away from the desktop and hence to apply GIS anywhere. This is called distributed GIS (DGIS). This chapter describes the current capabilities in distributed GIS, the place of mobile GIS and what distributed GIS has to do with our project.

4.1 Distributed GIS

We have already explained the six components of a GIS as its hardware, software, data, users, procedures and network. In this paragraph, we describe how an extended network has enabled a vision of distributed GIS, in which the component parts no longer are located in the same place. The new technologies in information technology, together with a more and more mobile society are moving us to the point where we can operate and conduct a GIS project not only from our desktop, but anywhere we choose to be, using data anywhere on the network and using software, provided by sites on the network or installed on a (mobile) device. So, in distributed GIS, the six components may be at different locations. This poses a few challenging questions, such as one about locations. In the next paragraph, we examine this "location problem."

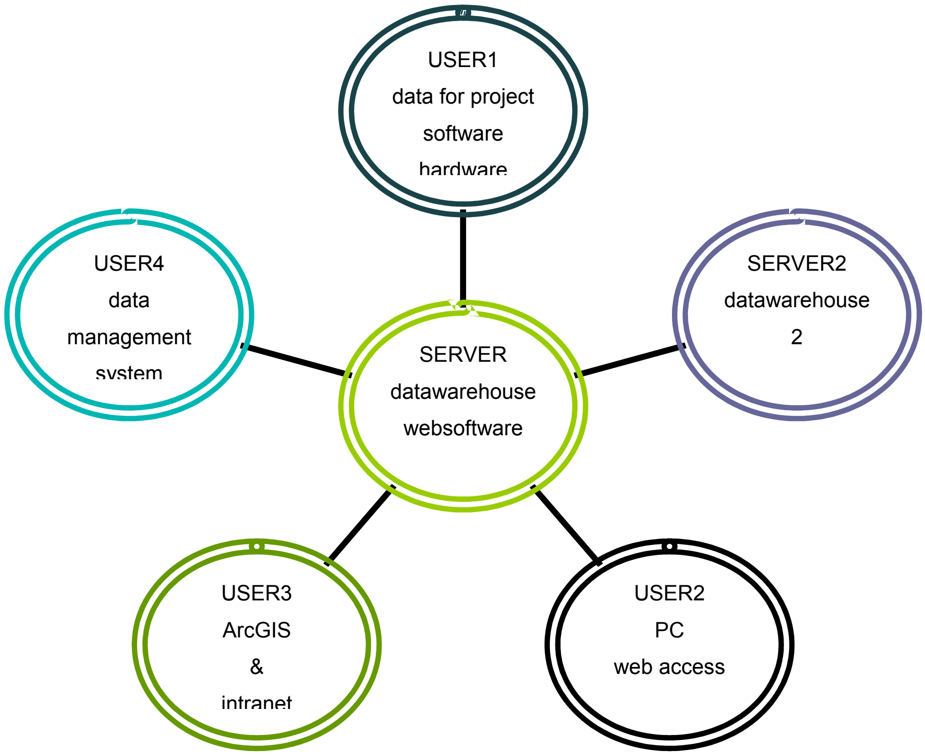

figure 28: Structure of a distributed GIS

4.2 Relativity of locations in distributed GIS

In the previous paragraph we mentioned that the core of distributed GIS is the fact that all of the components of a DGIS can be at different locations. Partly, this was already possible before the introduction of mobile GIS, but mobile GIS strengthened the idea of the different locations even more by its mobility. Let us take a closer look at an example of the locations:

- the location of the user and the interface from which the user is operating his GIS, let us call it U;
- the location of the data being accessed by the user, denoted by D;
- the location where the data are processed, denoted by P;
- and at last the area that is the focus of the GIS project, called A.

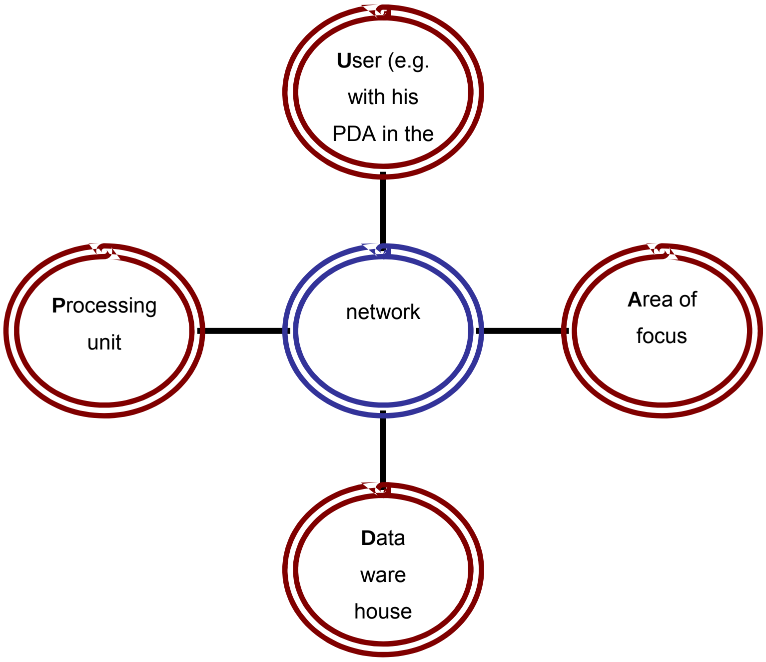

figure 29: Scheme of the different locations in DGIS

In traditional GIS, U, D and P are the same location and are almost never the same as location A. By the introduction of fast network connections it isn't necessary any more that U, D and P, D are in the same location. It's even possible that D hasn't one central location or even a distributed static location. This is the point where mobile GIS interferes. By using mobile devices like handhelds, tablet pc's or cell phones, that also can store data, the data can be distributed over a wide area without any static location. Part of the GIS might be held in the user's hand, stuffed in a backpack, or even mounted on a vehicle. The place of the data will be maintained by a central server that holds all the connections to certain datasets. This means that, as never before, in distributed GIS, the user's location and the focus area can be the same.

Mobile GIS not only acts as a distributed data warehouse, it also makes the processing unit (P) being distributed. The progression in mobile devices gives PDA's faster and faster processors. This enables the user to do also some simple queries and statistical calculations in the field. So distributed GIS reinforces the notion that today's computer is not simply the device on the desk, but something more extended and much more mobile. Computing becomes ubiquitous or location independent. We can state that distributed GIS is one of the technologies that brings GIS into the fieldworker's hand.

4.3 *Benefits of distributed GIS*

Distributed GIS has many potential benefits, these are discussed in the following paragraphs. First we will explain the feasibility of distributing data. Afterwards, we discuss the mobile technologies within a distributed GIS and the benefits for the user particularly within area A. In the following text, we try to distinguish the vision of distributed GIS and what is practical at this time.

4.3.1 Data exchange

In most cases, users use a homogeneous GIS model. In the simplest case of software form, one vendor is used on one operating system (OS). This means that also a certain software-specific file format is used. On first sight, there's nothing wrong with this, but functionality is restricted to that specific system. The internal data standard is difficult to share with other users, who use other software or another OS. To share your data, human processing and the right software will be needed. This is costly and time consuming as well as open to errors. A homogeneous approach can just be used as long as one doesn't have to interact with non-aligned systems.

In an attempt to diminish the restrictions of a homogeneous GIS model, distributed GIS or heterogeneous GIS is introduced. The terms distributed and heterogeneous not only refer to the location problem we mentioned above but also to a computing environment in which a variety of software and hardware co-exist and interact. In such an environment, users are not restricted to vendor systems or formats. This is interoperable GIS. The major benefit is the ability to distribute and combine separate data to produce new datasets, independent of the original format, not only to decrease conversion cost within an organisation but also to enable multidisciplinary teams with members from several organisations to work together without dependency on one software package.

4.3.2 Distributing the data

Since the popularization in the early 1990s, the internet has had a tremendous influence on the accessibility of GIS data and on the ability to share data. Many websites provide GIS data, for free, for sale or for temporary use. The vision of distributed GIS goes beyond the access and retrieval of remotely stored data. In the world of distributed GIS, users can search for data, on their own servers, on remote servers and examine their fitness for use. To get these search and examination commands done from our PDA, three concepts are very important:

- Object-level metadata (OLM) describe the contents of a single dataset. OLM are needed to search through the archives. It's comparable to a library's catalogue, where books are organised by author, title and subject. This makes it easy to find a particular book. When we find our dataset, the OLM will help us to determine whether the data could fit our requirements - like resolution and quality - or not, in other words, to examine the fitness for use. When we select a book on a certain subject, by a certain author, we like to know if we understand the language in which it is written. This is the third goal of OLM. It provides the information needed to handle the dataset. This may include format, compatible software, location, volume. Finally, OLM provides information on the dataset's contents. In case of remotely sensed images, we talk about percentage of cloud or shadowing. So, object-level metadata are formal descriptions of datasets that satisfy many different requirements.

- Geolibraries are the digital technology to support search and discovery. We can do searches, but we can also reorder the catalogue by any property of the OLM, add our own collections. The sorting by location or data are for example of great use for GIS users. Longley says: “The term geolibrary has been coined to describe digital libraries that can be searched for information about any user-defined geographic location”.

- Collection-level metadata (CLM) are metadata that describe entire collections of datasets, rather than individual datasets as OLM do. Many geolibraries exist on the internet, but this abundance of accessible data presents a problem. How does the user know which collection to search for a given dataset? So, the CLM defines the information needed to make an intelligent choice, based on the information of each collection’s contents. This seems all very logical, but CLM is still largely unorganized. A possible solution, according to Longley, could be to develop internet wide search engines to discover geographic datasets directly on the level of OLM.

This collection of metadata is of capital importance for a smooth operating distributed GIS. Without good metadata, a user cannot find the right dataset to serve his goals. The metadata helps users understand the data. It provides consistency in terminology, focuses on the key elements of data and helps to determine the fitness of use. Metadata enables people to use data in an ecological way by protecting from investment in data as well. The metadata sets the stage for a data re-use and update and provides documentation of data sources and quality. And, last but for surely not least, it cuts down the overall costs an organisation has for maintaining and providing their data.

4.3.3 Location-based services

One of the four big trends in software is location-based applications[4].

In this age of a significant telecommunications competition, mobile computing world continuously seeks new and innovative ways to create differentiation and increase profits. One of the best ways to do accomplish this is through the delivery of personalised services. One of the most powerful ways to personalise mobile services is based on location. We will discuss these Location Based Services (LBS), but we will first discuss the basis of LBS - location technology.

Traditional computing devices, such as desktops or laptops, have no way of knowing where they are, and their functions are not changed when they are moved. But increasingly, the essential information on a device’s location is available, and is used for a wide variety of purposes.

One of the most obvious technologies behind LBS is positioning, with the most widely recognized system being the Global Positioning System (GPS). There are however, other means of positioning in addition to GPS. These other technologies are network based positioning and typically rely on various means of triangulation of the signal from cell sites serving a mobile phone. In addition, the serving cell site can be used as a fix for location of the user.

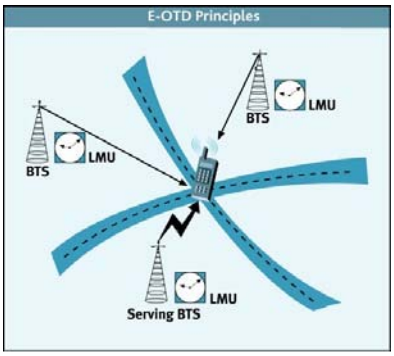

figure 30: Positioning by mobile antennas[5]

[4] Bill Gates, Wireless 2000 Conference, March 2000

One of the strongest motives driving this process is emergency response. A large and growing portion of emergency calls come from cell phones, and while the location of each land-time is likely to be recorded in a database available to emergency responder, in a significant proportion of cases the user of a cell phone is unable to report his or her current location with sufficient accuracy to enable effective response. One solution to this problem is to install a GPS in the vehicle that communicates its position to the dispatcher. The Onstar system is one such system. OnStar's in-vehicle safety, security, and information services use GPS and cellular technology to link the vehicle and driver to the Onstar Centre. At the Onstar Centre, advisors offer real-time, personalized help 24 hours a day, 365 days a year. In the event of a moderate to severe frontal or side-impact crash, data is transmitted from the affected sensors to the SDM. Regardless of whether the air bags deploy, the SDM transmits crash information to the vehicle's Onstar module. Within seconds of a moderate to severe crash, the Onstar module will send a message to the Onstar Call Centre through a cellular connection, informing the advisor that a crash has occurred. A voice connection between the advisor and the vehicle occupants is established. The advisor can conference then in 911 dispatch, which determines if emergency services are necessary. If there is no response from the occupants, the advisor can provide the emergency dispatcher with the crash information from the SDM that reveals the severity of the crash. The dispatcher can identify what emergency services may be appropriate. Using the Global Positioning System (GPS) satellite, Onstar advisors are able to tell emergency workers the location of the vehicle.

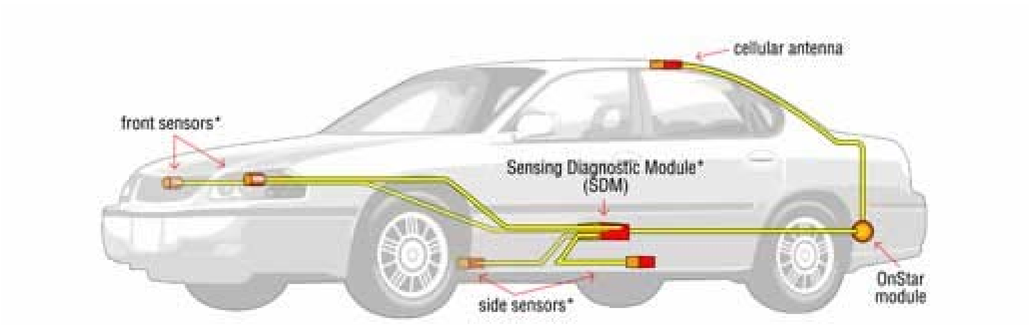

figure 31: Onstar system

There are many other examples of LBS that take advantage of location enabled cell phones, e.g. yellow page services, trip planning or even games like Undercover.

[5] http://www.evaluationengineering.com/archive/articles/e10-wire1.jpg

4.4 Back to our mobile GIS

Computing has become so much part of our lives that for many people, life would be difficult without it. We use it to communicate, to shop, to work, to entertain ourselves. In the early days, the only place one could compute was in a computing centre, within a few meters of the central processor. Computers have been extended to the office is the 1970s and to the home in the 1990s. The portable computers opened the possibility of computing anywhere in the house, in the garden, on the beach, in the park etc. Wireless communications now allow also broadband connections anywhere near the so-called "hot-spots." The range of these mobile devices is also multiplying rapidly, from a heavy laptop to a PDA, tablet pc or even a cell phone. Within a few years, we might see the convergence of these devices in one powerful mobile personal device.

For our project, we use a MobileMapper CE from Thales as mobile computing device. The connection between our device and the main database to participate in the distributed network, is made hard-wired. This means we use a cable to load data into the memory of our PDA. We don't take advantage of the wireless communications or Bluetooth[6] because of the wide area of usage. Forests in Finland take approximately 70% of the area, so our GIS must be used in this whole area and that would ask for too much technology to get a full coverage of the area. If many people are working in the same area, let's say at about 300 m round a central communication post, e.g. a car, it could be possible and might be useful to setup a wireless local area network (WLAN) that holds all the necessary data to do the fieldwork. This makes it possible to take more data with you than the memory of the PDA accepts. If there's no way of using a WLAN, this connection to the laptop, holding all the necessary data, can also be made hard-wired.

4.5 When does a distributed GIS make sense?

The continued advances in remote sensing, mapping and geospatial technologies, including an increasing variety of data acquisition capabilities and low cost and more powerful computing capacity, coupled with the development of GIS technology, have increased the demand for geographic information. As the importance of geographic information in solving complex social, environmental, and economic issues around the globe is growing, the establishment of a DIGS to support the sharing and use of this data locally, nationally and internationally makes increasing sense.

[6] Link, info over wat bluetooth is

Without a coherent and consistent DGIS, and spatial data infrastructure, we lose opportunities and create more efficiency in the use of geographic information to solve problems. Furthermore, as spatial technologies are increasingly being used by diverse organisations in developed and developing countries, a number of obstacles add up to a geographic information bottleneck. Lack of institutional co-ordination, insufficient flow of information, overlapping of initiatives, duplication of field activities and results and poor management of resources are some of the most pressing problems. In addition, there can't be a lack of standardised metadata system and poor documentation on who is doing what and the types of available information. This could have a double negative effect. On the one hand, potential data and information users have difficulties finding or having access to the needed relevant information and, on the other hand, information suppliers do not know what they have which in turn prevents better organisation of information and enhanced value of the information.

It is important to take into account that the longer the harmonisation of stand-alone databases is delayed, the more difficult it will be to make them interoperable. Costs for integrating stand-alone systems into a distributed GIS are increasing exponentially with time and the number of data sets. This suggests that a co-ordinated initiative should be considered as soon as possible.

4.6 Prospects

Distributed GIS offers enormous advantages in reducing duplication of effort, allowing users to access remotely located data and services through simple devices, and providing ways of combining information gathered through the senses with information provided from digital sources. Many issues continue to impede progress like complications resulting from the difficulties of interacting with devices in the field, limitations placed on communication bandwidth and reliability and limitations inherent in battery technology. Perhaps this time, more problematic than any of these is the difficulty of imagining the full potential of distributed GIS. We are used to associating GIS with desktop, and conscious that we have not fully exploited its potential.

Chapter 5 Enterprise GIS

5.1 Introduction

In business and government agencies, GIS is often developed with diverse departments relying on a mix of software and information systems. Each department uses its individual system to increase efficiency, but sharing data and applications across the enterprise is nearly impossible. The resultant redundancy prevents local governments and industry from realising business goals, leveraging investment in data and technology, and controlling costs.

5.2 What is an Enterprise GIS?

Enterprise GIS (EGIS) uses a shared central geodatabase that allows integration and dynamic updating of multiple GIS data sources without time-consuming compatibility and translation issues. It is based on IT standards and web services so it also enables non-GIS applications and systems to easily access GIS functionality, and GIS applications to easily access the functionality of mainstream business applications and IT systems. With an enterprise GIS, users of spatial data spend more time on the analytical capabilities and business functions of a GIS and less time searching for, compiling, and integrating the data they require.

An EGIS delivers many benefits, increasing worker productivity and capacity to deliver goods and services to customers:

- support for the best tools for any job - each department can use its preferred software and data types, while working from a shared enterprise database;
- increasing productivity - eliminate the time wasted to convert or translate data and eliminate out-of-sync data or errors;
- increasing data accessibility - when data is stored in an enterprise database, all users and key decision makers have quick access to the most accurate and up-to-date data;
- improving communication among departments - an enterprise system requires that all independent systems communicate quickly and effectively, regardless of data format;
- increasing data security - by storing spatial data in a central database, your organization will maintain secure, high-quality data;

- enhance speed and reliability;
- enable easy web-based access for data sharing and community participation.

5.3 Aspects of an Enterprise GIS

The goal of this paragraph is to provide a comprehensive synthesis of the current knowledge on EGIS. First we set out a conceptual framework for an EGIS and then we describe a five-step process for implementing an EGIS.

5.3.1 Conceptual framework

To develop a good conceptual framework, we must consider some main aspects:

- technical needs: what's the goal of our EGIS? How many users will use the EGIS? What software and hardware will we use;
- business needs: what goal will our EGIS serve;
- current needs: what are we going to do with the GIS today and in near future;
- future needs: what's on the idea list in the development of the EGIS;
- emerging technologies: you have to take full advantage of the emerging technologies in order to build a modern and future resistant EGIS.

The three concepts we're using are the role of the stakeholders, a complete geospatial data cycle and the design of data warehouses.

5.3.1.1 The role of the stakeholders

The design of an EGIS begins with understanding the needs of the different participants or stakeholders.

Data providers need consistent standards and effective tools to prepare, organize, and document their data, as well as to ensure that the data will be responsibly managed. So they receive and review the data, rename them according to a chosen standard, add metadata and themes and then, after reviewing again, transfer them to the data warehouse where data managers organise the data in the data warehouse.

Data managers need consistent workflow procedures that ensure efficient, standardised means to manage and deliver data. GIS users are professionals and analysts who need consistent mechanisms to locate and access well-documented and reliable data to recombine them in their work.
Customers must benefit from timely and reliable service.

GIS stakeholders share common needs, such as data quality standards, data documentation (metadata), consistent data formats, and data archiving. However, each stakeholder has unique goals and requirements, in terms of infrastructure (hardware/software) and data, as well as unique ideas about the value of enterprise GIS to his or her goals and willingness to participate in data sharing. Successful EGIS design means facilitating every stakeholder's task in the geospatial data cycle.

5.3.1.2 The geospatial data cycle

A complete, or unbroken, geospatial data cycle involves flows of data from data source to database, from database to applications, and, if modifications have been made, from applications back to the database, with necessary steps to ensure that data are complete, secure, documented, and accessible. These steps include some data operations: formatting, quality assurance, documentation, cataloguing, tracking, backup, delivery, and updating.

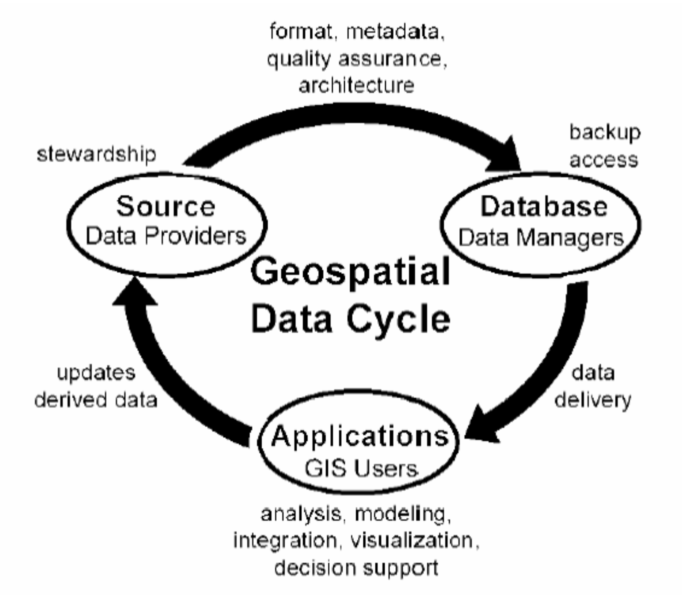

figure 32: geospatial data cycle

This circle is formed by three main aspects: source, database and applications. Every aspect has its own responsibilities and its own stakeholders:

- source: stewardship is the generator of the responsibility. This includes quality and assurance of the up-to-date data, good data documentation by a set of metadata;
- database: data management means ensuring organisation, access, delivery and monitoring of changes in the up-dating process. This is mostly the domain of IT specialists and data managers;
- applications: here we can find most of the efforts in GIS. This could be caused by the instant solving of problems, leading to a wide variety of specialised application.

In this cycle, the importance of quality control cannot be overstated. This involves standardised procedures for ensuring data needs and for communication about quality. A useful way to do this is metadata or “data about the data”. Metadata document essential characteristics of data, including source, content, geospatial extent, format, quality and means for access.

5.3.1.3 Data warehouse design

The role of a spatial data warehouse within an EGIS is to provide a clean structure for the management of geospatial data and consists of three main steps: staging, storage, and delivery. The three steps that define data flow within the context of the work performed are as follows:

- staging involves receipt of data and preparation for placement in the data warehouse;
- storage involves the actual housing of data in the data warehouse; and
- delivery involves distribution of warehoused data to GIS users.

A spatial data warehouse can provide access to shared data necessary to perform the day-to-day operations and research and development (R&D) activities.

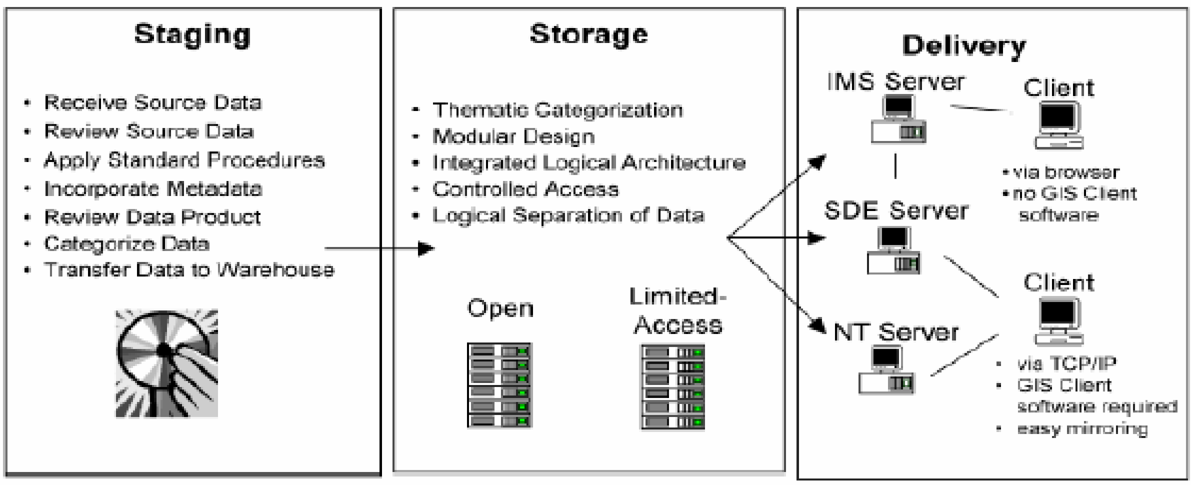

figure 33: GIS data flow

When using ESRI-software, as in our project, the data warehouse is normally an ArcSDE driven database. The software, ArcSDE has following tasks:

- managing large GIS databases that are stored physically on the servers;
- holding the links of the distributed data parts together.

When we combine this with for example the ArcIMS (Internet Mapping Service) then the following tasks are added tot the data warehouse:

- internet delivery of geographic information;
- hosting central GIS Web portals for information discovery and use;
- centrally hosting GIS functions that are accessed by many users in an organization;
- back-office processing of enterprise GIS databases;
- internet delivery of comprehensive GIS functionality.

Looking at the tasks, we can summarize the task of the data warehouse as delivering data to anyone who has access to the data.

5.3.2 Five-step design process

Jack Dangermond[7], CEO of ESRI, Inc., (2002) proposes the following five elements for the success of enterprise GIS:

- attain management support;
- develop a plan;
- be customer focused;
- ensure in-house “ownership” for the process;
- build a “team of two” of technical expertise and management support to make enterprise GIS a reality.

[7] Keating, 2003, Challenges for Enterprise GIS

According to Dangermond (2002), the plan should address five aspects:

- definition and design specifications for enterprise GIS;
- description of internal and external databases being managed;
- plan for conceptual applications and database architecture;
- system architecture, including hardware, software, and applications;
- implementation plan. The scope of the implementation plan encompasses tasks, methods, and activities; a schedule; funding sources; and organizational responsibilities. While the details are outside the scope of this article, this outline provides the basis for the development of the geospatial information management plan.

5.4 *Why Enterprise GIS*

There is a trend towards the integration of information through internet and intranet. This is a challenge for further development of local GIS teams into true enterprise resources. The use of geographical data is increasing beyond the capabilities of individual departments and the value of geographical data is increasingly being recognized. So there's a need to leave the small project-oriented GIS applications and let GIS teams work together across several departments, e.g. to develop a good regional transportation system. It focuses on the consistency, integration and extensiveness of agency-wide applications of GIS. By using an EGIS, the ability to access shared GIS resources, including data, analysis software, and computing capacity, can greatly increase efficiency and flexibility to complete a wide variety of GIS tasks. Enterprise design can enable a GIS user to access clean, consistent and properly documented spatial data from institutional servers 24 hours a day without the assistance of data specialists. Such resource sharing, with access by multiple users with multiple access rules, is surely the number one among the advantages of an EGIS.

An EGIS also diminishes in a very important way the costs of data exchange. When ad hoc project-oriented systems are used, every system needs its own data set, made by collecting, copying and exporting data. This is a time and money consuming process that isn't free from errors at all. So by setting up an EGIS, where an unbroken data cycle is of great importance, an organisation can diminish the setup cost of a system and spend this money on e.g. quality control and quality assurance.

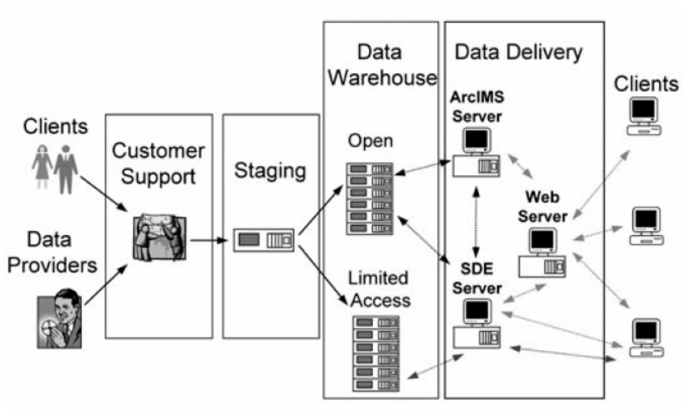

figure 34: structure of an EGIS, based on ESRI-software[8]

5.5 Enterprise GIS & the mobile user

Many mobile users welcome mobile computing devices and see the value of having such power, performance and capacity. At the same time, some software solution vendors focus on the form factor of such devices and loose sight of the true mobile requirements in the field and the problems involved with it. It's crucial to step back and evaluate mobile solutions from a field user's point of view, to better understand what exactly the pain points are. Vendors who create the mobile software solutions need to first focus on what is needed by an enterprise's mobile and field users. Understanding those needs is paramount to providing solutions that will be adopted in the mobile market. Technology should be seen as an enabler not as the main driver of the end solution. This doesn't mean technology cannot drive some parts of the process. Without innovative technology vendors the industry would not have many of the mobile solutions it has today. But we need to be careful not to lose sight of what problems we are trying to solve in this space. Some of the high level requirements for mobile users are:

- software and hardware tools that enable jobs to be done better and faster;
- access to corporate information when needed;
- automate and enhance the process of incorporating captured field data into a corporate system or incorporate into a streamlined workflow that enables quick access to the most up-to-date corporate information;
- solutions that are easy to use, efficient and stable. The ease of use is a crucial requirement that can mean acceptance of the solution;
- device independency. Field users have many different tasks with varying degrees of complexity and device requirements and mobile crews need to be agile in response. Solutions

[8] Keating, 2003, Challenges for Enterprise GIS

that are device independent enable mobile crews to respond without having to take another tool each time;

- network independence. Mobile users need software solutions that are network independent and occasionally connected. This means users can continue performing tasks when there is no network coverage without losing any of their work.

Some of these requirements are delivered by the idea of the EGIS, other require investigations in the field of the distributed GIS and even IT plays a big role in developing a properly functioning EGIS that's suitable for mobile applications. The combination of DGIS and EGIS will be discussed in § 1.6.
The mobile staff supervisors who are responsible for managing the field crews have another set of requirements that must be adequately addressed by the solutions they use. Some of those requirements include:

- mobile crews presence management, also called "tracking and management." Supervisors need to know
    - where their field crews are and;
    - what their progress is in their daily tasks along an assigned route;
- dispatching jobs or tasks to the mobile crew in real time, based on pre-defined business rules;
- adaptive systems to respond to unplanned events or situations;
- five rights of mobile solutions. The ability to assign the right job to the right resource with the right equipment in the right location at the right time;
- incorporating information about location, job asset, and field status in real time;
- full audit and reporting to enable planning and process improvements.

In addition to mobile users and supervisors, the IT staff responsible for maintaining and managing mobile solutions has requirements that must be addressed. Some of those requirements are:

- solutions based on open standards to guarantee future IT investment and improved IT support;
- commercial-off-the-shelf (COTS) mobile software solutions;
- scalability to meet future demands and growth;
- security solutions should extend over potentially unprotected networks while still preserving the integrity of user data and protect against security breaches.

Each of these requirements is important to actual users of mobile solutions. Vendors need to listen to the requirements of the users instead of making assumptions. Don't fall into the trap of assuming that more device resources (memory, processing speed and storage) for laptops and Tablet PCs mean that performance, ease of use, and software architecture are no longer an issue. Advancements in hardware and competitive pricing in the mobile industry should not cause software vendors to lose sight of the problems they are trying to solve in the mobile space. The main approach needs to continue to focus on meeting the requirements for the field. At the end of the day, success or failure of mobile solutions is defined by those in the field who need and adopt the solutions.

5.6 Combining distributed & enterprise GIS

We have already examined the fact that data is no longer restricted to a single machine in an organisation, but is widespread through the organisational network and, of course, across the ever spreading internet for the wider global community to freely access, with increasing frequency. GIS reaches the same people that the institutional enterprise business system reaches. Here we need the distributed GIS to get all the pieces of the database together in one widely accessible EGIS. By combining these two technologies, the field worker can have access to all the information spread around the network without having much trouble of finding the location. Field workers are still required to return to their office to utilise or modify data that is managed and maintained within the enterprise. Moving forward, into the not too distant future, mobile GIS can be considered, very simply, as an extension of the existing enterprise GIS. The operations and data that decision makers use today will be made accessible to the entire workforce of an organisation in both the office and field environments without any hard-wired connection. The entire workforce will become knowledge-enabled, to the extent that they will no longer be dependent on others to assign tasks or to carry out spatial queries. The field workforce will have access to the same information that everyone else in the office environment has made use of for many years now.

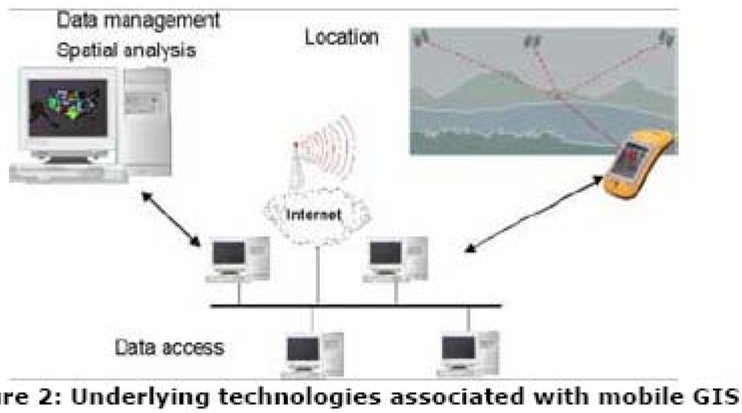

figure 35: Mobile GIS in and DGIS and EGIS environment

Chapter 6 Data collection in mobile GIS

In this chapter, we don't describe the data encoding process for the GIS. In almost every basic handbook on GIS, this is explained better and wider than we can. For further reading on the collection of spatial and attribute data, see Heywood et al., 2002 and Longley et al., 2005. We start our discourse with a ready-to-use database, where, in fact, there will be the need to add data. To add data, or to setup a new database and fill it with data, we follow, as stated by Heywood et al., 2002, this data stream:

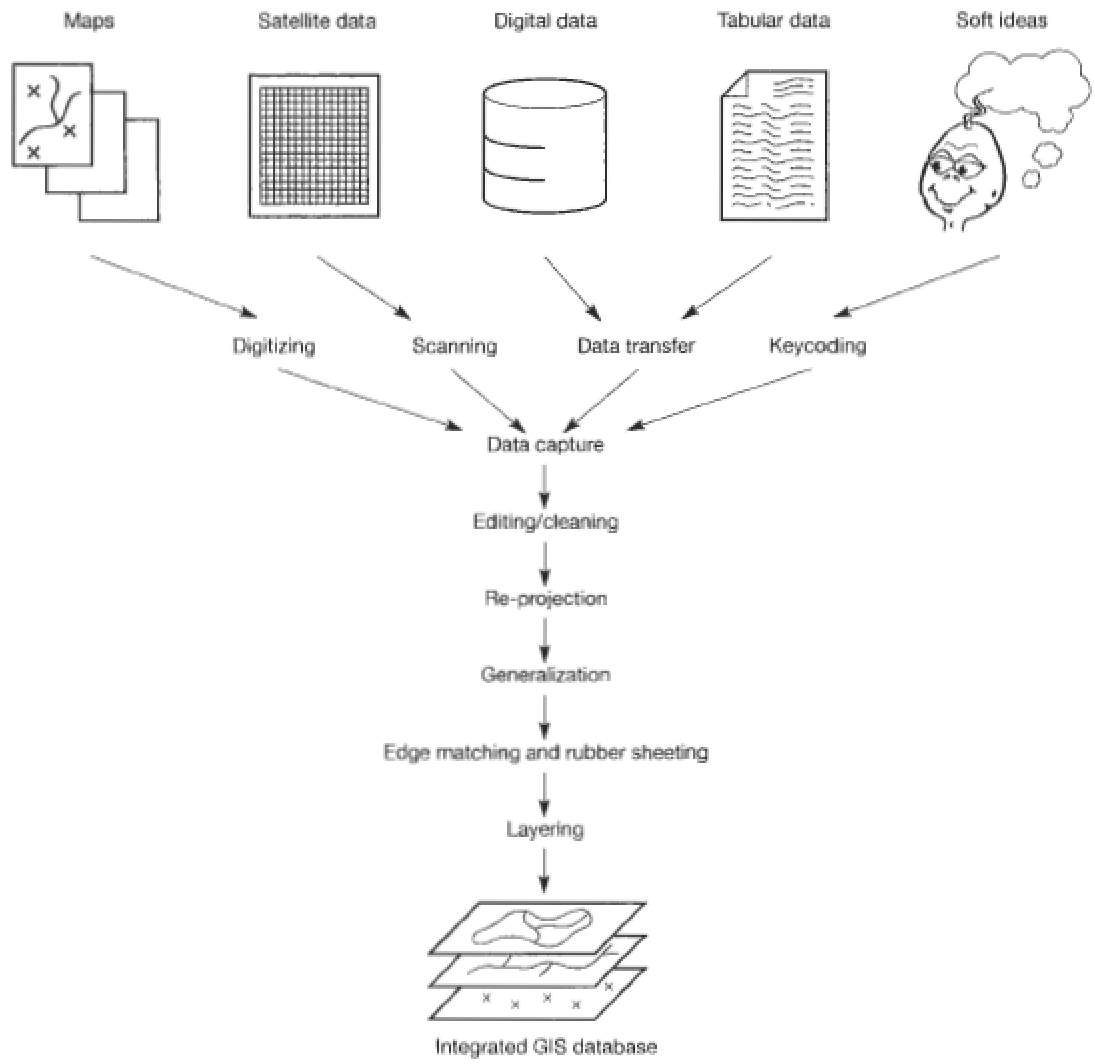

figure 36: Data stream[9]

[9] Heywood, 2002

Before implicating mobile GIS, it’s needed to make a distinction between the types of data we need in our GIS:

- spatial data: maps, satellite data. These data can be analogue or digital, or of course in both formats. The maps and aerial images serve as a background while collecting and retrieving data with our mobile GIS;
- attribute data where in the past collected in an analogue way by surveying. This is the place where mobile GIS has some great advantages in the digitising process, but this will be explained in the next paragraphs.

6.1 GIS data collection vs. mobile GIS

With the growing diversity of GPS, form factor often is confused for function. Just because two products use GPS for positioning, that doesn't mean they're developed with the same application in mind. Two such applications that have emerged from the GPS positioning market are "GIS data collection" and "mobile GIS," but GPS is where the similarities diverge.

6.1.1 GIS Data Collection

There are many ways to populate a GIS, and one of the more costly methods in time and money is infield data collection. However, after a GIS becomes mature or populated, field data collection often becomes the most cost-effective method and sometimes even the only one, to maintain and update an existing database.

Onsite collection becomes a necessity, because it's often the only way to ensure the accuracy of location and provide the ability to add site-specific database information and keep it up to date.
GIS data collection usually begins with a library of feature templates that's representative of feature classes in a GIS. The feature template defines the geometry of an object (i.e., point, line or polygon) as well as the attribute data structure. When the template is ready, it can be populated with positional and attribute data.

GIS data collection can be considered a one-way data flow: field to office. However, most GIS data collection applications provide the ability to take data into the field to update position and attribution.

6.1.2 Mobile GIS

A GIS is populated so it can be used for query, analysis and modelling. The idea of an enterprise GIS working from a multi-user database, along with Internet and wireless technology, makes mobile GIS an exciting reality. We explained the use and advantages of an enterprise GIS in Chapter 5. Multiple users have access to a common dataset, and real-time connectivity can provide a live workflow between field and office.

Unlike GIS data collection, a mobile GIS benefits from an already populated and mature geographic database. Although this doesn't require taking the entire GIS into the field, it demands that the needed dataset is available to perform the necessary tasks on the field. Mobile GIS can so, in relation to GIS data collection, be seen as a two-way data flow: from field to office and from office to field.

Another important aspect in considering GIS data collection vs. mobile GIS is the workforce that will be using the technology. Full-time field data collection isn't a job to be carried out by GIS professionals. This doesn’t make sense as we know a GIS serves some economical goals. Those who collect data, however, often face adverse conditions and unreasonable deadlines. Therefore, the main criteria for a field data collector should be accuracy, simplicity and, if possible, indestructibility.

If you're using a mobile GIS, you need to determine what form factor best suits your needs. Will you need to collect data in a vehicle or on foot? Is screen size important? Do you need your GPS integrated inside, instead of connected to, your computer, or do you require the flexibility to work with multiple devices and the freedom to upgrade your computer to respond to the fast-paced market?

Where Windows CE once appeared to be the panacea for mobile applications, advancements in chip technology and power management now have created the possibility of bringing desktop power into the field. Tablet PCs have hit the market strong and are available from several vendors.

Tablet PCs boast processor speeds greater than one gigabyte, seemingly unlimited RAM, full screen size, built-in wireless capabilities and the Windows XP operating system. ESRI, for example, developed a free set of downloadable tools for ArcGIS that take advantage of the Windows XP Tablet operating system.

6.2 Advantages of mobile GIS

The most important reason to use mobile GIS is the two-way data flow. But what is this? How can we translate a two-way data flow in advantages of mobile GIS? During this paragraph, we take a closer look to the possibilities of the data flow and show how we can take advantage of it to make our mobile GIS competitive to other techniques.

6.3 Improved field processes

A mobile data collection system fastens the collection of data. According to ESRI, we can divide this advantage into four main processes:

- inventory: recording the location and attribute information of an asset on a digital map;
- maintenance: managing asset location, condition, and maintenance schedules in the field;
- inspections: maintaining digital records of field assets for legal code compliance;
- incident reporting: spatially recording accidents or events.

Some examples of these processes

- inventory: street sign inventory, storm water inlet inventory, mineral exploration;
- maintenance: road condition surveys, crop management;
- inspections: road pavement management, housing conditions, habitat studies, damage assessment;
- incident reporting: well sampling, property damage assessment.

These are only a few examples of the use of a PDA in the field and there are many more (see figure 3)

The main reason why field processes are improved lies in the two way data flow. Mobile GIS makes It possible to capture data (spatial or attribute) directly in the field. A properly managed mobile GIS offers considerably improved data retrieval, database searching, archiving and remote accessibility compared to conventional paper-based methods. There is not only the capability to collect data and bring it to the office, you can also easily navigate to earlier collected data, check it, keep it up to date … When we combine this with the field-based analysing methods, built-in in the mobile GIS software package, it’s clear that field processes, that take a lot of digitising work after the data collection, are improved by the use of a GPS-enabled PDA.

The efficiency of fieldwork can be thought of just in terms of the time it takes to collect the field data. In the experience of general digital fieldwork, the time savings made during acquisition of field data are often marginal when compared with traditional methods of data collection. However, the digital nature of the acquired data gives large time savings because there’s no need for digitising, when subsequently carrying out detailed analysis (e.g. producing maps, spatial analyses) and producing reports.

6.4 The use of on-the-field quality improvement

Quality of data plays a very important role in the development of a GIS in any area. This is one of the prime factors securing the reliability of information as obtained from the GIS and quality of the decision making. Reliability of a GIS mainly depends upon the data quality with which the GIS is arranged and the way it is integrated and displayed for the purpose of extracting information for decision making. Since decision depends on the information contents, the quality of data must be effectively controlled[10]. Mobile GIS offers a great opportunity to do this on-the-field. First there is the fully digital data flow that reduces already every error occurring during digitising. This can be stated as the most important advantage of mobile GIS. Another less known possibility to improve the quality of the collected data is programming semantic controls. This means that during the data collection process, the software constantly controls every entry, e.g. by the use of statistics or algorithms, on inconsistencies. The codeword here is “fitness for use.” Data collection with semantic plausibility control aims to supply enough information, based on error calculations, to come to increased data applicability and a better decision making.

6.4.1.1 Data quality

For about 30 years, two different meanings have been associated with the term ‘quality’ in the literature, the first one restricting quality to the absence of errors in the data (i.e. internal quality) and the second one looking at how data fit the user’s needs (i.e. external quality) (Van Maercke) . This second definition, usually identified as the concept of ‘fitness for use’ (Juran et al. 1974; Van Maercke), is the one that reached an official agreement by standardisation organisations (e.g. ISO) and international organisations (e.g. IEEE). More precisely for the latter case, we define quality as the closeness of the agreement between data characteristics and the explicit and/or implicit needs of a user for a given application in a given area.

For more than 20 years, standardisation bodies have identified characteristics describing internal quality (e.g. ICA, FGDC, CEN, ISO, OGC). If these characteristics differ between standards, there is however an agreement on most of them and common criteria are often identified as the ‘famous five’: positional accuracy, attribute accuracy, temporal accuracy, logical consistency and completeness (ISO-TC/211 2002). It is intended to document these criteria within the metadata provided with datasets by data producers.

[10] This can be done by using ISO 19101 to ISO 19135. This International Standard defines the framework for standardisation in the field of geographic information and sets forth the basic principles by which this standardisation takes place. More information on ISO: http://www.iso.org

6.4.1.2 The famous five for data quality

There exist several criteria to describe the quality of spatial data. These are called “the famous five” and are:

- lineage is a record of the data sources and of the operations which created the database. The means that we keep track of all digitising methods, when en who did the surveys, what steps were taken to process the data … ;
- positional accuracy. This is defined as the closeness of the measured location information to the true position of the object;
- attribute accuracy, defined as the closeness of attribute values to their true value. Note that while positional accuracy does not change true time, attribute accuracy can change true the time. Attribute data are usually obtained through a combination of field work and interpretation and the categories used in the representation may not always be easy to check;
- logical consistency refers to the internal consistency of the data structure, particularly applies to topological consistency. E.g. do the polygons close;
- completeness concerns the degree to which the data exhausts the universe of possible items.

The widespread acceptance of these quality elements does not necessarily bear any relation to their suitability of the task to describe the quality of any dataset to allow the users to determine the fitness of use. So, by adding semantics, we get information about the number of correctly encoded entities according to a set of representation or integrity rules.

6.4.1.3 Semantic accuracy

To improve the semantic accuracy, we can use a more knowledge-enabled way of capturing data. The automatic plausibility controls in the field enable the field worker to correct errors in the field, thus guaranteeing a higher quality of data. This can be implemented in field GIS to warn the observer if inaccuracies occur in the database. The use is very knowledge based and fits only one particular GIS but they let the observer reconsider the database outdoors en let him find reasons why the inaccuracies occurred in the database. He can correct the database seeing the reality, not later in the office where it is difficult to bear all relevant facts in (human) memory.

Chapter 7 Forestry

7.1 *Introduction to Finnish forests*

7.1.1 Forestry areas

Finland is situated in northern Europe and reaches from the Baltic Sea to above the Artic Circle, therefore the climate varies greatly from south to north (semi-maritime climate). The average altitude is only 120-180 metres above sea level and there are 60000 lakes estimated throughout the country.
About three-quarters of the total land area is covered by forests. Forestry land is divided into forestland (volume increment more than 1 m³/ha/year), scrub land (volume increment 0,1 – 1 m³/ha/year), wasteland (increment < 0,1 m³/ha/year) and roads.
The soil is more fertile in the south than in the north.

1 000 ha

Land use	Northern Finland	Southern Finland	Whole Finland
Total land area	14 992	15 466	30 459
Forestry land	14 219	12 006	26 225
• Forestland[1]	8 962	11 065	20 027
Scrub land[1]	2 427	490	2 916
Waste land[1]	2 761	362	3 123
Roads, depots[1]	69	90	158
• Mineral soil sites[2]	8 407	8 708	17 115
Mires[2]	5 744	3 208	8 952

Source: The national forest inventory (Finnish Forest Research Institute 2000).

figure 37: Forestry land areas

7.1.2 Forest structure

Pine and spruce dominate Finnish forests. Some 48% of the growing stock volume is pine, 33% spruce and 19% deciduous trees (mostly birch). Forests are also quite pure (dominance of one tree species in a forest) and young (67% of the forests are under 80 years old), mostly in northern Finland old-grown forests can be found. Forests are also to a very large extent even-aged, due to the management practices.

				% of forestland
	Dominant tree species of forest stand			
	Pine	Spruce	Birch	Other deciduous
Southern Finland	56.9	31.6	8.6	1.1
Northern Finland	74.8	15.6	8.0	0.2
Whole Finland	64.9	24.4	8.3	0.6

Source: The national forest inventory (Finnish Forest Research Institute 2000).

figure 38: Tree species dominance

7.1.3 Growing stock, increment and drain

Growing stock is 2091 million m³ o.b. The annual increment of the growing stock has been bigger than the drain since the 1970's. The annual increment is 86,7 million m³ o.b. per year and the growing stock drain was 69,9 million m³ o.b. per year in 2004.

7.1.4 Employment

The forest sector employs 91500 persons (2000), which is 4,1% of the national total.
The national forest programme predicts that the number of employees will drop in the future.

7.2 Main goals of forest management

The forests make up one of the earth's greatest reservoirs of renewable natural resources. Managed properly, they can provide us with essential products and at the same time they can remain home for wildlife and outdoor use and a vital source for water supplies. However, the management of the forests for each of the many products, services and benefits presents a complex problem. Management of forest becomes especially important as human population increases and forest area decreases.

According to the Eurostat environmental inquiry, forested land was estimated to fall into four categories by its main function: 19,3 million ha of forestry, 1,7 million ha of reindeer husbandry, 1,3 million ha of protection and 0,7 million ha of recreation. One of the main goals is to increase roundwood production. The state subsidies to forest management and protection will increase without losing ecological sustainability.

Forest management would be simple if all forest resources were readily renewable and if it were possible to use one resource without affecting other resources. Virtually all timber management practices affect the wildlife and fish in forest ecosystems. The interactions can be 'neutral' (one does not affect another i.e. a photographer and a fisherman), it can be 'compatible' (i.e. small clearcuts on wildlife) or it can be ‘incompatible’ (i.e. wilderness and intensive timber management). Incompatible uses may result in conflicts.

7.2.1 Definition

Forest management planning is the process of organizing a collection of forest stands so that they produce the resources that the landowner wants from that forest. The landowner may be a private person, a forest industry, state, government,… The resources might be timber products, wild life, recreation, aesthetics or any combination of these. Production of biodiversity

Production areas and guidelines in production forests ensure that biodiversity is protected. Forest management in production forests is controlled by forest law and nature conservation law. Nature conservation law defines nine protected nature types and forest law defines seven environments of special importance and five other valuable environments, which have to be treated with special care.

7.2.2 Timber and peat production

Other than the protected area, the forest area is in timber production (most of the forests are semi-natural). In Lapland poor growing conditions and reindeer husbandry set restrictions to timber production. The main goal in wood production is to increase annual roundwood production to 63-68 million m^3 per year, which will be sustainable in the long run.

7.2.3 Carbon sequestration

Finland has agreed to decrease emissions of greenhouse gases. The national forestry programme (which will obtain to increase the roundwood production) will influence it significantly.

7.2.4 Non-wood forest products and recreation

Finland, like other Nordic countries has public rights of access to both public and private forests, which includes picking berries, mushrooms and herbs from the forests. Other forms of forest recreation are; hiking, cross-country skiing, hunting, mountain biking, orienteering… Also timber production area can be used for recreation.

7.2.5 Reindeer husbandry

Reindeer husbandry is an important activity in the northernmost part of Finland. There is also a cultural value, as most of the reindeer owners are Sami people. It is also the only form of forest grazing in Finland. In Lapland all forests should be managed in a way that reindeer herding is taken into account.

7.2.6 Multiple use

A forest has a great variety of uses. Trees can be used for furniture, construction elements or firewood. An outdoor enthusiast will enjoy flora and fauna during hiking, mountain biking or orienteering. This variety of uses reveals the challenge to modern forest management, both in choosing which resources should be used and in giving society access to them.
Also combinations of for example recreation and wood production are possible.

7.3 Management

7.3.1 Ownership

The majority of the Finnish forest owners are private owners. In southern Finland private owners own 73,5% of the forestry area, companies 12,2% and the state 8,2%. In northern Finland the state owns 54,6% of the forest, private owners 37,1% and companies 4,2%.
All together private and company forests are situated on more fertile soil and state owned forest on poor soil in Lapland.
The difficulty of the management depends on the size of the forest, the value of the wood products involved and the resources and tasks the forest has to support.

7.3.2 Management practices

Management practices do not differ considerably by forest owner.
The private owners have forest management guidelines, which are based on forest law and certification requirements. Companies and Finnish Forrest & Park Service have their own management guidelines, but they are quite similar to the guidelines of the private owners.

Guidelines contain the main principles according to which the forests could be treated.
When there will be an increment in the roundwood production, there will be more trees felled.
Therefore artificial regeneration of trees (seeding and planting) is necessary.

Natural regeneration is used where it is possible and economical.

	ha
	Area
Seeding	36 200
Planting	78 800
Afforested arable land	6 163
Tending of seedling stands and improvement of young stands	210 264
Pruning	3 761
Forest fertilisation	21 519
Forest drainage	84 814

Source: Finnish Forest Research Institute (Finnish Forest Research Institute 2000).

figure 39: Forest management practices other than fellings in 1999

Also precommercial thinnings are achieved and are based on the number of stems at a certain dominant age. Other thinnings are based on the basal area and height of the stand. There are different thinning models for southern and northern Finland, different tree species and site soil types, so there are three curves in thinning models. When the upper curve is exceeded, thinning is recommended.

7.3.3 Harvesting

Only the commercial part of the trees is harvested, the cut-to-length method is used.
Trees are felled, delimbed and cross-cut into logs in the forest (most of this is mechanised).
Haulage is done with forwarders and only few with farm tractors. Most of the long distance transportation is made by truck. The transportation used to be done by floating, but nowadays it isn't that popular anymore, because it's slow and a lot of work.

7.4 Measuring and monitoring forest resources

There are as many reasons to measure forests as there are uses of forests, and each use has its own specific needs for information.

7.4.1 Land surveying and mapping

Forest type maps are very useful to forest managers because they show the locations and boundaries of individual compartment maps (areas with similar species, size and density of trees). These maps also show non-forested areas such as lakes, rivers and fields. Vertical aerial photographs can be useful for preparing forest maps because they can be viewed with a stereoscope to provide a three-dimensional picture of the forest. Trained interpreters are able to identify forest stands on the photographs and outline their boundaries.

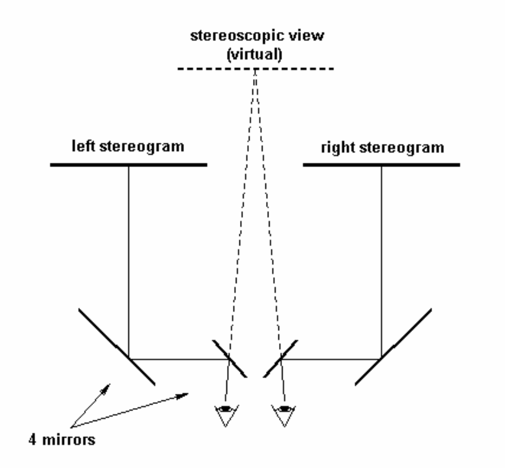

figure 40: Schematic view of a stereoscope

7.4.2 Measurement of forest resources with a focus on timber

There are many variations in the types of timber focused surveys, such as precise measurement of individual trees or measuring a large forest.

7.4.2.1 Standing trees

Most timber surveys require the measurement of individual trees. Standing tree measurement may be required to estimate the volume or mass (weight) of various products obtainable from trees or to know the relative sizes of trees to aid the forest management.

Diameter at breast height (dbh): one of the most useful measurements is the diameter at breast height, this is the diameter of the tree stem at a height of 1,3 meters above the ground.
The tree calliper is one of the most accurate instruments for obtaining this measurement. Another instrument, but not really accurate is the Biltmore stick, and is based on the principle of similar triangles.

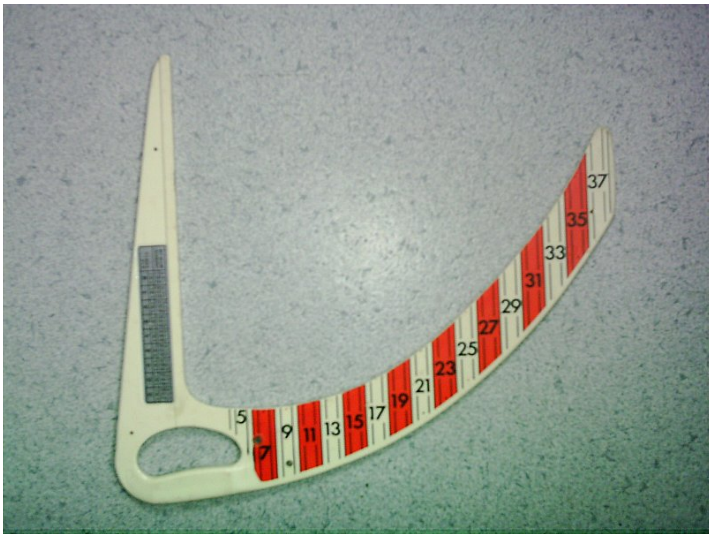

figure 41: Example of a tree calliper

Basal area: the diameter at breast height (dbh) is frequently converted to basal area, which is the area (in square meters) of the cross section of the tree at breast height. The formula for the area is: (π * dbh) / 4

The basal area of a forest stand is expressed as the sum of the tree basal areas divided by the area of the stand and is expressed in square meters per hectare (m^2/ha).

Height: there are a number of different instruments for measuring tree height and the required level of accuracy dictates the instrument of choice. Height poles (direct measuring) provide very accurate measurement for trees that are not too high, otherwise it becomes too awkward. Tree heights can be measured indirectly with instruments called hypsometers. They work either on geometric (similar triangles) or trigonometric (angles) principles. Mostly the result of the tree height is directly visible on the scale of the device.

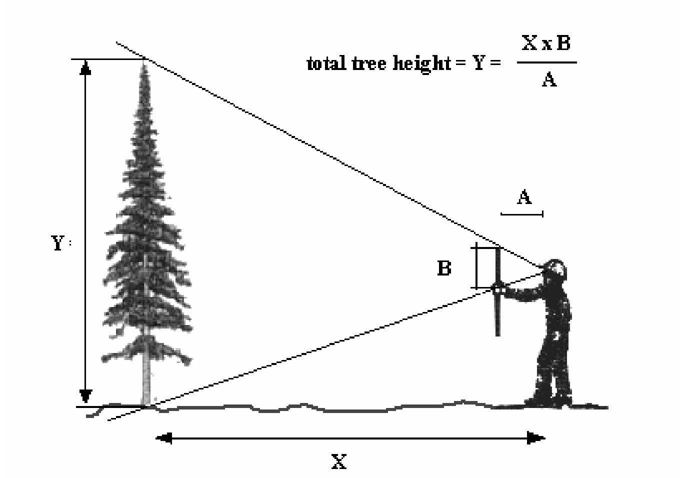

figure 42: Height measurement based on geometric principles (similar triangles)

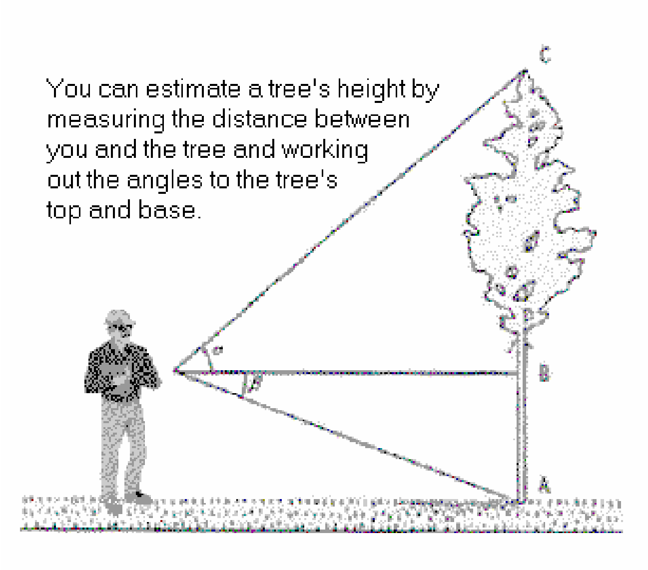

figure 43: Height measurement based on trigonometric principles (angles)

When trees are measured to access the volume or weight of merchantable products in the tree, the ‘merchantable height’ or ‘length’ is more important instead of the total height (this is the height between the stump and the point where the diameter becomes too small to be utilised).
Therefore tables with percentages are used.

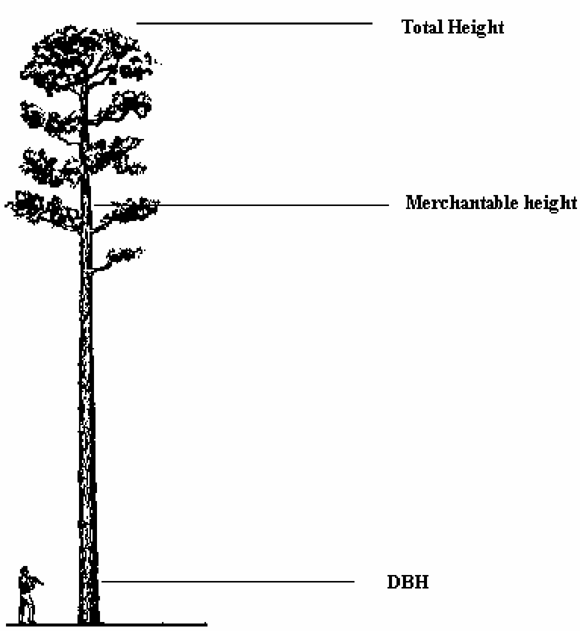

figure 44: Important tree measurements

Volume and mass: there are at present no instruments that allow the direct measurement of the volume or mass (weight) of a standing tree. Instead, volume and mass must be estimated from other tree dimensions. Tree height and diameter at breast height are most frequently used for this purpose and tree volume tables giving the average volume for trees of different diameters and heights have been developed. In most cases forest management planning programs calculate the volume based on mean height and basal area of the stand.

Age and radial increment: tree age can be measured by counting the annual rings in the tree stem. This can be done by using an increment borer, which takes a horizontal sample of the tree.
Volume increment of a forest stand is calculated by models (formulas).

7.4.2.2 Forest sampling: Estimating stand characteristics

It is seldom necessary or desirable to measure every tree in a forest. Accurate estimates can be obtained from measurements of a subset or sample of the trees in the forest. This process of selecting a representative sample of trees and obtaining the required estimates is called forest sampling.

Measuring distances in forests is not that important, but when it needs to be done, pacing is the most common way.

Sampling units: sample trees are usually selected in groups at different locations throughout the forest. Each group of trees is called a sampling unit and may be selected in a variety of ways. Sample plots may be square, rectangular or circular and are usually between 0,01 and 0,20 acre in area. Circular plots are often preferred because of their ease of installation. All trees with a midpoint at breast height lying in the plot boundary are tallied.
These data can be used to calculate estimates of the average number of trees, basal area and volume per hectare. The most widely used method to take samples, is to make use of the relascope.

figure 45: Relascope

The relascope is a very simple but at the same time ingenious little and cheap device. The use of the relascope is very simple: Position yourself in the centre of a tree stand that is representative for the average of the forest. Hold the end of the chain against your cheek and sight through the slot on the edge of the relascope towards a position 1,3 meters up the tree (breast height).

All trees wider than the slot are counted. Every second tree having the same thickness as the slot is also counted. Trees which are smaller than the slot are not counted. Proceed counting trees as explained as you turn around (360°). The number of trees counted represent the current basal area of the forest.

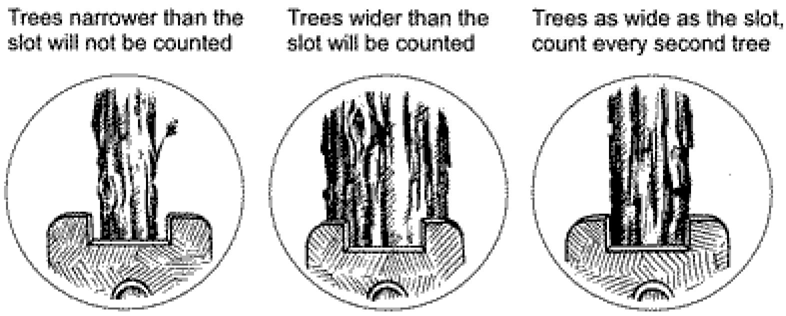

figure 46: Use of the relascope

Sampling methods: once appropriate sampling units have been selected it is necessary to decide how many units to measure and how they will be located in the forest. The total number of sample units is called the sample size and the manner in which they are located is called the sampling method.

Random sampling is a method in which sample units are located completely random within each stand. This ensures that the result will tend toward the true stand values. Systematic sampling is often preferred because it is easier to implement, the time it takes to walk between plots is usually less and sketching field maps and adjusting type lines on aerial photographs is more easily done. An exercised person can point sample plots in the forest in a way that he becomes a mean value (5 – 8 relascope sample plots per compartment is a good average).

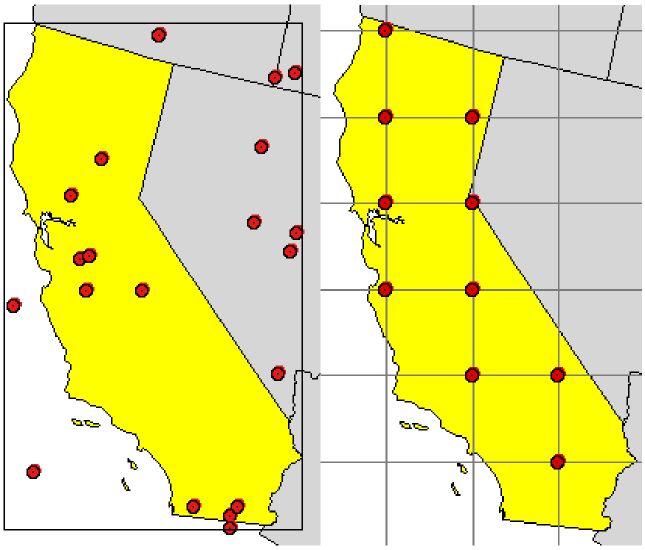

figure 47: Random sampling vs. Systematic sampling

Statistics: Estimates obtained from forest sampling are called statistics and they will vary in detail according to the type of timber survey. In the forest management planning, when timber production is the main goal, the timber volumes per timber assortment, tree species, age, tree size, volumes and site are the basis for treatment suggestions. In addition, of particular importance to management planning are the rate of growth of timber and the rate of loss through natural mortality, insects, decease, fire, weather and harvesting.

7.5 GIS and remote sensing in forestry

7.5.1 GIS

The explanation about GIS in its different forms will be explained in the chapter on GIS.

7.5.2 Remote sensing

Remote sensing is the measurement of characteristics from a distance. Practically defined for forest science applications, remote sensing is the use of airborne cameras, scanners and satellite imaging devices to gather information on forest resources. Aerial photographs have been used since the 1930's and widely applied. The use of satellite and airborne scanner imagery in forestry is more recent, having begun in the 1970's. Whatever the medium, remotely sensed imagery is a unique and valuable data source that is used worldwide.

All remote sensing is based on the detection of electromagnetic energy. Electromagnetic energy is defined by wavelengths and may be categorized into spectral regions. Different wavelengths have different energy intensities and are sensed as different colours. Differences in reflected electromagnetic energy forms the basis for remote sensing. Sunlight falling on the forest is either absorbed or reflected. Different materials have different spectral reflectance patterns across the electromagnetic spectrum and these different patterns lead to different colours, allowing a photo-interpreter to distinguish between different surface features.

7.5.3 Aerial photography

Four types of photographic film are commonly used.

- *Black-and-white panchromatic* film has approximately the same electromagnetic spectrum as the human vision.
- *Black-and-white infrared* film is sensitive for the infrared reflections from many vegetation types, so infrared films are desirable when the photographs are used primarily for vegetation mapping.
- *True colour* photographs are sensitive to the same wavelengths as the human eye, so the full range of visible colours.
- *Colour infrared* films have three dye layers. Broadleaved tree and grass reflects infrared light more strongly than visible light, so colour infrared photographs are typically red in areas of dense vegetation. That's why broadleaved and conifer forests can be distinguished.

The scale of an aerial photograph is important, but is rarely constant within a photograph, because planes may fly at nearby constant height, the elevation of the earth surface varies below the aircraft. Photograph scale may also be affected by camera tilt, the film plane is not parallel with the earth surface so there will be some perspective distortion. In Finland orto-rectified aerial images are used (= corrected images), so there is no distortion anymore. Increasing the flying height, hence decreasing the scale, increases the area covered in each photograph and the other way around. Also the degree of overlap among adjacent photographs is another factor which will affect the number of photographs required to cover an area.

Photo-interpretation involves converting the variation in colour and tone on aerial photographs into information about the location and characteristics of important resources. Forest photo-interpretation is most often performed to produce a vegetation type map. The boundaries of homogeneous vegetation units are based on cues in the photograph. Colour, brightness, texture or pattern, size, shape, topographic position and proximity to other features are all used to define the boundaries between different vegetation types. The art of photo-interpretation is gained throughout experience.

Forest managers and scientists are often interested in mapping forest types by species and sometimes age classes, timber volume, soil type, etc… Aerial photographs are also extensively used for regenerating surveys, forest health monitoring and to assess disease, insect, storm and fire damage. Other uses of aerial photographs are harvest planning, property lines surveys, timber and land appraisal, road design an layout, erosion evaluation, estimating wildlife population and recreation planning.

In the last two decades we have seen a rapid development of imaging systems that not depend on film. One of the most amazing achievements is the engineering of image scanners that collect millions of observations in only a few seconds, reconstructed to form geometrically accurate images. These sensors can detect wavelengths well beyond the capabilities of the human eye or film and in wavelength ranges specifically chosen to provide the most information. These scanners are mostly used in satellites for remote sensing, such as Landsat, SPOT and Radarsat. Laserscanning is the newest method, whereby immediately the type and height of trees can be extracted, and that because the difference in wavelength.

As you can see, remote sensing is a very important aspect in forestry. Without remote sensing and mapping, forestry wouldn’t be that evolved as it is today.

Chapter 8 Materials and methods

This chapter concerns all types of data, materials and methods we use. This is in fact the basis for our project, a kind of manual on getting the data ready for the fieldwork. A good understanding of the different data types and methods is a key word in the setup of the fieldwork. That's why we will describe this in detail.

8.1 Compartment maps and compartment data

The management objectives of forest owners have become diversified. Forest management planning is an effective tool to integrate these objectives into estate and stand level operational recommendations. Planning also makes systematic data collection and management possible.
The data collection described in the field manual consists of two parts:

- the compilations of estate and owner data;
- and the collection of forest stand data.

We don't take a closer look to the estate and owner data. Only some parts of the forest stand data are from a certain importance for our project.

8.1.1 Compartment maps

All forest areas are divided into compartments. These are drawn on a map, usually with an aerial image as background to distinguish the different parts in a forest. Afterwards, these compartments can be stored as a shape-file to use in ArcPad and ArcGIS.

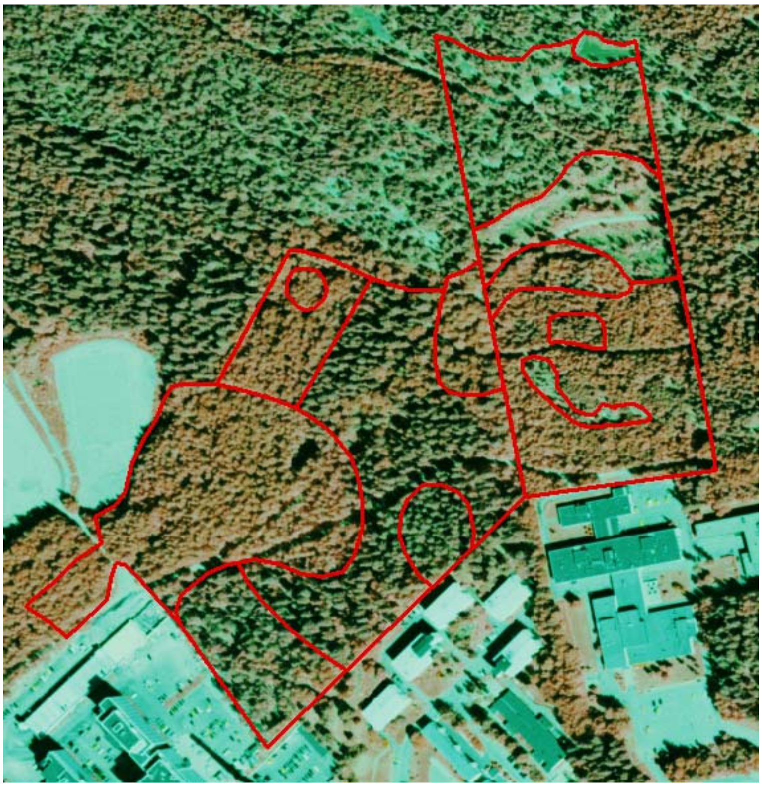

figure 48: zoom on the aerial image and the compartments

8.1.2 Compartment data

The data start with some identification data (municipality, area, planner code, …) followed by site information (compartment number, main land group, development class, …). For the core of the project, these data, except of the compartment number, have a secondary importance. In this part of the text, we focus on the tree stand stratum and the tree species stratum.

The tree stand characteristics are collected by strata in all the compartments of the forest land. A stratum can be a tree stand or a tree species stratum. According to the characteristics, several tree stand or tree species strata are defined. We use one tree stand stratum and three tree species strata per sample. In the tree stand stratum, we enter the mean tree stand characteristics. The three tree species we use are pine, spruce and birch.

8.1.2.1 Tree stand stratum

This paragraph is an explanation of the tables above.

- Stratum number. Every stratum / sample gets a number. This is automatically given by the software under the form of a unique identifier, given by ArcPad / ArcView.

- Tree storey. Tree storey tells, which canopy layer each tree stand stratum and tree species stratum belongs to. If necessary a planner can define three types of storeys: dominant tree storey, undergrowth and predominant tree storey.

- Age. The mean age of each tree stand stratum is determined. Mean age can be entered with the accuracy of one year, but in practice, using age classes of 5 years is satisfactory. Age is determined by age-boring of one representative basal area median at breast height[11] tree within each tree stand stratum.

- Basal area. Basal area is measured at a height of 1,3 m from germination level, namely from the starting point of the stem. Basal area and number of stems are alternatives, so the planner estimates either the basal area or the number of stems of each tree stand stratum, according to that, which is easier to measure. The basal area is determined by measuring relascope sample plots, which are located either in a systematic grid or otherwise evenly distributed in the forest stand. There have to be at about 4 to 8 sample plots per hectare to achieve a satisfactory accuracy of mensuration results.

- Number of stems. Number of stems is entered by tree stand stratum with the accuracy of 10 stems/ha. It is an alternative characteristic for the basal area. So, for every tree stand stratum either the basal area or the number of stems is estimated, according to that, which is easier to measure. The number of stems is measured on circular sample plots, distributed evenly in every part of the compartment. E.g., if the area of the circular plot is 50 m², the number of stems on the sample plot multiplied by 200 gives the number of stems per hectare.

- Mean diameter. The diameter of the basal area median tree among the living trees in the tree stand stratum is meant by mean diameter.

- Mean height. This is determined by measuring the height of the median tree of the tree stand stratum, and then by estimating the mean height of tree stand stratum with the accuracy of 1m.

[11] Breast height is 1,3m high from the germination point, to the pith)

8.1.2.2 Tree species stratum

- Tree species stratum number. Tree species stratum number is always the same as the tree stand stratum number. A tree stand stratum can have a maximum of nine tree species strata.
- Tree species. Different tree species are named according to a numerical coding system.
- Tree species percentage. The percentage of a tree species in the forest stand is determined in percents based on basal area/number of stems of the tree stand stratum.
- Logwood percentage. Determined in percents based on the volume of the median tree of each tree species. In logwood percentage estimation the general quality requirements and minimal log dimensions of the given tree species are followed. It is possible to let the calculation program accomplish the logwood calculations.

8.1.2.3 Sampling process

To take sample plots in the forest, we need following devices:

- GPS-enabled PDA with ArcPad to enter data;
- relascope;
- device to measure the diameter of a tree, see figure 34;
- device to measure height of the trees, see figure ;

A sufficient amount of relascope sample plots (4 – 8 plots / compartment) are defined to estimate the mean tree stand stratum characteristics as reliable as possible. The development stage, the structure of the forest stand and the need of operation affect the recommended determination method of mean characteristics.

8.2 Other maps

8.2.1 Base maps

This layer is useful to get a good view on the environment. In the field it is from time to time useful having this layer around to find out where you are walking around. Base maps are high-scale topographic maps on building level.

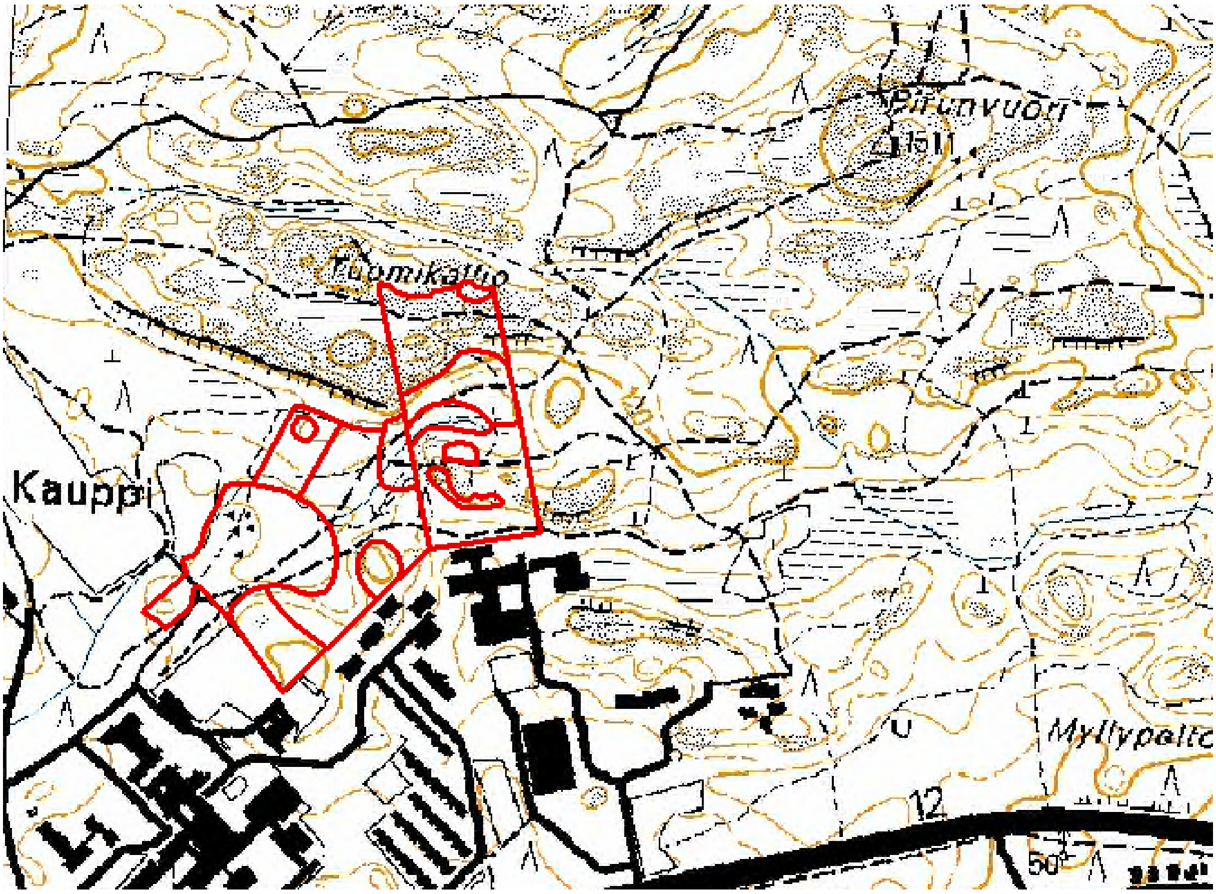

figure 49: zoom on the basemap and compartments

8.2.2 GT maps

GT Maps give a wider view on the project area. The helps to stimulate the location awareness during the project and it is useful to plan the road before measuring in the forest.

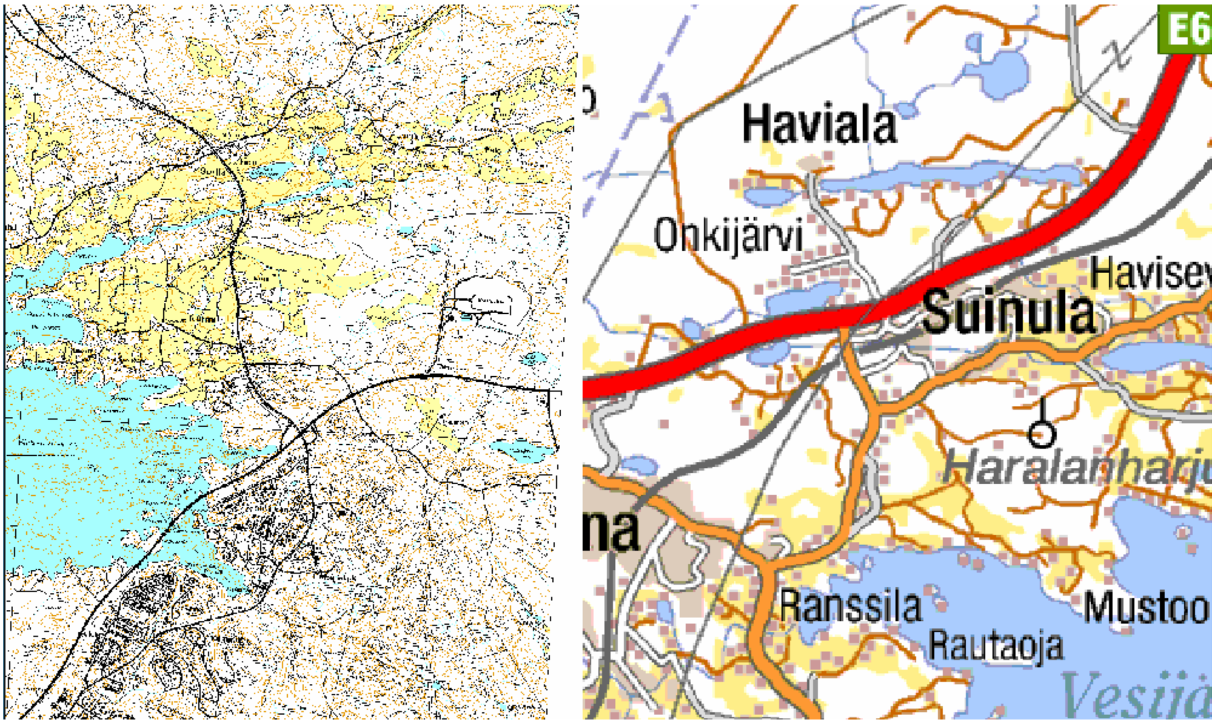

figure 50: Base map vs. GT map

8.3 Aerial images

Information on the use of aerial images in forestry can be found in chapter 7. We used following aerial image:

figure 51: aerial image of the environment of our compartments

8.4 PDA and ArcPad

The PDA and ArcPad are almost the goal of our project. We made the database and file setup as easy as possible to be able to concentrate on using the PDA and ArcPad.

8.4.1 Setup of the PDA and ArcPad

8.4.1.1 installation

Step 1: set up the PDA according to the manuals delivered with it. Don’t forget to set the DGPS corrections.

Step 2: installing ArcPad on the PC
First install the Microsoft Active Sync[12] to make synchronised connections with the PDA.
Install ArcPad on the pc following the instructions given during the installation process.

Step 3: Installing ArcPad on the PDA
All instructions are clearly explained in the PDF files provided with the PDA. The only remark we have, is to look carefully where to install Arc Pad on the PDA. The program will ask if you want to install ArcPad into a default directory (see figure 52 below). Click No.

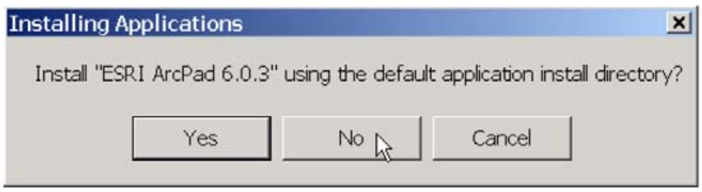

figure 52

The installation program will ask you into which destination directory, called “Destination Media”, you wish to install ArcPad on the MobileMapper CE. The default is "Main Memory" but you should click the down arrow next to “Main Memory” for more options and select "MyDevice." See figure 53 for that. After highlighting “MyDevice” on the Select Destination Media window, click OK and follow the rest of the instructions for installing ArcPad on your MobileMapper PC.

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[12] More info on Microsoft Active Sync on:
http://www.microsoft.com/windowsmobile/downloads/activesync41.mspx.

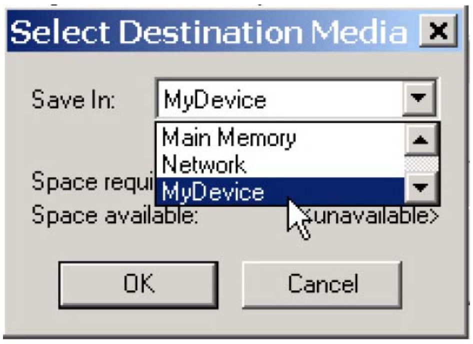


figure 53

A note on installing ArcPad into MobileMapper CE's "MyDevice" directory PDA's typically store their software programs within "Main Memory."

> Main memory on a Windows CE device is volatile - which allows programs to launch rapidly. To prevent the programs being erased upon power down, PDA's never really turn off. This is why you must reinstall all PDA programs when their internal batteries fail. Fortunately, it is easy to continuously power the volatile main memory because PDA's are typically returned to a synchronization/recharge cradle daily.
>
> MobileMapper CE, however, is designed so you can take it to the field for weeks at a time, and store it for months between uses. To permit this mode of usage, it is important to shut the power off completely to conserve power. To keep ArcPad from being erased when the MobileMapper CE is shut down, you should install it into the "MyDevice" directory. This directory resides on an internal non-volatile NAND flash card and so is never erased, except deliberately by the user.

8.4.1.2 Setup of the GPS

Once ArcPad is installed, we need to configure the GPS to get it working properly. Run ArcPad and tap the down arrow to the right of the Tools (figure 54) icon.

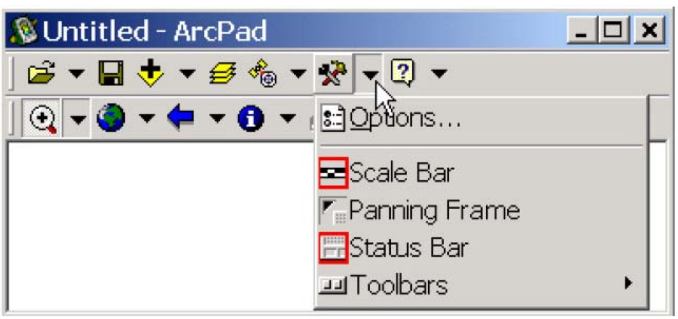


figure 54: Tools icon

Select Options. Tap the Protocol tab and set the protocol to NMEA 0183 and the GPS datum to WGS84 (figure 55).

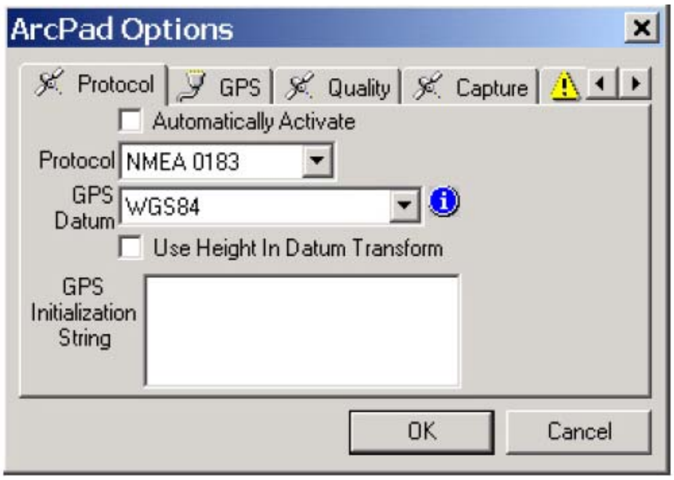


figure 55

Tap the GPS tab and configure GPS communications as indicated on figure 56 below and tap the OK button.

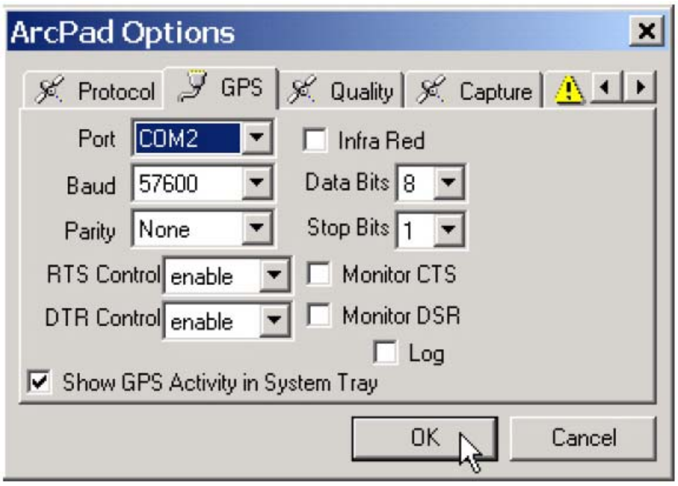


figure 56

If you wish to average a number of GPS positions over a point feature, tap the Capture tab, check the Enable Averaging option and input the number of positions you wish to average at each point feature. MobileMapper CE outputs a GPS position every second. Averaging for 30 seconds improves accuracy (figure 57).

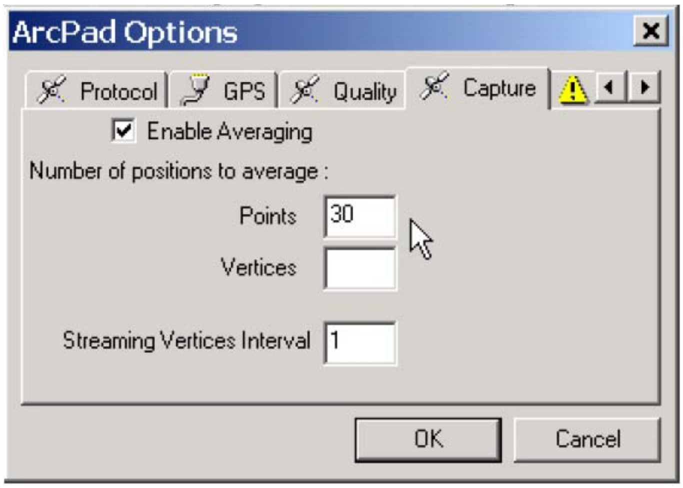


figure 57

8.4.2 Preparing data: ArcPad Tools for ArcGIS

ArcPad tools for ArcGIS is a toolbar for ArcGIS Desktop that provides tools for preparing data for use with ArcPad. The toolbar has following functions:

- export ArcMap layer symbology to ArcPad layer files;
- create an ArcPad map;
- create subsets of large datasets and, if necessary, convert the data to shapefiles;
- provide a summary of the data and fonts used by the ArcPad map;
- and packing shapefiles.

This toolbar has the basic functions built-in. All other tools needed for data preparation can be found in ArcMap, ArcCatalog and ArcToolbox, e.g. setting coordinate systems.

8.4.2.1 Setting up the ArcPad Tools toolbar in ArcGIS

- Start ArcMap.
- Click the Tools menu.
- Click Customize.
- Click Add from file.
- Navigate to the installation folder of ArcPad.

- Open the apTools8 subfolder.
- Click the apTools8.dll and click Open. The Added Objects dialog box appears and reports which new objects have been registered.
- Click OK.
- Click the toolbars tab and check the ArcPad Tools custom toolbar check box. The toolbar is now added to ArcMap.
- Click Close.

8.5 ArcView

ArcView is full-featured GIS software for visualizing, managing, creating, and analyzing geographic data. Using ArcView we manage the compartment data and we can understand the geographic context of the data. In our project ArcView serves as a platform to export and import data to the PDA. Further developments can enable ArcView to manage a whole forest management geodatabase. Although this has some very powerful characteristics to make management much easier, we concentrated on the data collection with the PDA. For more information on the capabilities of the ArcGIS software family, read the information on http://www.esri.com.

8.5.1 Manual for setting up Arc View

8.5.1.1 File conversion

The original Finnish forest management system is built in Tforest with an underlying Solid[13] database. At first, we taught that would give some exporting troubles, but there's a built in export function to the common Dbase and ESRI-formats. The export of data was made very easy in that way. This gave us a Dbase table with all the attribute data and a shape file with the compartment borders.

The shape file has another very useful function in it. In fact of using the join or relate function, we used the built-in attribute table from the shape file. When you perform an attribute join, the data is dynamically joined together. This means that nothing is written to disk and edits on the underlying join tables appear in the appended columns. Relates let you associate data with a layer. The associated data isn't appended into this layers data attribute table like it is in a join. Instead you can access the related data when you work with this layers attributes or vice-versa. So, the exported shape file had already all attribute data in its layer attribute table.

---

[13] More information on Solid databases can be found at http://www.solidtech.com.

8.5.1.2 Structure of the data folder

We organised all data in one folder (see figure 58). This is the easiest way to set up a small project. The bigger the project becomes, the more advanced the database technologies can be. Then, it's getting useful to use some distributed and/or enterprise techniques to make the database open to many users. For our project, it wasn't necessary to set up a database and our knowledge does not reach far enough to build a performing database.

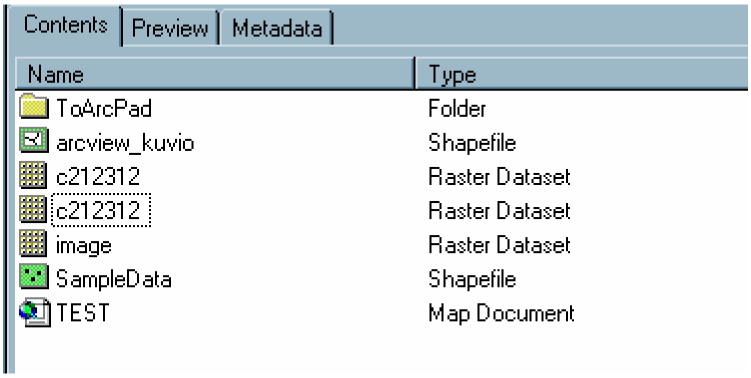


figure 58: folder structure

8.5.1.3 Setup of Arc View

Fist step here is creating the sample data layer. As explained before, this layer is needed to create the points where we take the samples in the field. Therefore, we make, via ArcCatalog, a new shapefile in the data directory. We add the fields, right the same as the fields of the compartment shape file. To do this:

- browse in ArcCatalog to the project folder;
- right click in the contents window – New – Shapefile;
- the name for this layer is "SampleData" and the feature type "point." Select the following coordinate system: click [edit] – [select] and browse to projected coordinate systems – national grids and select "Finland Zone 3". Click [OK];
- Right click in the contents window on the shapefile you just created and click in the context menu on "Properties". Go to the Fields tab and add all the necessary fields. A list of all the fields can be found in appendix II.
- The second step in setting up Arc View is providing all the images (aerial image and base maps) and the compartment shapefile "arcview_kuvio" with the right coordinate system. For images follow these steps:
- right click the image in the content window of ArcCatalog;
- click [edit] in the field next to "Spatial Reference", as shown on the figure below;

- select the coordinate system as explained in the part on creating the SampleData Shapefile (see also figure 59);

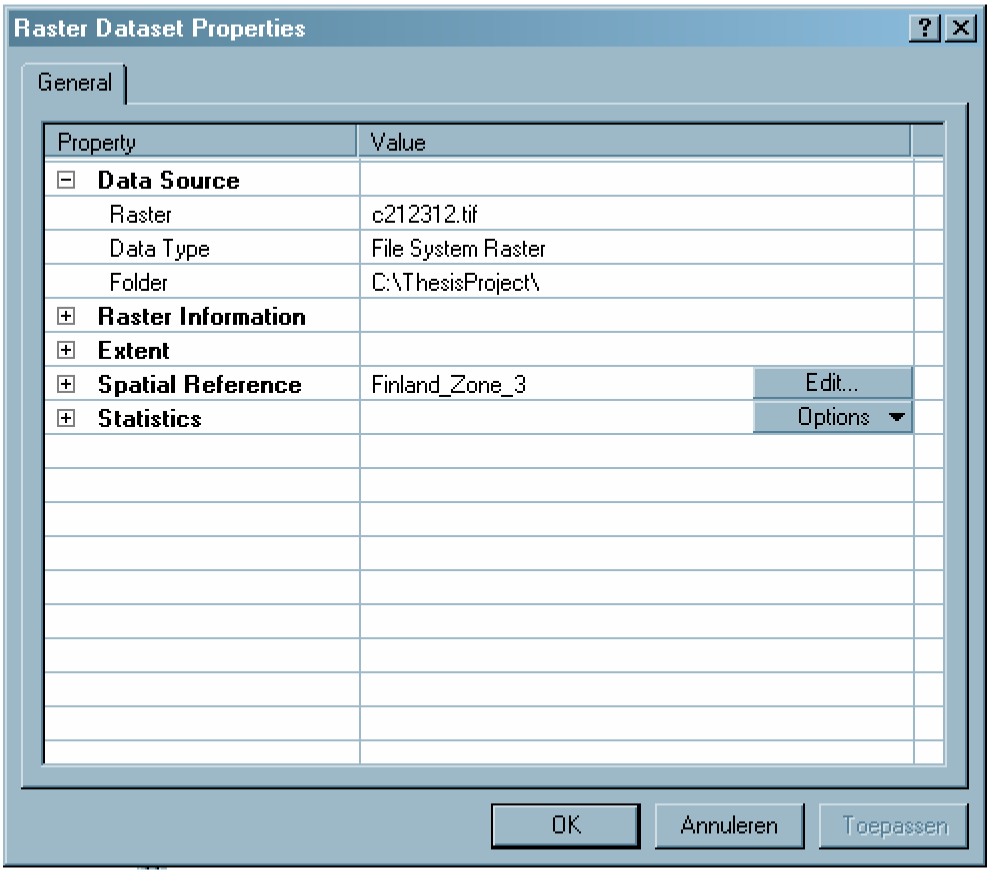


figure 59: Raster Dataset Properties

- click [OK].
- Adding the right coordinate system to a shapefile works this way:
- right click the shapefile that needs a coordinate system and select “Properties” (see figure 60);
- Browse to the “Fields” tab and select the row where the field name is “Shape”;

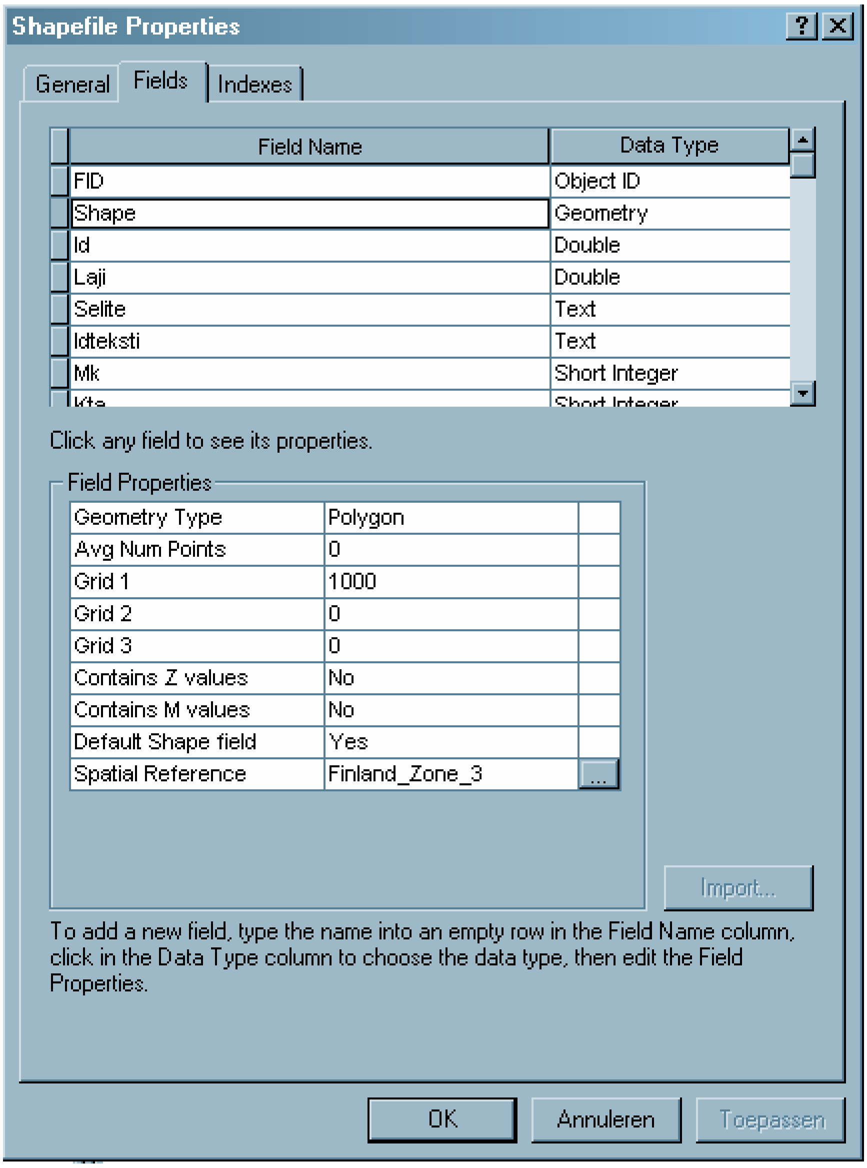


figure 60: Shapefile properties window

- Click […] near “Spatial Reference” and select the “Finland Zone 3” coordinate system.

Now we made all the layers ready to be used in ArcView. As we explained already, ArcView serves for us as a desktop application to import and export data from Arc Pad and the PDA. Therefore, we make a new basic ArcView Map Document:

- create a new map in ArcView;
- right click on “Layers” in the Display tab and select “Properties”;
- click the “coordinate system” tab;
- select “Finland Zone 3” as shown on the figure 61 below;

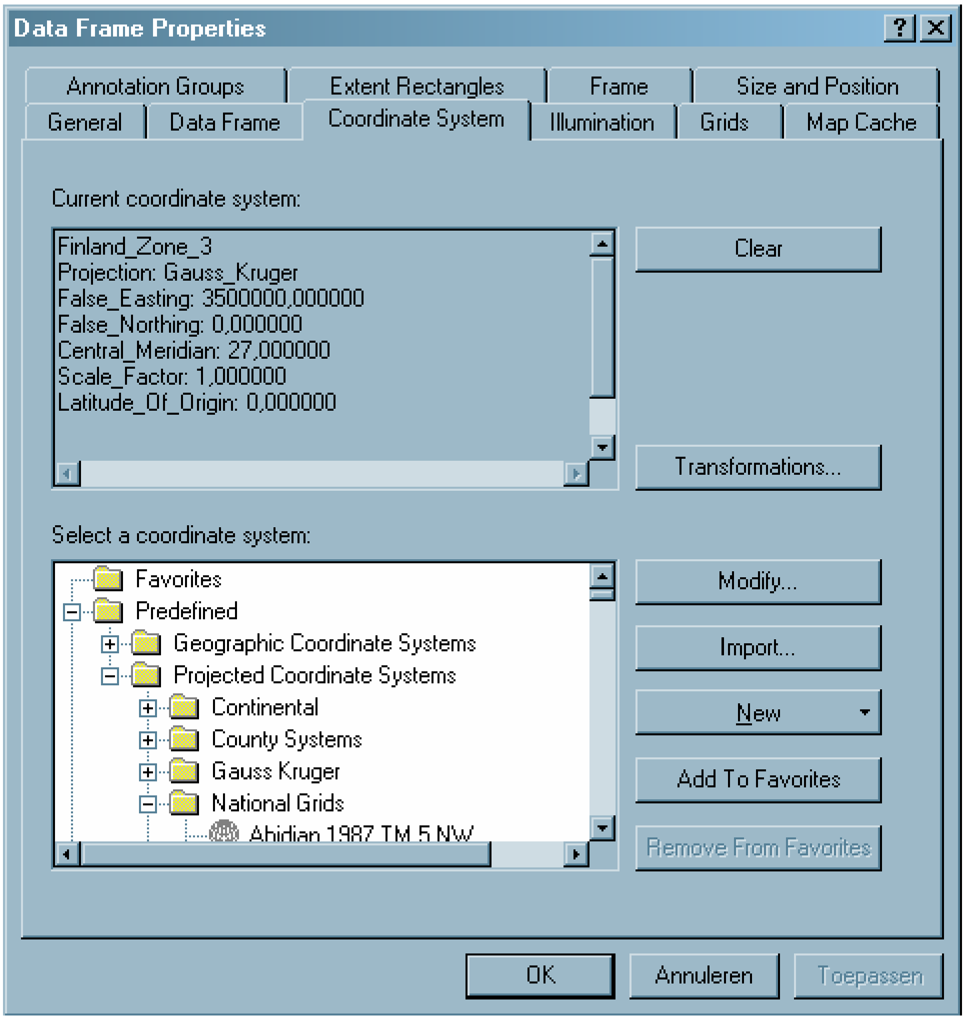


figure 61: Data frame properties window

- click [OK]

Now we can add the layers (see figures 62, 63 and 64) to the map document:

- Top layer: sample data (SampleData.shp) This is the only layer we created ourselves. We needed a way to add samples, with the same attribute data as the compartments without letting the sample data interfere with the compartment data. A separate layer for samples was the best solution for this problem. Later on, we can calculate the new compartment data by adding the data of the sample layer. This layer is only meant to capture data on the PDA, so, except of removing sample points that are calculated, this layer needs no editing in Arc View.

- Layer 2: compartments (arcview_kuvio.shp). The compartment layer holds the compartment borders and an attribute table with all the compartment attribute data. Why we use the built-in table and not an external database is explained earlier.

- Aerial image. All info on the why of aerial images in forestry is explained in chapter 7.

- Base maps. This layer is useful to get a good view on the environment. In the field it is from time to time useful having this layer with you to find out where you are walking around.
- GT maps. GT Maps give a wider view on the project area. The helps to stimulate the location awareness during the project and it is useful to plan the road before measuring in the forest.

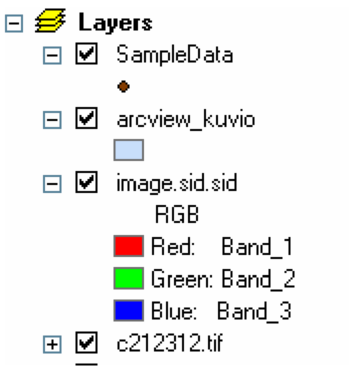


figure 62: layer structure

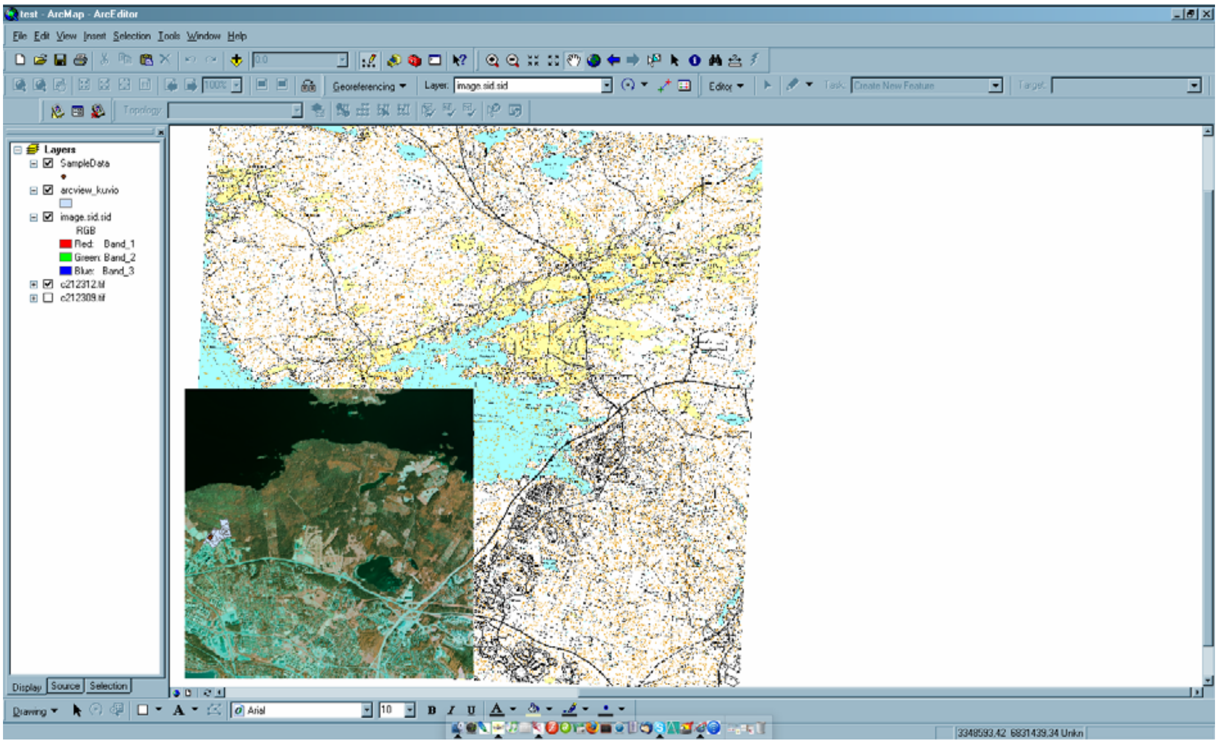


figure 63: Screenshot form the finished map document

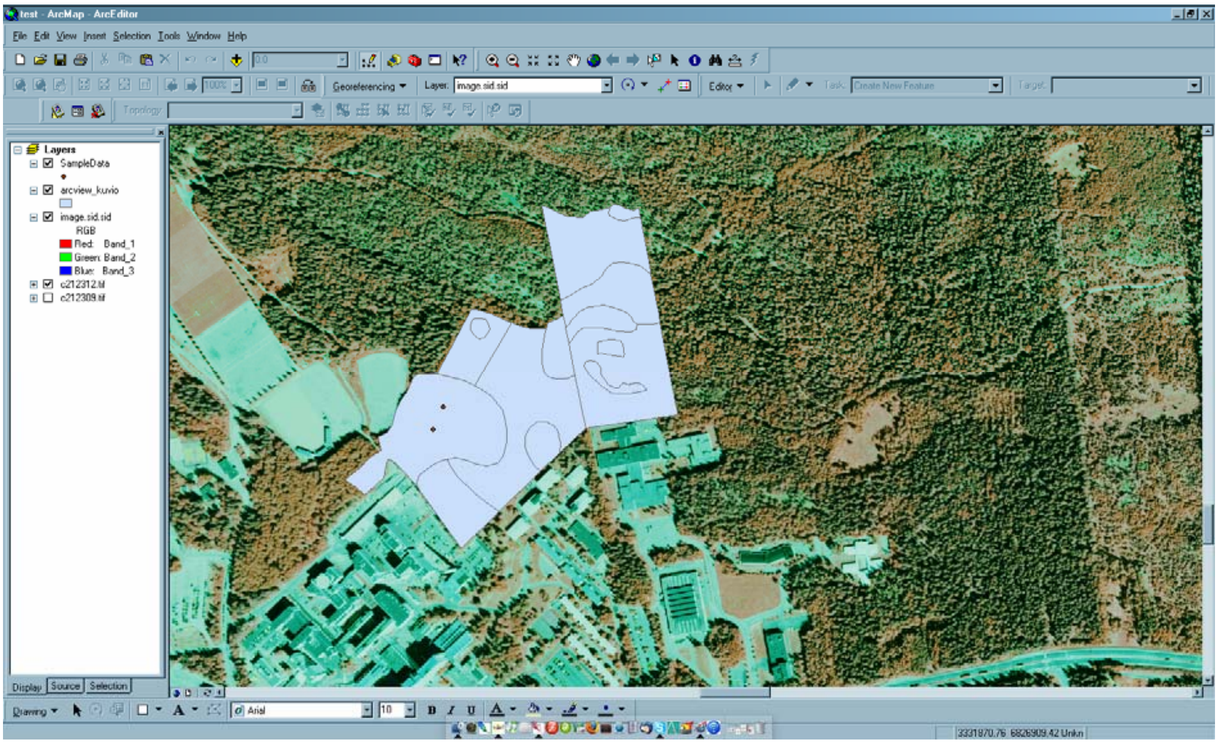


figure 64: Zoom on our compartments

8.6 Conclusion

This is the whole setup part for the project. This part of the project was mainly about reading manuals, installing software, thinking about project organisation and getting the GPS working. To make the chapters not too long and to make the differentiation between the setup of the project and the testing part, the Arc Pad manual for forest measurements, is written in a separate, next chapter.

Chapter 9 ArcPad manual for forest measurements

9.1 *Basic ArcPad functions*

The best way to learn Arc Pad is not reading a manual, it's just trying yourself. Therefore, ESRI developed some sample files and a tutorial that guides you along the basic Arc Pad stuff like exploring data, adding layers, working with geographic features and editing features. We added this tutorial at the end of the thesis; you can find the files on the cd-rom, provided at the end. After reading this tutorial, you know enough about Arc Pad to get in the field with the PDA.

9.1.1 The ArcPad Tools for ArcGIS

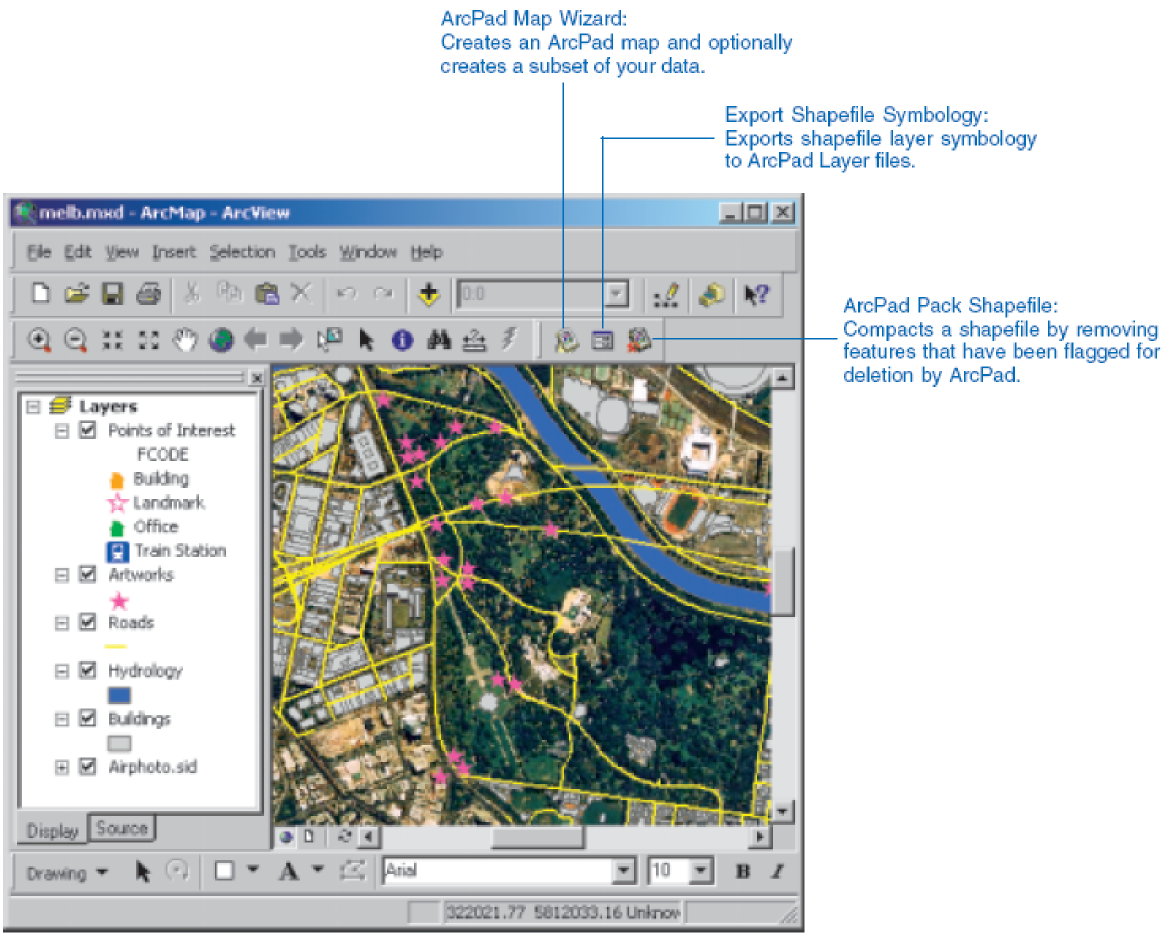


figure 65: ArcPad Tools for ArcGIS (source ArcPad Manual)

The ArcPad Tools for ArcGIS form the basic ArcPad functions. We mainly use the ArcPad Map Wizard to create an ArcPad Map from our current ArcMap file and Export Shapefile Symbology to export the symbology of ArcMap layers.

9.2 *Fieldwork possibility 1*

9.2.1 Preparing data for field work

9.2.1.1 Setting up the ArcPad map

The first step in preparing data for field work is zooming to the needed data. The more accurate your zoom is, the less storage space is needed on the PDA. Taking the limited storage space into account, this is a very important step in the field work process. In the following example, we want to do some measurements in compartment 124. So, we will restrict the view to this compartment and a little bit of the environment. This can be seen on the following screen shot (figure 66).

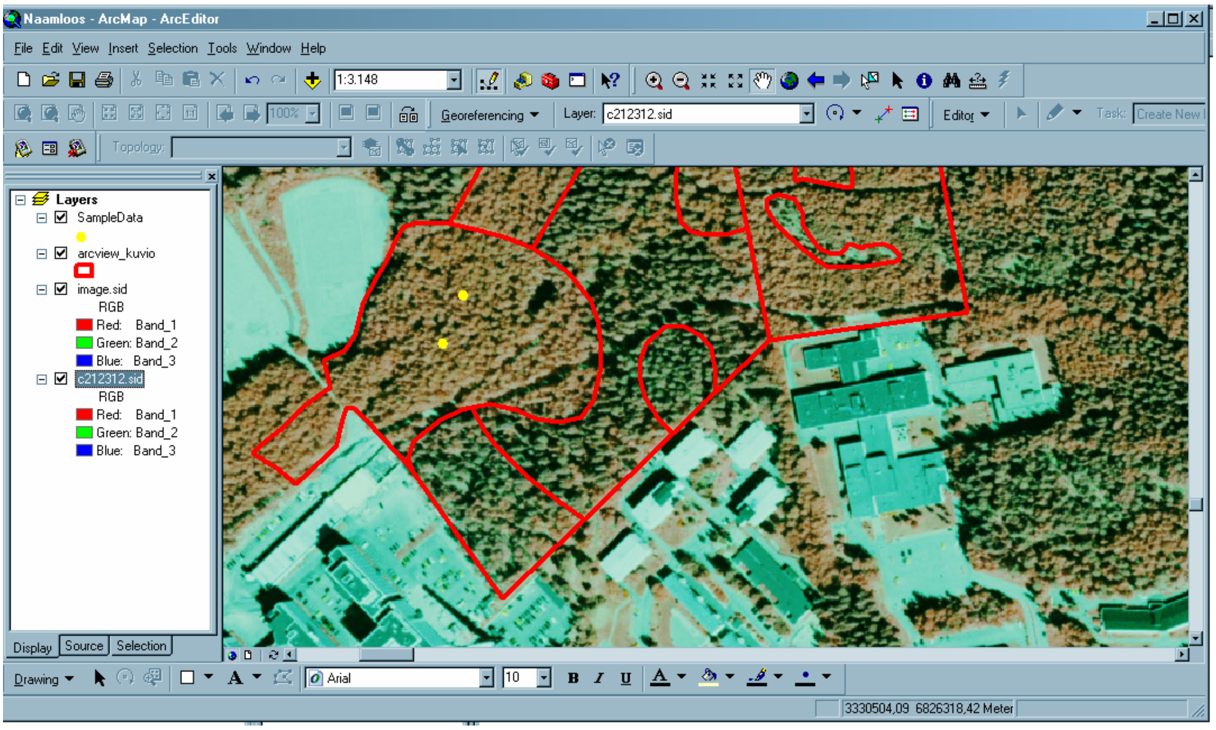


figure 66: Screenshot ArcMap

Next step in the preparation of data is the ArcPad Map Wizard. This is the link between the ArcGIS *.mxd-files and the ArcPad *.apm-files.

Step 1:

Click the ArcPad Map Wizard icon (figure 67) to start the wizard that guides you through the steps to create ArcPad-ready files. The start screen will be shown as on figure 68.

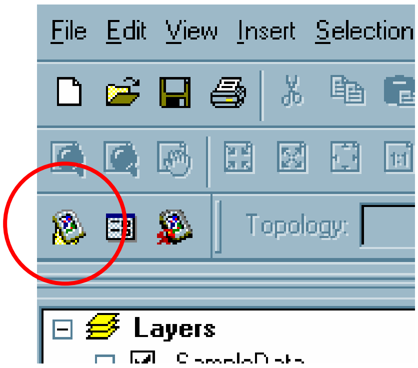


figure 67: ArcPad Map Wizard

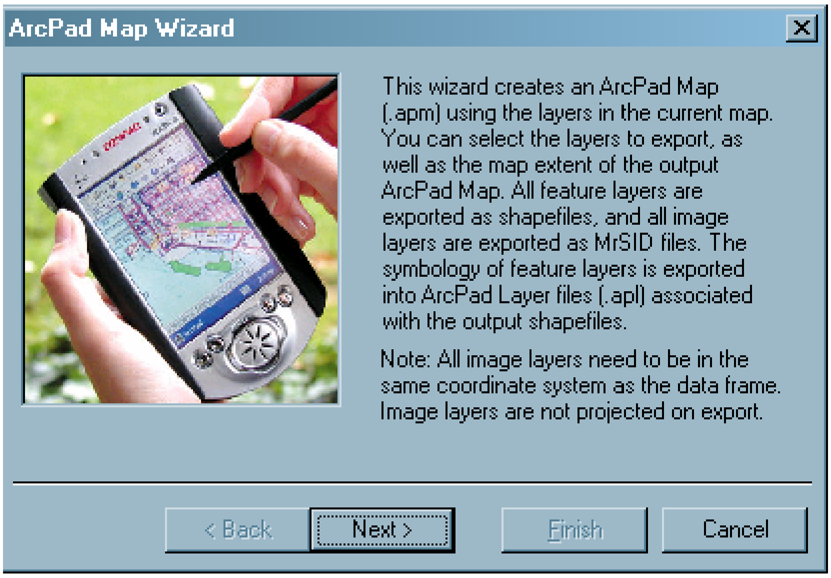


figure 68: ArcPad Map Wizard start screen

Step 2:

Click “Next” in the start screen. Then you can select the layers (figure 69) you want to be exported and the output extent. Be aware of this last! The output extent is only available for vector-type files. All rasters will be exported at the full layer extent. This will not only take quite a lot of memory, this slows also the PDA remarkably down while working in the field. Also: the harder the PDA has to work, the shorter the battery time. Click again “Next” to go to the following step in the export process.

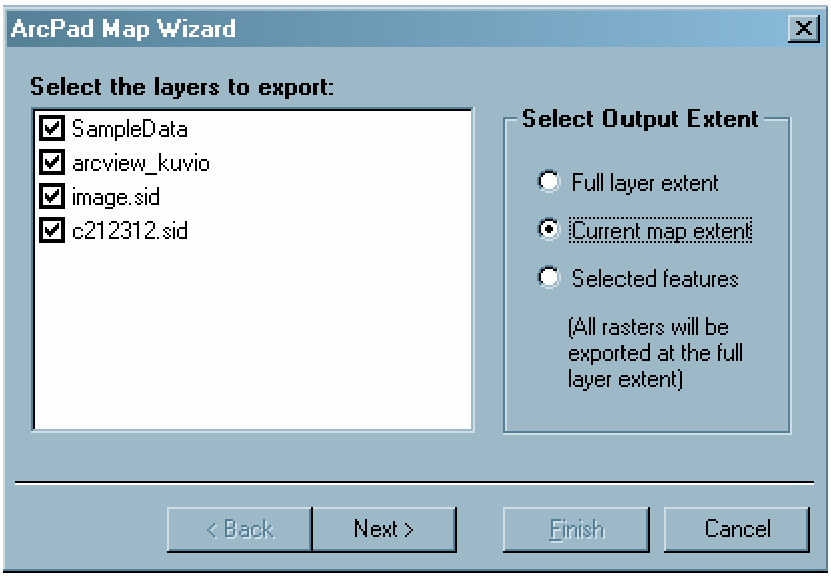


figure 69: ArcPad Map Wizard screen 2

Step 3:
Specify an output folder and a map file name (figure 70). Be aware of this restriction and from our view even a big mistake: the pad to the output folder can't have any spaces! Click "Finish" and the files will be converted and a summary is shown (figure 71 and appendix IV).

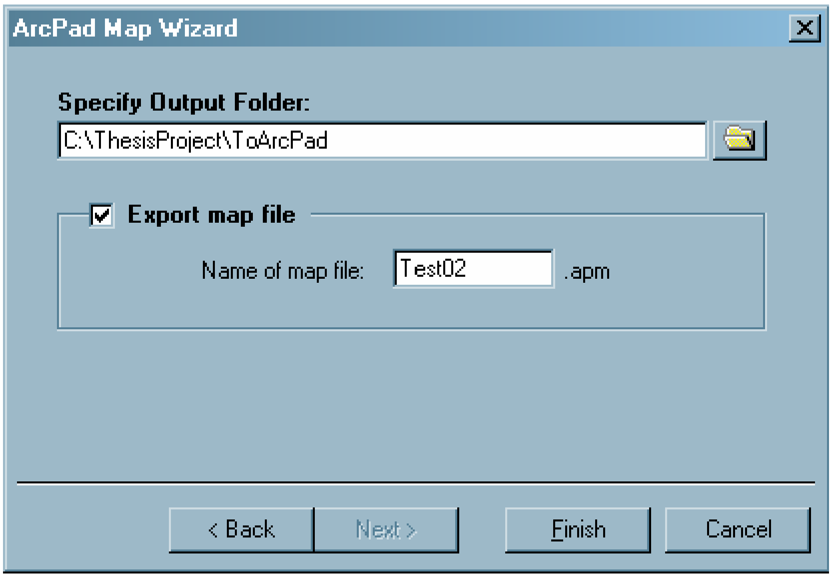


figure 70: ArcPad Map Wizard screen 3

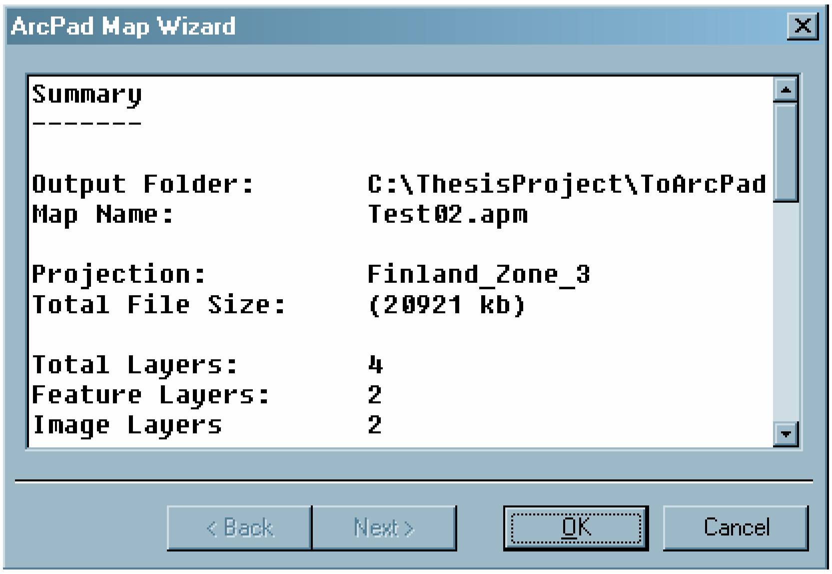


figure 71: ArcPad Map Wizard report

9.2.2 Copying data to the PDA

9.2.2.1 Connecting the PDA

To make a connection between the PDA and the PC:

- clip the I/O module on the PDA;
- connect the power cable and boot up the PDA;
- connect the USB cable between the PDA and the PC and wait till Microsoft Active Sync and the PDA give you the audio signal that the connection has been established. The Microsoft Active Sync icon and screen will look like this:

figure 72: PDA connected

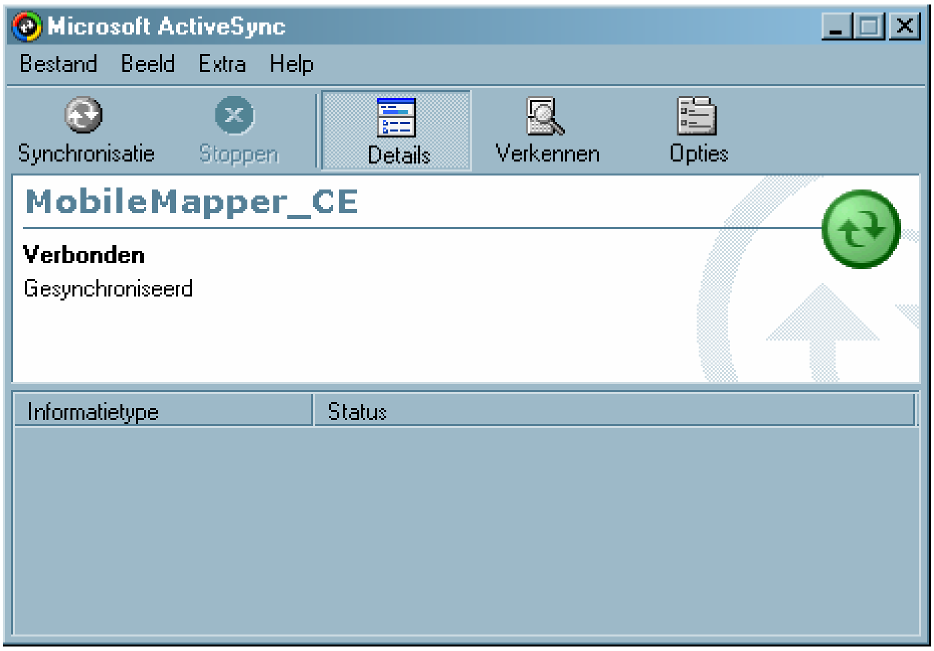


figure 73: Microsoft ActiveSync

Connection has been correctly established.

9.2.2.2 Copying data to the PDA

Copying ArcPad data from the PC to the PDA is as easy as copying between folders on the pc. Copy the necessary data from the source folder on the PC to e.g. “My Documents” on the PDA. The PDA can be found in Windows Explorer as “Mobile Device” or in Dutch “Mobiel Apparaat” (see figure è’)

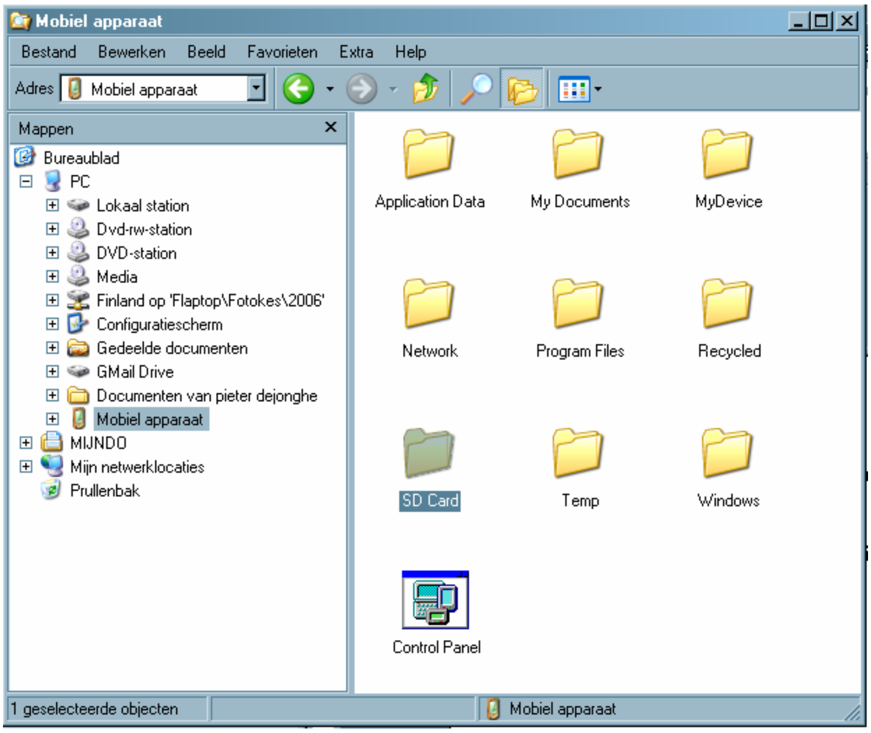


figure 74: The PDA works like an external drive

9.2.3 Collecting data in the field

Data collection can be split in two parts: one that has to do with the forest measurements and on that has to do with the PDA. In this part, we concentrate on the work with the PDA. This will keep this manual as general as possible. Further readings on the forest measurement techniques we use in the forest can be found in chapter 7 on forestry.

9.2.3.1 Get the PDA ready

When arriving at about the compartment, start up the PDA and ArcPad, open the map you copied to the PDA and set the GPS status Active by clicking the GPS icon (figure 75).

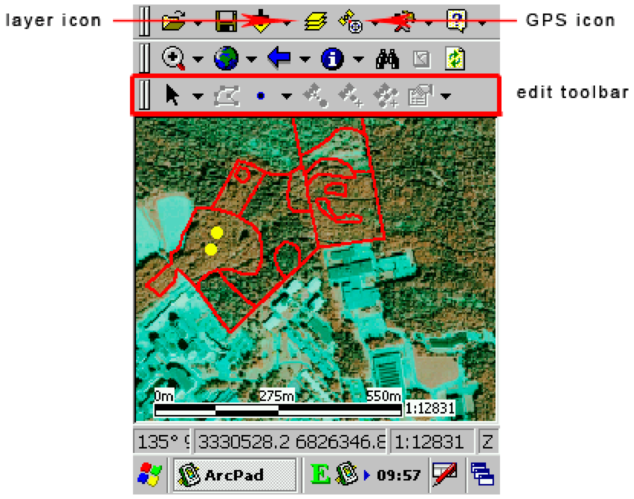


figure 75: ArcPad toolbars and icons

Click the layer icon and mark the SampleData layer edit property (figure 76) to make this layer editable and mark the identify property for arcview_kuvio and SampleData layers.

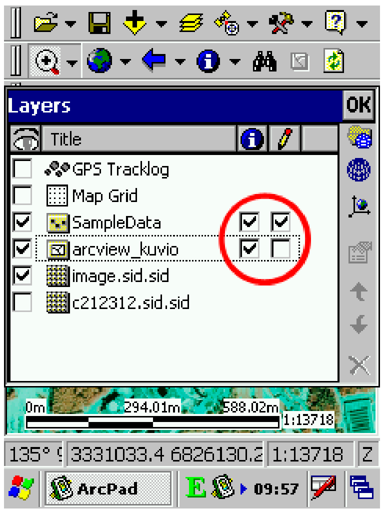


figure 76: ArcPad layers screen

Double tap the arcview_kuvio layer to make the layer properties appear and browse to the symbology tab to uncheck “Use symbology” (figure 77).

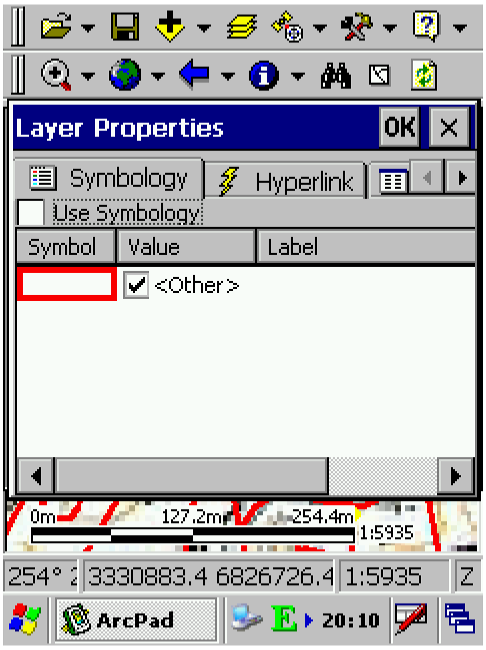


figure 77: ArcPad Layer Properties – Symbology tab

Browse back to the “Polygon Style” tab and set the characteristics in that way that there’s no fill colour and that the border is clear to see on the aerial image. This can be seen on figure 78 below.

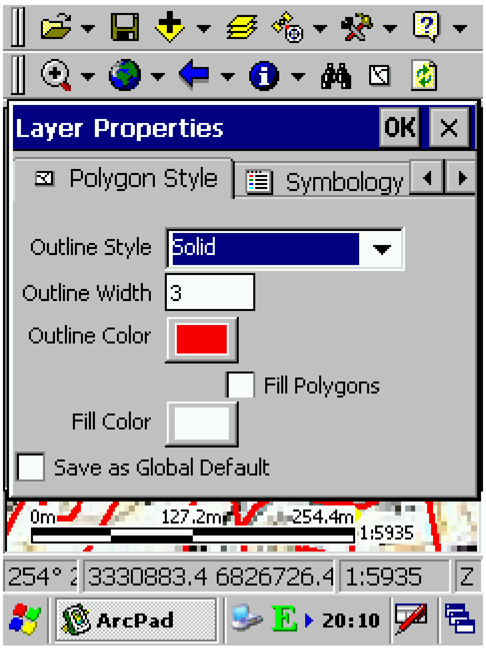


figure 78: ArcPad Layer Properties - Polygon Style

Click OK. You go back to the main screen and the edit toolbar will be visible or make it visible through the options button – toolbars (figures 79 and 80).

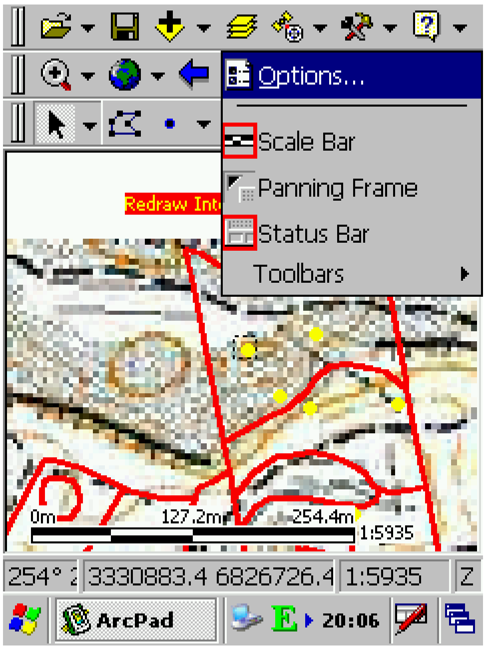


figure 79: ArcPad options pull down menu

Click the options button and go to the capture tab. Mark the checkbox for Enable Averaging and set the textbox to the value you want the GPS to repeat the point measuring.

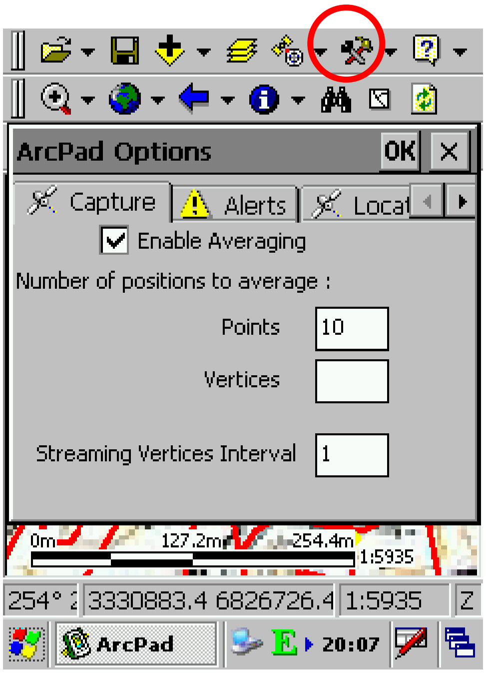


figure 80: ArcPad options button and Options window

Don't walk around until the alert (see figure 81 below) doesn't appear anymore. This means that the GPS found enough satellites to calculate and fix an accurate position. Now we're ready to get samples in the forest.

figure 81: ArcPad no position fix

9.2.3.2 Adding a sample point and entering the attribute data

Once the PDA is ready to operate in the field, you can walk through the forest to take samples.

- Once you chose the place where you want to take a sample, check the number of the compartment where you are now. This can be done by using the identify button and then clicking the compartment where your GPS marker is in.
- Click the GPS point icon to add a sample point on the current GPS coordinates.
- The Feature Properties window (figure 82) will pop up. You can now fill out the table. Click on the desired property and the input panel will appear to enter a value.

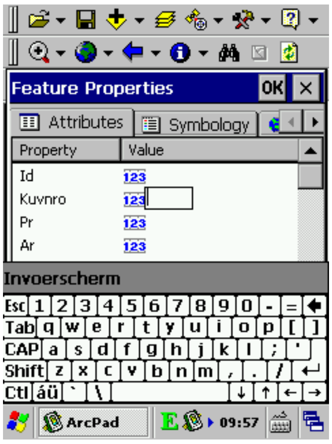


figure 82: ArcPad Feature Properties window

- After entering al the values, click OK. The new sample point is added to the SampleData layer. Back on the main screen, you will see that a point is added (figure 83).

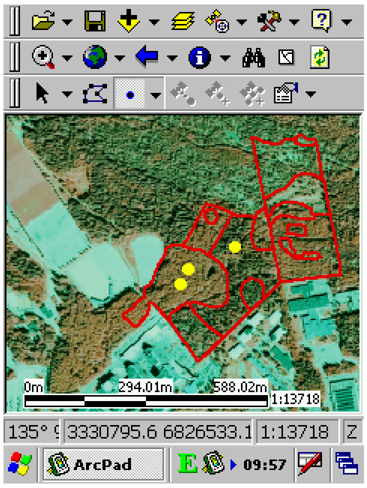


figure 83: ArcPad main screen after adding points

9.2.3.3 Changing the attribute data of a sample point

From time to time, it can be necessary to change the attribute data of a previously added sample point. Maybe you entered a wrong value in the attribute table, you forgot to fill out some properties or you tapped the OK button by accident. To change the data:

- Activate the select arrow.
- Double tap the sample point you want to change or tap the sample point and click the Properties button.

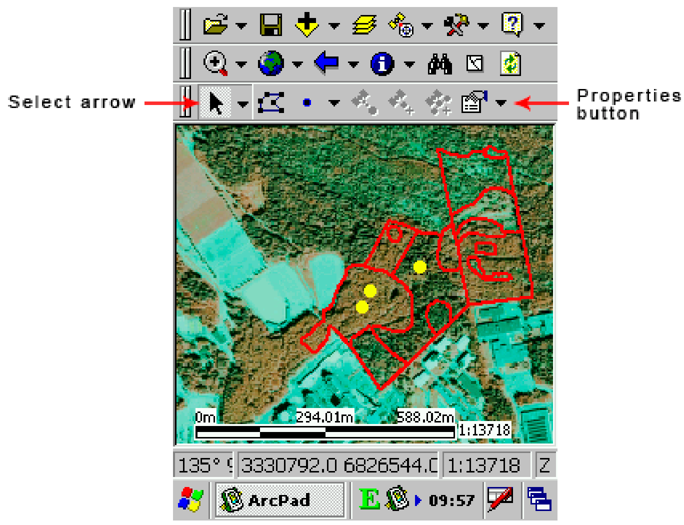


figure 84: ArcPad - change attributes

- Click the property (first column of the attribute table) you want to change. The value will become editable and the input panel will appear.
- Change the value and tap [OK].

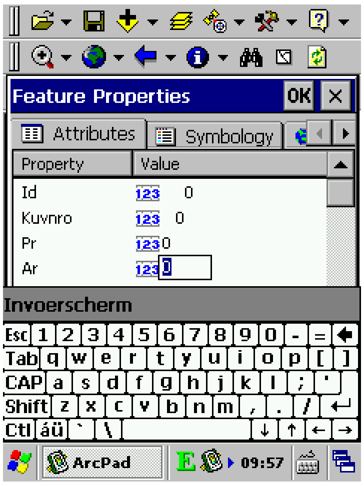


figure 85: ArcPad Features Properties window with keyboard

9.2.4 Synchronising data between the PDA and the PC

9.2.4.1 Synchronising in our project

There are different ways of synchronising data, depending on the place where you save your data: you use the MobileMapperCE_MyDocuments directory. This means that you can use the synchronisation function in Microsoft Active Sync. The major problem here is that you have to copy the data manually from the folder where you exported the ArcPad files to this MyDocuments folder because the ArcPad Map Wizard isn't able to export to this folder. This is due to the problem with spaces in directory names we mentioned before.

You use the ArcPad Map Wizard in ArcMap only once. For copying the data from and to the PDA, you can just copy from the folder where you stored your original data to the folder on the PDA. This is only suitable for small projects like the one we are working on;

If you use a geodatabase, you can use the check in/check out functions. This is far most the best way to keep your data synchronised, especially when you're working with multiple PDA's at the same time.

9.3 Fieldwork possibility 2

Fieldwork possibility 1 is a very easy way of working, although not the most catholic way. We started working on that path for a few reasons:

- we had troubles with building a geodatabase. Importing aerial images and maps was no problem but trying to import arciew_kuvio.shp and SampleData.shp only gave us two empty shapefiles in the database. We solved this problem by not thinking about importing files in a database from a folder, but using the export function from a folder to a database. This seems the same but the figures 86 and 87 below make this idea more clear;

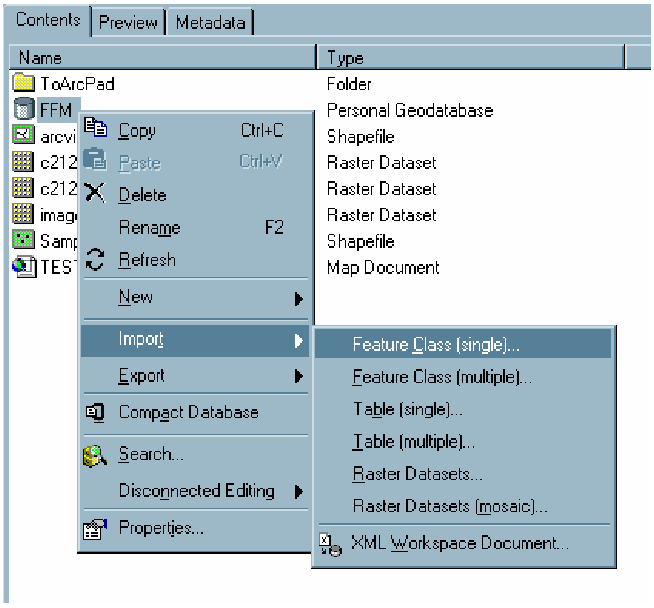


figure 86: import a feature class in a database

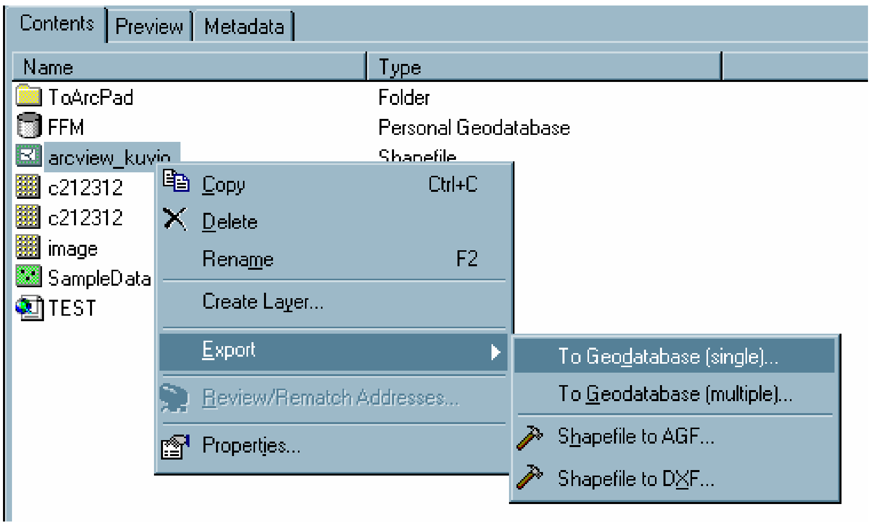


figure 87: export a feature class to a database

- in the ArcPad 6.03 manual is nothing mentioned about how to structure projects, importing and exporting data from databases to ArcPad … The only way of working according to the manual is the ArcPad Tools for ArcGIS. And even this lacks some clarity. You can get the files ready, but copying from PC to PDA and the other way round is never mentioned;

- we didn't know anything about the second toolbar that is installed automatically in ArcMap. This one doesn't have only an export function, there's also an import function (figure 91).

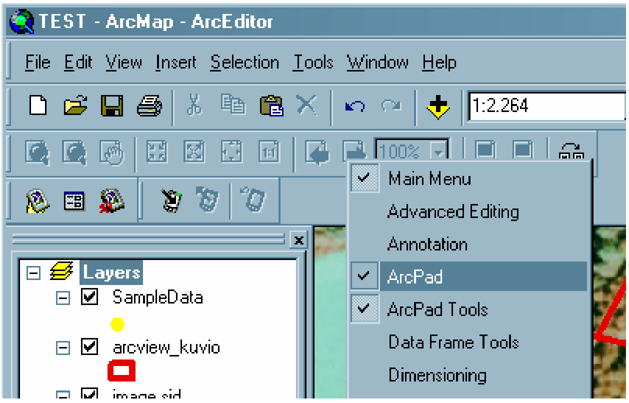


figure 88: Arc Pad toolbar in ArcMap

These are major mistakes, maybe not in ArcPad itself but for sure in the manual. This means that we can restart the setup process almost from scratch. I start the description of the steps from the setup of the geodatabase.

9.3.1 Setup of a personal geodatabase

- Put all the necessary files (aerial images, base maps, shapefiles) together in a folder and set all the coordinate systems as mentioned in Chapter 8 materials and methods.

- Right click in the contents window of the location where you want your personal geodatabase (see figure below) and select New > Personal Geodatabase (figure 89).

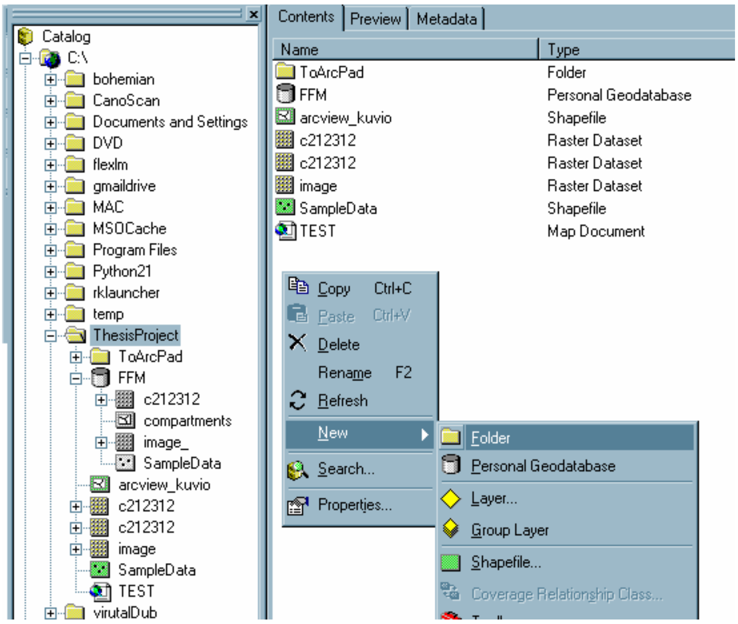


figure 89: making a geodatabase in ArcCatalog

- A new Personal Geodatabase file appears, rename it and your database is created.
- To fill the database with your shapefiles (be aware of the problems we mentioned in the beginning of this paragraph) right click on the files and select Export > To Personal Geodatabase (figure 87).
- To add the images to your database, open the database, right click in the contents window and select Import > Raster Datasets (figure 90) and select the raster images you want to add.

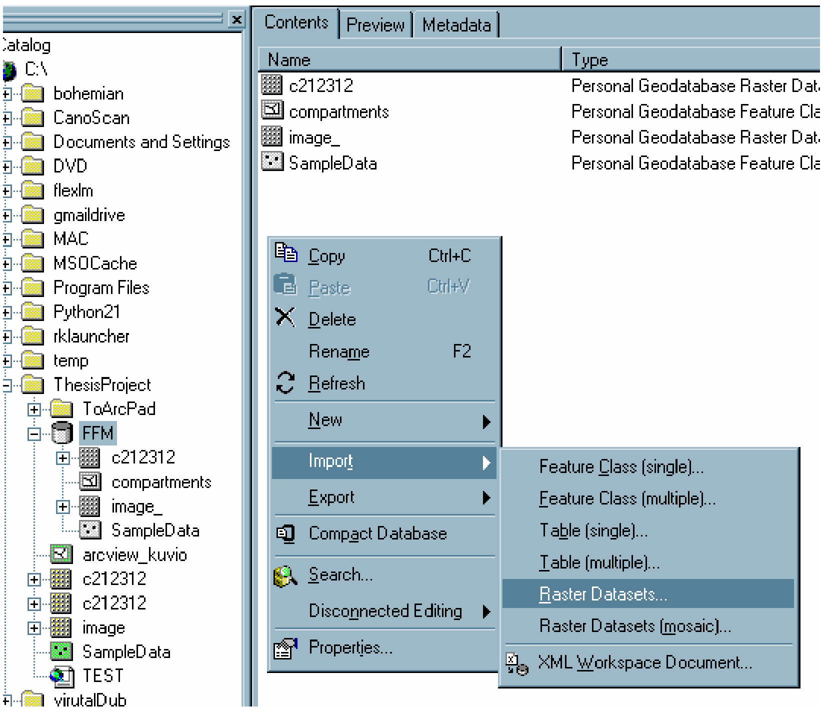


figure 90: Importing Raster Datasets in a geodatabase

- All files are imported and the database is ready to use now.

9.3.2 Building the ArcView map

The layers are added to an ArcMap map document in the same way as we described in chapter 8 Materials and methods. The only difference is the location where the data are stored. In this case, you have to pick the files from the geodatabase.

9.3.3 Transferring and synchronising data

9.3.3.1 Overview

In conjunction with ArcMap's ArcPad toolbar, the Custom Toolbar also allows data to be output to and input from a handheld device.

Getting data to a handheld involves only 1 step: use the ArcMap ArcPad toolbutton to "Get Data for ArcPad" (see figure 91 below). This will prepare the base maps and aerial image and the sample points to be sent to the PDA. It also flags sample points as being "Checked out for editing in ArcPad". This flagging process allows ArcMap to later check in the edited and added sample points and reconcile any changes made to them with the main project geodatabase.

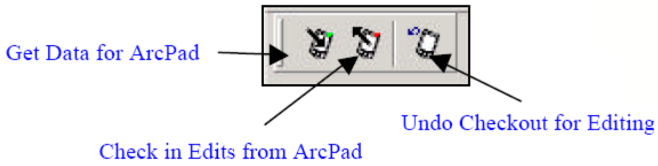


figure 91: ArcPad toolbar in ArcMap

Getting data from a handheld involves also only 1 step: use the ArcMap ArcPad toolbutton to "Check in Edits from ArcPad" (see figure 91 above). This step utilizes ArcMap's ArcPad tools to reconcile any sample points that were edited in ArcPad with the main ArcMap project geodatabase.

9.3.3.2 Getting data from ArcView to ArcPad

- Cradle the PDA and wait for all synchronization to finish (monitor the Active Sync window to verify that the device has synchronized).
- Zoom to a given work area that you would like to take into the field. Recall that smaller areas are less taxing on the PDA's resources.
- Click the "Get Data for ArcPad" button, and the following dialog box appears:

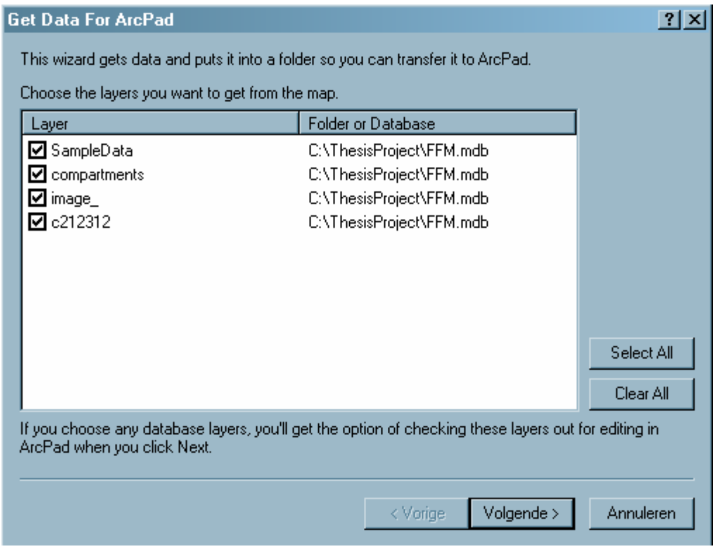


figure 92: Get Data for ArcPad screen 1

- You will see the SampleData layer and any other base map layers listed (see figure 92 above). Check the layers you will need in the field on the PDA and then click the Next ("Volgende" in Dutch) button.

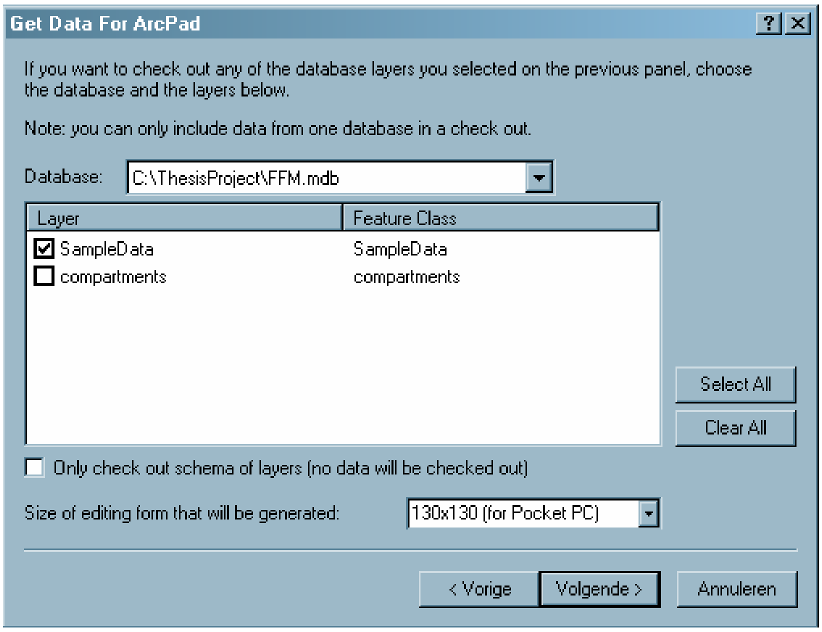


figure 93: Get Data for ArcPad screen 2

- The ensuing, critical dialog box (see figure 93 above) allows you to choose which database will be "Checked Out for Editing". Make sure you select the SampleData layer from the project geodatabase. Click "Next" to continue to the next step.

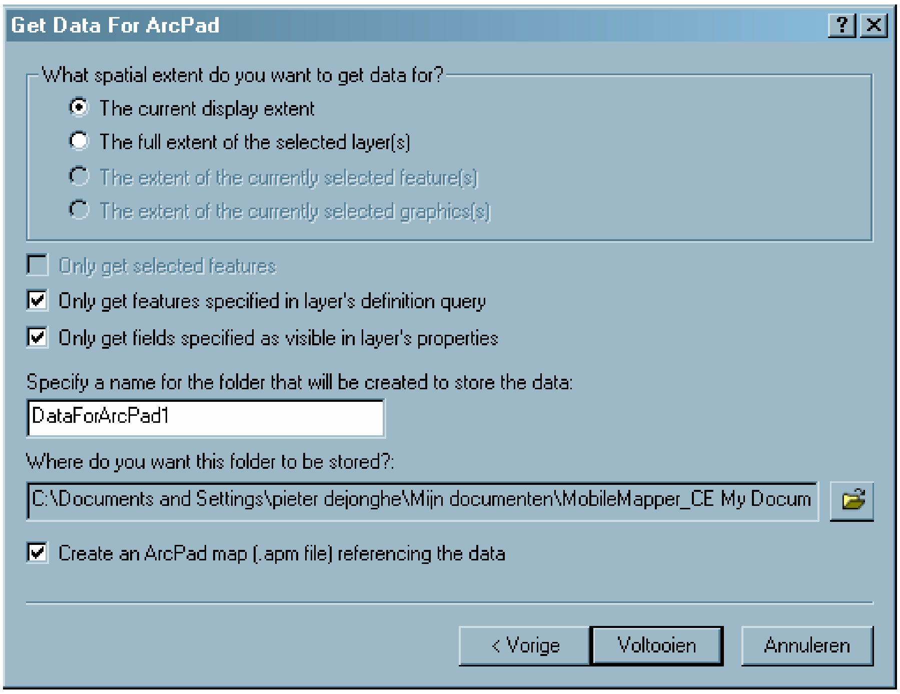


figure 94: Get Data for ArcPad screen 3

- The last dialog box that appears (see figure 94 above) allows you to verify if the current display extent is to be output to ArcPad. Also make sure that the "Only get selected features" checkbox is NOT selected here. Verify that the "Create an ArcPad Map (.apm) file" checkbox is checked. You can also browse to an output location to store the ArcPad data folder. The folder's default name is DataForArcPad*x* where x is some number. For auto synchronization with your handheld, your target folder storage location will be under:
  in general: C:\documents and settings\ username\my documents\pocketpcname My Documents
  in our case: pocketpcname is MobileMapperCE
- Click [Finish] ([Voltooien] in Dutch) and if everything's successful, you get report like this (figure 95):

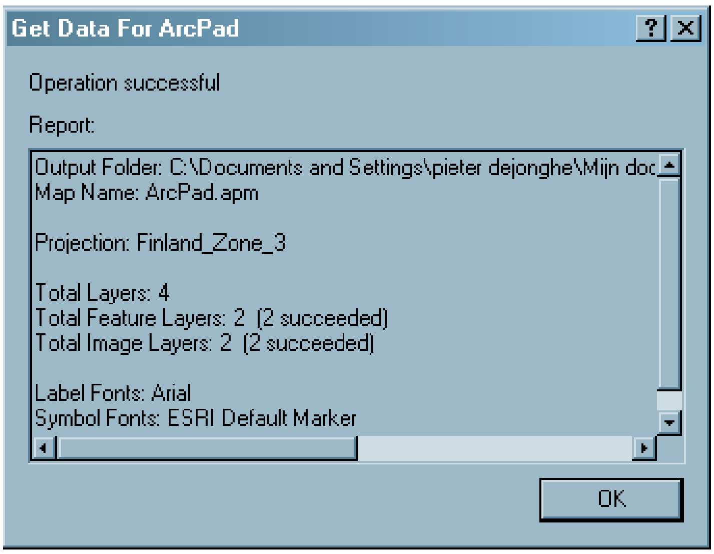


figure 95: Get Data for ArcPad Report

9.3.3.3 Getting data from ArcPad back to ArcView

- Cradle the Handheld and wait for all synchronisation to finish (monitor the Active Sync window to verify that the device has synchronised).

- Start an ArcMap Editing Session by clicking Editor > Start Editing on the ArcMap Editor toolbar. (You may have to under View Menu > Toolbars to turn on the Editor toolbar.)

- Click the "Check In Edits From ArcPad" toolbutton and the following dialog box (see figure 96 below) allows you to select the proper PDA ArcPad "Check Out Session". Check "SampleData" and click [Check In].

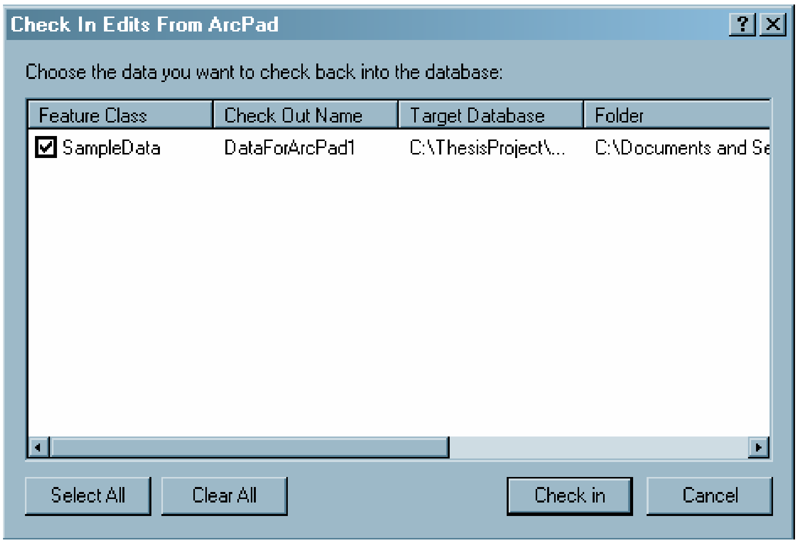


figure 96: Check In Edits from ArcPad window

- Click "Yes" ("Ja" in Dutch) on the resulting verification request (see figure 97 below).

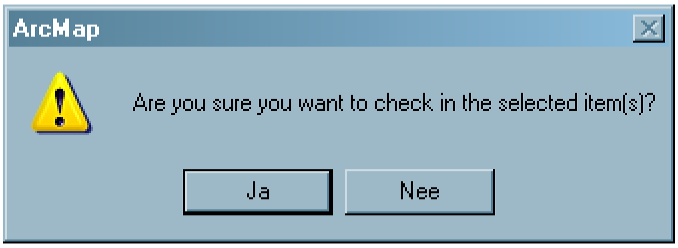


figure 97: Check In Edits from ArcPad verification request

After a successful Check In operation you get an "Operation successful"-message. Check in process is finished after you save the edits.

9.3.4 Collecting data

This process is very similar to the one described at paragraph 9.2.3 Fieldwork possibility 1.

9.3.4.1 Get the PDA ready

Follow the same steps as mentioned in 9.2.3.1 Get the PDA ready under Fieldwork possibility 1.

9.3.4.2 Adding a new sample point to the layer

Once the PDA is ready to operate in the field, you can walk through the forest to take samples.

- Once you chose the place where you want to take a sample, check the number of the compartment where you are now. This can be done by using the identify button and then clicking the compartment where your GPS marker is in.
- Click the GPS point icon to add a sample point on the current GPS coordinates.
- The Feature Properties window will pop up. You can now fill out the attribute form. Click on the desired property and the input panel will appear to enter a value (figure 98).

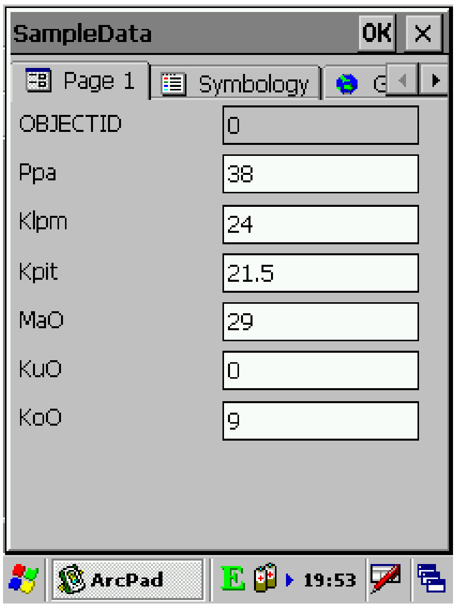


figure 98: Feature Properties form when adding a new point

- After entering al the values, click OK. The new sample point is added to the SampleData layer. Back on the main screen, you will see that a point is added.

9.3.4.3 Changing the attribute data of previously captured points

This process is the same as the one in 9.2.3.3, the only change is the look of the table. In this way of working, you don't see a long attribute table. In fact ArcPad generates a very clear form, as seen in figure 98 above.

Chapter 10 Project testing phase

10.1 Forest test 1

10.1.1 Field work report

Before we could do some practical things, we need to make the PDA ready. This part consisted of transferring the aerial images into the right format so that they can be read by the PDA (ESRI-format), database (already filled in) and making a new layer to put the sample points on. This is all described in the two chapters before. After preparing the PDA, we went to the forest for some first measurements, to collect data.

With the help of a Finish student we managed to understand more about forest sampling and forestry in general. He started to show us some basic things we knew from the theoretical part, but only now came clear.

There are a few measurements that are important for getting al the data needed (here in our project only the most important measurements are used to put in the database, because forestry is in fact 'just' an application to test the use of ArcPad-ArcGIS & the PDA-GPS).

We started with picking a good point to make a first sample plot. To do this you need a trained eye to take a point that positions in a mean part of the forest, so the most global data is gathered (a place not near the border, mixed trees, a point that resembles the consistency of the forest in a true way). When we found a good point, the fellow student showed us the use of the relascope, which we only knew from the theory.

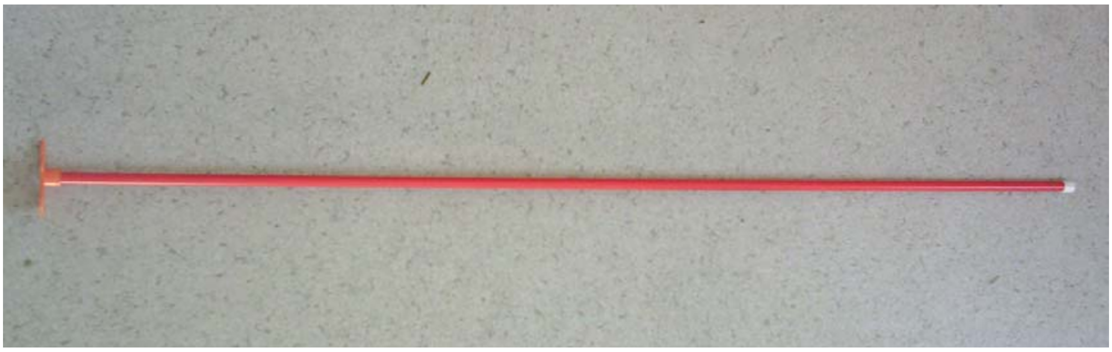


figure 99: The relascope we used in the forest

figure 100: Detail of the slot of the relascope

We tried to use the relascope on the sample point, and it worked quite well (for the information about the working of the relascope; see the chapter about forestry: count all the trees that fit in the slot on the relascope). We found some values that were possible, when u compare them with the given values in the existing database.

After counting the trees with the relascope, we had to look for a tree in the sample plot that was about the mean tree, and which gave a good example of the sample plot. This tree was important for the diameter at breast height, which was measured with a tree calliper, from which u could read directly the diameter on the curved part of the device (and the surface of the section on the silver table).

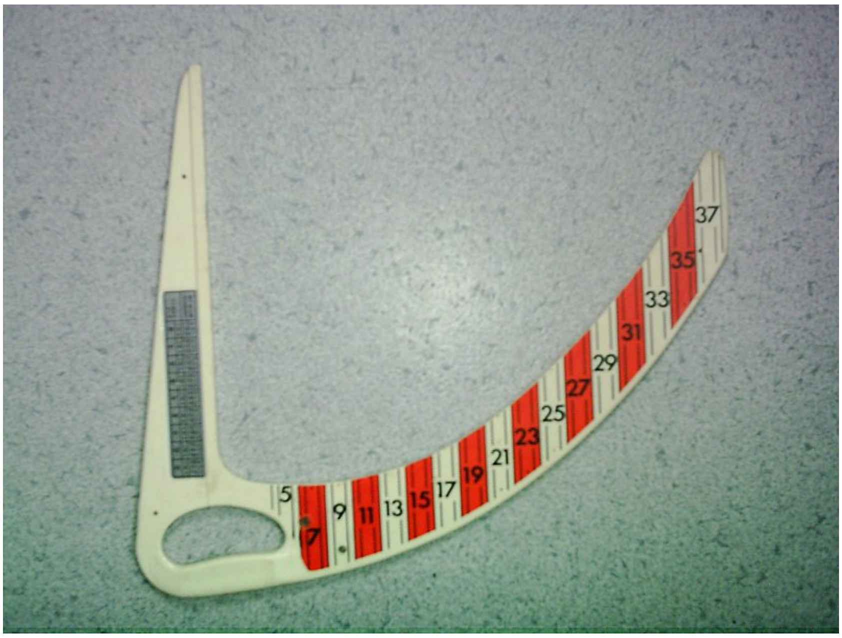


figure 101: The tree calliper

The chosen tree was also important for the height.

We first had to pick a point at a certain distance of the tree (at least 10m – the further the point, the accuracy will improve). This distance was measured with a normal roll meter.

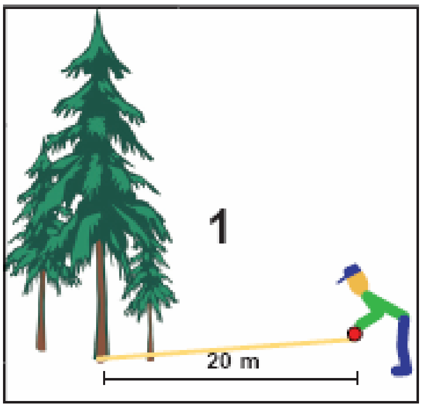


figure 102: Measuring the distance to the tree

To determine the height of the tree, we used a little device (6 x 4,5 x 2 cm – 50g), called Haglöf Electronic Clinometer (Swedish brand), which has a built-in display.

figure 103: The Haglöf Electronic Clinometer

With this device measuring the height of the tree was simple, quick and accurate. The use of this kind of clinometers eliminates counting errors when using formulas to define the height of the tree. We had to input the distance to the tree, than point towards the birth point of the tree (point above the crotch – few decimetres above the ground) and than point the device to the top of the tree and fix.

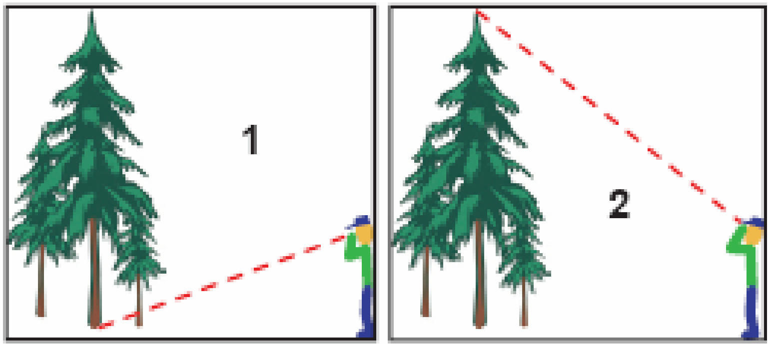


figure 104: Pointing towards birch point & top of the tree

Now we could read the accurate height of the tree directly from the screen.

figure 105: The display of the Clinometer – direct reading of the height

Once we knew this information (number of trees trough the relascope, diameter at breast height and height) we could calculate the other data to put in the database (timber volume, number of stems,…)

What is more important for us was the use of the GPS receiver and the database, the forestry part was just to provide us with some data.

During the use of the PDA while forest sampling and entering the data, we had some issues. Globally the PDA worked perfectly, but there were some small things which could be improved, making the use of the programs and the input easier and faster.

10.1.2 Issues

Here is a little enumeration of the issues we found:

- The size of the maps and aerial images is too large, which makes the PDA slow, especially when you have to zoom in/out or move the images. This is quite irritating and slows down the work when walking around and taking sample points.

  In this case we thought we used only a small part of the aerial image and the map to cover the area we needed for the test and even then the files are too big. The aerial image was already 14 Mb large. This made us thinking and zooming to the full extent of the ArcPad layer confirmed our ideas: the shapefile is packed to the current extent, but the images are exported in full extent. Later on, we saw it was mentioned in the ArcPad Map Wizard (see figure 64 in chapter 8).

  The size of the images makes the device not only slow, but also the memory is quite small (128 Mb internal – SD card 32Mb), so there are not many images that can be saved on the memory. Or there would be the need to buy larger (and fast) SD memory cards, which would make everything more expensive. If you would measure a whole day, the memory is not sufficient to fit all the maps and aerial images.

  A solution for this problem could be to resize the pictures in a way that the quality is not affected and still sufficient for the use on the PDA. When the size would be smaller, the zooming and moving will be faster and thereby the use of the PDA in general. More images could be saved on the provided memory, so a bigger area can be covered, which makes the autonomy of the device larger.

- Another thing we noticed was that the compartment layer was not transparent, so when you put the compartment layer on you only see the compartments as a white area on top of the aerial images. This is not easy, because in this way you miss all the information from the aerial image of the compartments, such as forest structure, roads, small waterways, etc… The compartments should be transparent, so you would see the aerial image or map. So the only thing what should be seen, should be the borders of the compartments. We don't know yet how to solve this problem.

figure 106: The compartment layer is not transparent

- During the measuring, we could easily create a new point on the layer and input the data in the database. The only problem with the database was, when we closed it (after input) we couldn't change or complete the database. Clicking on the sample point gave us the list, but this was uneditable. This should be arranged, so when you forget something you can enter it into the database.

- Another issue with the database is that it's too large, there are too many columns in it (for this project). This makes the whole system slower again, and also the ease of use is affected, because you have to scroll the whole time. A solution for this problem could be to just delete the rows we don't need, and only save these who are necessary for this project.

- The GPS receiver was quite accurate, and had a good view of the satellites, even under tree canopy. The only problem with the GPS receiver was that it couldn't fix its position while walking through the forest (see figure). When we stopped (to take a sample plot), the receiver fixed immediately its position, so we didn't have to wait. We consider this not as an important problem.

figure 107: The message on the PDA when there was no position fix

- exporting the files back from the PDA was our last issue during the first test. When we start up ArcMap, we only found export wizards, no import wizards to find, anywhere. The only way we could get the data in ArcMap again was doing a normal copy and paste from the PDA's data folder to the PC. It worked out, but we know this is an non-catholic way. As long as you're working with normal files in a folder, it is works fine, but the moment the project gets bigger and bigger and you're using a geodatabase, the troubles will start to arise. In fact, how could you copy and paste the ArcPad files to a geodatabase?

Considering all these (smaller) problems, we can improve the system bit by bit, making it better and faster, so we can do more tests in an easy way.

10.1.3 Solutions

Although the problems we had during the first test are quite small, they needed a solution. We browsed around through the ArcPad manual and found for every ArcPad problem, except of the GPS fix, a solution. Some were more catholic than others, but we solved all problems.

In this first test, we had all the single files organised in one folder and we used the way of working (except for some minor differences that caused the issues mentioned above) as described in the previous chapter under 9.2 Field work possibility 1. This way worked out, but we felt that it wasn't the right way of working. The aerial images stay too big, you have to change the symbology of the arcview_kuvio layer every time you load new data into the PDA. So, we were quite sure that there's another way to use ArcPad. Browsing through the manual didn't help us further. Next step was messing around in ArcMap and exploring all the toolbars. There we found out that there's another ArcPad toolbar. The reason we didn't saw it before, is the fact that it disappears from the screen every time you start up ArcMap but it stays marked as on in the pull down menu. Switching it off and on again makes this toolbar again visible. This discovery lead to the field work possibility 2 as mentioned in the previous chapter. This methods helped us a lot more forward and fixed all the problems except the GPS fix problem, which is not really a problem because the GPS finds his fix back quite quickly

10.2 Forest test 2

After finding the solutions for the issues we had in the first test, we could go into the forest for a second test. This time we went alone in the forest, without help of a student, because we already know how to take samples in the forest.

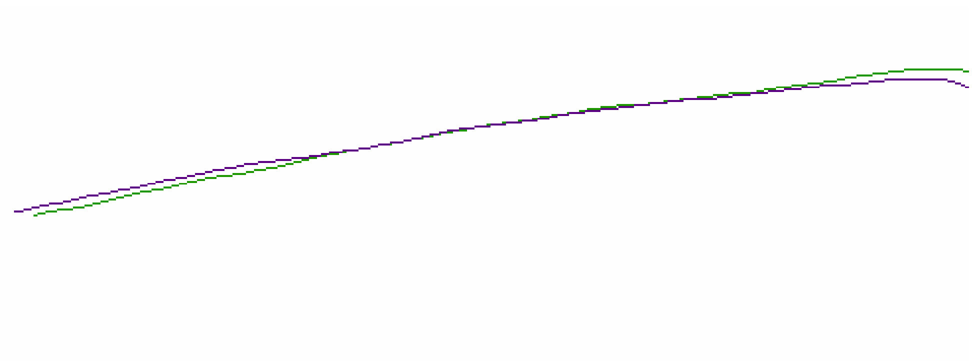
We started to walk around the compartments and took some sample plots in all compartments, to have a good view of the trees in the compartments. It was easier to see now, because the compartments are now transparent, so you can see the underlying map or aerial image. Everything went fine, once we got some routine in taking the samples, it went quite fast. Now the database was easier to fill in and more clearly; only the things we needed (for this project) were in the table, so we didn't had to scroll down the whole time. When we had enough data for the test, we could return. The only things we could remark were some minor things; the lines (which are the borders of the compartments) that were too thick (it was less clear when not zoomed in totally), and also the sample points were too large, so we can make them smaller. Also the keyboard that appears on the touch screen when you want to input some value in the table, is quite stodgy. It covers a big part of the screen, so when u want to type something in the table, sometimes that keyboard covers the table. You can put it of, but if you click the table it flips on. You can also move it across the screen, but it still stays stodgy.

Now we have the data we can use it and incorporate it into the project.

10.3 GPS performance test

We performed a little accuracy test with the GPS receiver. It basically existed out of two parts; first one was to test the difference between accuracy in holding the receiver horizontally or vertically, the second test was to measure two points each 9 times and check the differences between the results.

For the first test (difference in accuracy between holding the GPS receiver horizontally or vertically), we walked down the border of a sidewalk, and let the GPS place one point each other and let it put into a polyline, and this both holding the receiver horizontally and vertically. The problem here is that we don’t know which one is the correct position, and we only did one measurement in each position.

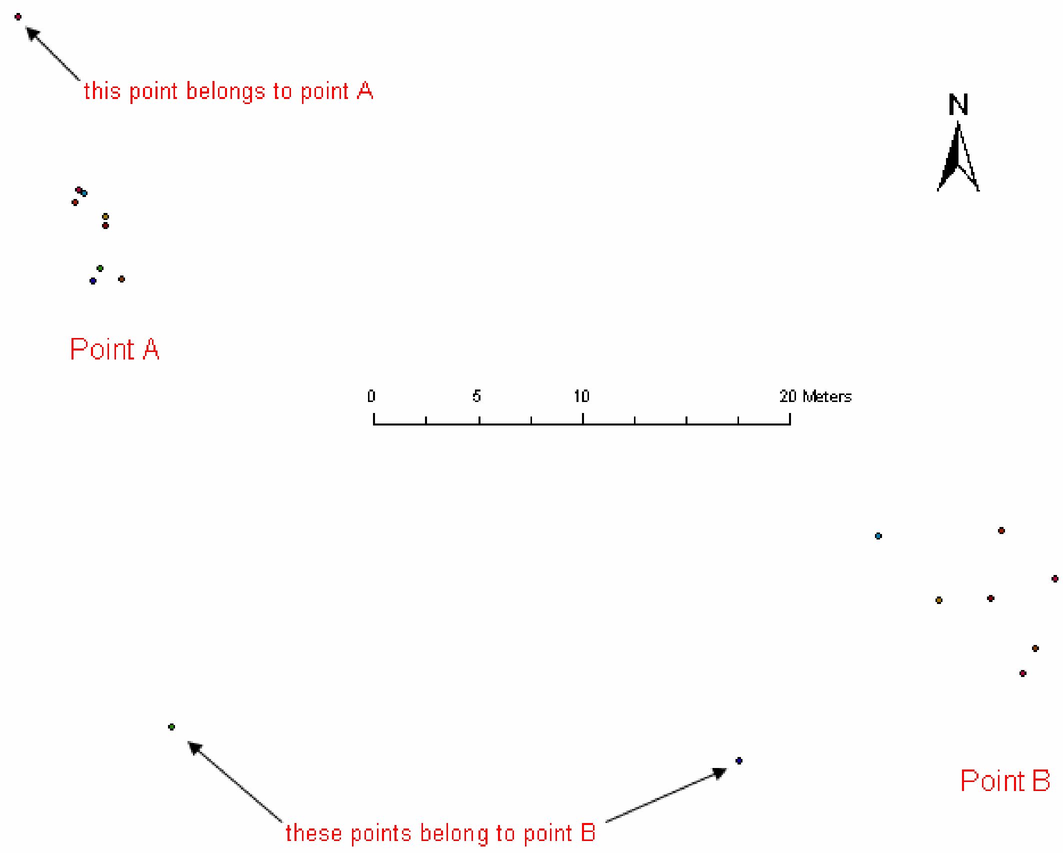


Horizontal vs. vertical position

You can see that there is a difference between both lines, but when you would hold the GPS receiver in the same position and walk the border of the sidewalk twice, you would also have a different line.
So we can say that this test is not worth to be taken into account.

The second test existed of measuring two different points each 9 times, and compare the results. The points were next to the school, so quite close to building and thus more vulnerable for multipath errors.

The first point was measured ten times per time we were standing on the point - internally, before it fixed it position - you can adjust it in the configuration of the GPS receiver. The second point was measured 20 times, every of the nine times we were on the point.



Performance test of two points

When you take a look at the figure, you can clearly see which one of the two points was measured twenty times per point by the GPS receiver, and which one only ten times. The point on the left (point A) was measured twenty times, the one on the right (point B) only ten times. You can clearly see that the accuracy is much better in the point that has been internally measured twenty times.

When you take a look at point B, you can clearly see that there are two points which are quite at a long distance from the mean point B (take a look at the scale bar). Now it's no problem, because we have some other measurements that show us that these two are not really reliable. But when u only have that measurement as an only point, it's not correct!

The measurements at point A are denser, because the GPS took the double of points (twenty instead of ten). There is also only one point that differs a lot from the position of the others.
In the table you can find the exact X and Y coordinate positions of the measurements. Also the mean value and the standard deviation are calculated. You can clearly see in point B that there is a value which differs a lot from the others (highlighted in red), and that's why that standard deviation is very large. When you let the worst point out, you can clearly see that de standard deviation is much more less than with that point.

Coordinates:	Point B	(10 times before fix)	Point A	(20 times before fix)
	X	Y	X	Y
1	3330126,256	6826071,253	3330082,324	6826089,021
2	3330127,199	6826074,603	3330077,37	6826101,706
4	3330118,708	6826076,653	3330080,506	6826093,144
5	3330124,651	6826076,912	3330080,056	6826092,785
6	3330125,644	6826070,053	3330080,287	6826093,339
7	3330112,018	6826065,899	3330080,974	6826088,989
8	3330084,727	6826067,528	3330081,25	6826089,561
9	3330121,637	6826073,59	3330081,572	6826092,014
10	3330124,097	6826073,706	3330081,565	6826091,646
Mean value:	3330118,326	6826072,244	3330080,656	6826092,467
Standard deviation:	13,455	3,857	1,424	3,872
	5,046	> without measurement nr 8 (large difference)		

figure 108: Coordinate table

After this little test, you can clearly see that the amount of measurements the GPS takes before it fixes a point, is decisive for the quality and accuracy of the result.

Chapter 11 Further developments

In the previous chapters, we proved that, if you skip the manual and find the right tools, ArcPad is a performing piece of software that makes the fieldwork lots easier. In this chapter, we describe some techniques and theories about things we didn't, wanted or couldn't realise because of lack of knowledge or lack of time.

11.1 ArcPad application builder[14]

ArcPad Application Builder is the development framework for ArcPad. With the Application Builder you can program custom toolbars, and custom data collection forms. This makes the fieldwork lots and lots more effective.

With ArcPad Application Builder you can:

- design custom forms to streamline data collection and ensure data integrity in the field;
- create new toolbars that contain built-in and custom tools;
- build applets for field specific applications and tasks;
- write scripts that interact with ArcPad software's internal objects;
- develop extensions to support new file formats, GPS receivers, rangefinders, cameras, projections, and datum transformations;

Many of the customisation tasks in ArcPad are performed directly using ArcPad Studio and require little or no programming. For more complex tasks, ArcPad exposes an extensive object model that can be accessed by writing VBScript or JScript code. Developers can build custom applications within this environment and deploy them on numerous ArcPad software-based devices in their organisations.

With ArcPad Application Builder, you can

- improve the accuracy of GIS data collected in the field;
- convert paper-based field data forms, permits, and reporting methods into mobile GIS applications;

[14] http://www.esri.com/software/arcgis/arcpad-appbldr/index.html

- increase the efficiency and effectiveness of field-workers;
- tailor ArcPad applications to user skill levels;
- automate ArcPad tasks and processes;
- extend GIS capabilities to field-workers;
- incorporate other technology such as digital cameras, rangefinders, and monitoring devices.

In our case, the ArcPad Application Builder would do a great job for data collection if we can program a custom data collection form. For sure a custom toolbar will be very useful and creates more space on the screen and eliminates all buttons we don't really need while taking sample data. Maybe a module to calculate the new compartment data on the field can be a good idea, although this is also possible in ArcView.

figure 109: Custom form made with ArcPad Application Builder (source ERSI)[15]

Detailed information on the ArcPad Application Builder can be found at http://www.esri.com/software/arcgis/arcpad-appbldr/index.html and case studies at http://www.esri.com/software/arcgis/arcpad-appbldr/about/case-studies.html.

11.2 ArcView techniques

We described the forest management process with the help of a GPS-enabled PDA in previous chapters (chapters 8 and 9) and above we explained how we can increase the productivity in the field. That only leaves ArcView to make improvements in the data collection and management process. And

[15] http://www.esri.com/software/arcgis/arcpad-appbldr/about/forms.html

there can be made quite a lot of improvements in fact. These improvements are all located in the field of programming macro's to make frequent steps easier.

11.2.1 Check in / check out macro

The check in / check out process could be made faster and easier and more automated. Every time you check in or check out data, you have to fill out the same fields, probably with the same names, and mark the same check boxes. This asks for automation. With the use of one form where you have to fill out the export folder name (this can't be the same every time if you have more ArcPad sessions running at the same on different PDA's) or, in the case of importing data, a single form where you can select the right folder, this steps can be made lots faster.

11.2.2 Calculation macro's

After collecting data all the new sample points should be used to calculate (updated) compartment data. Now we had to do it by hand, this can be programmed in a single "update compartment data macro."

11.2.2.1 Structure for this macro

1. To build this macro, we have to add an extra column to the SampleData layer with a title as calculated. This can be checked or text set to "done" if the sample data of a point are added to the compartment data.
2. Check which sample points are not yet added = get the rows where the field "calculated" is not equal to "done."
3. Take the first unadded sample point
4. Get the compartment where the sample point is taken = point-in-polygon query.
5. Recalculate all the data and change the compartment data.
6. Set the "calculated" field to "done."
7. Take the next point and go back to step 4 until all points are calculated.

11.2.3 Tforest functionality

All functionality that is available in Tforest should be translated to ArcView, probably in the form of macro's.

11.3 Databases

When the project grows bigger and when data of other regions of the country are needed, there will come the need for more advanced database techniques, as we described in chapters 4 and 5. This will enable every forest management centre to share data with other centres and get data from other centres. Aerial images, base maps and GT maps can be shared across Finland.

11.4 MobileMapper Beacon[16]

The MobileMapper Beacon is a Bluetooth-enabled wireless differential correction receiver that improves the real-time positioning accuracy of GPS receivers by providing DGPS corrections. Specifically designed for Thales mobile mapping solutions, and compatible with most other GPS receivers, MobileMapper Beacon provides access to standard RTCM SC-104 DGPS corrections broadcast by beacon networks around the world. It can be easily connected to your GPS receiver using the integrated Bluetooth® wireless technology or the included serial cable.

figure 110: MobileMapper Beacon

[16] http://products.thalesnavigation.com/en/products/product.asp?PRODID=1022

11.5 GPSDifferential for ArcPad[17]

GPSDifferential™ for ArcPad® adds the power of post-processing to your ESRI® ArcPad software on MobileMapper™ CE. This extension software offers integration of ArcPad and the included MobileMapper Office suite to provide reliable, sub-meter, post-processed positioning data results, according to Thales.

GPSDifferential for ArcPad automatically logs raw GPS measurement data in the field for post-processing back in the office. With GPSDifferential for ArcPad you can always acquire the most accurate data for all your GIS and mapping needs even where real-time differential corrections are not available.

The MobileMapper CE offers proven real-time, sub-meter positioning accuracy. Now the post-processing option provided by the ArcPad extension makes sub-meter mapping possible in areas where real-time differential corrections are unavailable. The logging of raw data required for post-processed differential correction happens behind the scenes of ArcPad without interrupting your workflow. Back in the office, MobileMapper Office post-processes the data and enables export to shapefiles or other industry standard formats.

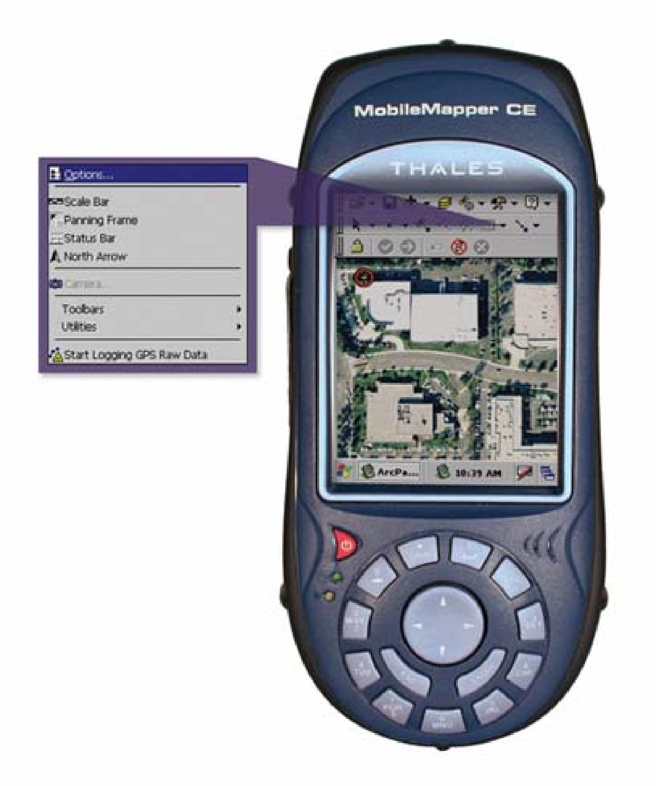


figure 111: GPSDifferential for ArcPad

[17] http://products.thalesnavigation.com/en/products/product.asp?PRODID=1225

Conclusions

Our conclusion will exist of two parts, one for Belgium and one for Finland, because they both have different purposes with the thesis.

The intention of our thesis for Belgium was to test the possibilities from the PDA-GPS and the combination ArcPad-ArcGIS. We can conclude that the performance of the GPS is sufficient. Maybe some more practise to make it more exact; the quality of the device is very good and the possibilities of the PDA are almost unlimited. We strongly suggest to procure the Application Builder from ESRI, because this makes the use easier and faster in bigger projects.

In Finland the most important purpose of our thesis was to digitalise the forest management system, and to see if it's possible to use ArcGIS (in combination with ArcPad) to put up the database and to administer all data, aerial images, maps, etc… Finland, on national level, wants to change their existing, more out of date, forest management system, called Tforest into the more universal ArcGIS system. If we put this together with all the possibilities of databases, ArcGIS can serve as a great base for a national forest management system where all national files can be kept in one place. In that way, a huge amount of storage space can be saved because there won't be double files anymore.

This in combination with GPS receivers is completely new. We tested some things and found out that it makes forest management not only quicker (once programmed), but also more accurate, easier to use and re-use the data, to import everything to the network (no paper and pen, no more overflowing writing and typing), etc…

In general we can state that the combination PDA-GPS receiver is a good and useful invention, in this case specially for mobile GIS purposes. Also the use of ArcPad and ArcGIS is a good combination and gives a lot of opportunities.

For the future we are quite sure that the use of these devices will increase a lot and also quality and compactness will enhance. It is a good thing to let students work with PDA-GPS, because these are the devices for the (nearby) future.

Also the use of ArcGIS (and ArcPad) instead of the Tforest program here in Finland will be well possible, and it will make it only better, quicker easier to use and more universal (which will help for the overall knowledge of the people who use it).

We would like to end with saying that the future of these devices and ArcPad/ArcGIS is bright, and that not all things have been said about the subject, there is much room for extension, further development and more investigation and exploration to improve the future of GIS and PDA/GPS-receivers. You can see this as a beginning, an introduction into a fascinating new world of digitalised and compact use of GIS, anywhere at anytime.

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List of appendices

Appendix I: performance test in the forest

Introduction

Since its introduction, MobileMapper CE has been enthusiastically accepted by the market.

MobileMapper CE provides accuracy, performance and high value. To underscore the accuracy and performance of this solution, stringent testing was performed and recorded here to better inform potential users and the industry.

This real-world performance was measured under the three most common data collection scenarios in mapping work:

- Open Sky Conditions
- Suburban Environment
- Tree Canopy

The results of the testing clearly prove that:

- MobileMapper CE is sub-meter accurate in the 3 data collection scenarios.
- The ability to adjust the sensitivity level of the MobileMapper CE dramatically increases its productivity under foliage.
- The MobileMapper CE has excellent responsiveness in dynamic data collection, i.e. lines and areas.

In all of the tests the default GPS settings were used, namely:

- Maximum PDOP: 6
- Minimum SNR[1]: 30
- Elevation Mask: 10

WAAS corrections were used throughout all of the tests with the exception of the foliage data collection where RTCM corrections from the MobileMapper Beacon were used.

Tree Canopy Data Collection

The final test scenario was designed to test the performance of the MobileMapper CE under foliage. For this test the foliage was deciduous trees (Eucalyptus) as shown on the two photos of Figure 7. The test was done during the summer.

Figure 7: Foliage test setup.

Data were collected over a control point surveyed by using a Theodolite. For this test, RTCM differential was used streaming via Bluetooth from a MobileMapper Beacon. Eight 60-second static occupations were completed.

Table 2: Accuracy under foliage (m).

Occupation	Horizontal Error
1	0.71
2	0.16
3	0.15
4	0.20
5	0.38
6	0.13
7	0.13
8	1.06

Several things are clear from the data. First of all, the accuracy of the MobileMapper CE is very good, given the nature of the setting. Only one point was outside 1 m of accuracy and in that case only by 6 cm. Secondly, MobileMapper CE was able to collect data during all eight occupations in circumstances where one would normally expect to lose lock at least some of the time. For this test, the SNR mask was set to 30 dBHz.

The fact that MobileMapper CE is so productive under foliage is partly due to the ability to set the SNR mask in the receiver. The range is from 24 to 32 dBHz with the default setting being 30. The user can adjust this level to obtain position data even in very dense foliage. For example, setting the SNR number to the lowest possible level (24) means that the MobileMapper CE will only reject signals with an SNR of less than 24, a setting that should be used only when a position is absolutely required even with the possibility of some error.

Appendix II: Translation compartment data

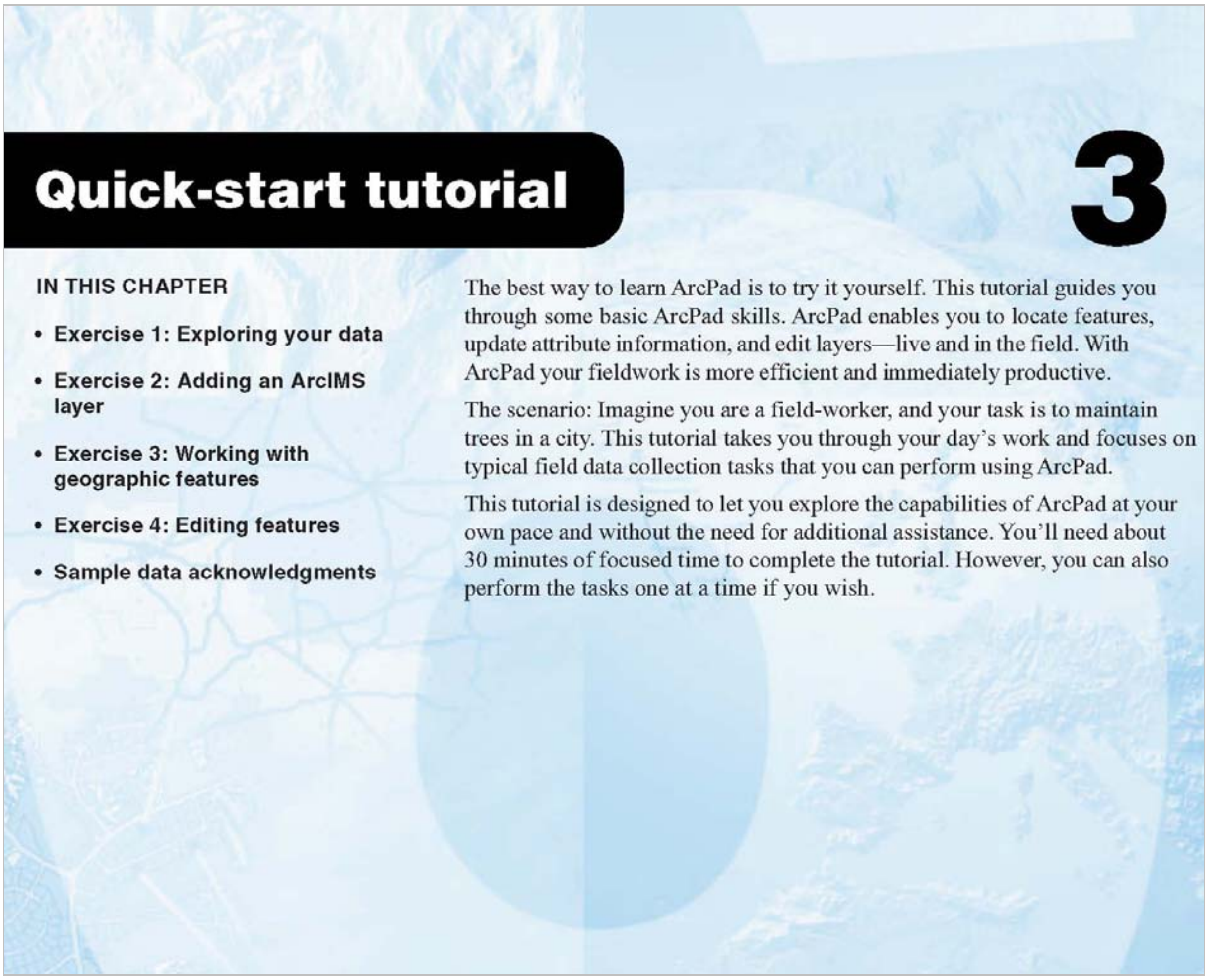
Id	Laji	Selite	Idteksti	Mk	Kta	Alue	Lko	Ms	Laatv	Laatija	Compartment number Kuvnro
2364344	5102	Kuviopiste 2 mm	238	5	837	830	31	31	2000	123	238
2364337	5102	Kuviopiste 2 mm	236	5	837	830	31	31	2000	123	236
2364330	5102	Kuviopiste 2 mm	235	5	837	830	31	31	2000	123	235
2364326	5102	Kuviopiste 2 mm	234	5	837	830	31	31	2000	123	234
2364323	5102	Kuviopiste 2 mm	233	5	837	830	31	31	2000	123	233
2364320	5102	Kuviopiste 2 mm	232	5	837	830	31	31	2000	123	232
2364311	5102	Kuviopiste 2 mm	231	5	837	830	31	31	2000	123	231
1816881	5102	Kuviopiste 2 mm	127	5	837	830	31	31	2000	15	127
1816880	5102	Kuviopiste 2 mm	134	5	837	830	31	31	2000	15	134
1816735	5102	Kuviopiste 2 mm	129	5	837	830	31	31	2000	15	129

Alanro	Pala	Main land group Pr	Sub soil group Ar	Site class Kap	Soil type Ml	Kt	Aioj	Kraj	Development class Kl	Mlt	Age years Ika	Basal area m² Ppa	Number of stems Rl	Mean diameter cm Klpm	Mean height cm Kpit	Volume m³ Til	Main tree species Ppl	Pine MaO	Spruce KuO
	1,5	1	1	5	50	1	0	0	03	1	50	9,9	429	18,4	12,0	59,2	1	48	12
	0,1	3	1	6	50	1	0	0		0	0	0,0	0	0,0	0,0	0,0	0	0	0
	0,9	1	1	2	21	1	0	0	T1	2	3	3,0	2991	12,3	10,8	15,7	2	0	5
	0,3	1	2	2	62	7	3	0	03	1	50	14,0	871	15,4	13,7	92,6	2	0	58
	0,1	1	1	2	21	1	0	0	03	1	50	32,0	1451	18,0	17,0	274,0	2	0	274
	0,2	3	1	5	50	1	0	0		0	35	1,0	103	12,0	8,0	4,3	1	4	0
	2,0	1	1	2	21	1	0	0	02	1	35	18,3	4006	12,9	11,8	107,8	1	52	13
	0,3	1	1	4	50	1	0	0	04	1	153	20,6	328	28,2	20,8	201,5	1	202	0
	0,9	1	1	3	11	1	0	0	02	1	33	17,9	1452	16,4	14,2	125,9	2	63	48
	0,4	1	1	2	22	2	0	0	Y1	1	86	20,8	666	24,5	21,6	203,3	2	7	46

Birch		% Pine saw log proportion	% Spruce saw log proportion	% Birch saw log porportion								m^3/ha Cutting volume	m^3/ha Pine saw log	m^3/ha Spruce saw log	m^3/ha Birch saw log	m^3/ha Hardwood log	m^3/ha Pine pulpwood
KoO	LpO	MatO	KutO	KotO	LptO	Kasvu	Hta	KiH	LmH1	LmH2	HO	Hke	Ksa	Mat	Kut	Kot	Lpt
0	0	25	2	0	0	3,6	0		0	0	0	0	K	0	0	0	0
0	0	0	0	0	0	0,0	0		0	0	0	0		0	0	0	0
0	11	0	0	0	0	3,4	0		0	0	0	0	K	0	0	0	0
34	0	0	8	4	0	6,5	0		0	0	0	0	T	0	0	0	0
0	0	0	99	0	0	7,7	3	H	0	0	0	75	T	0	14	0	0
0	0	0	0	0	0	0,9	0		0	0	0	0	K	0	0	0	0
39	4	12	0	2	0	9,4	2	1	0	0	0	18	K	0	0	0	0
0	0	177	0	0	0	2,7	5	3	0	0	0	228	A	207	0	0	0
12	3	42	2	0	0	8,4	0		0	0	0	0	A	0	0	0	0
151	0	7	17	127	0	5,7	0		0	0	0	0	T	0	0	0	0

m^3/ha Spruce pulpwood	m^3/ha Birch pulpwood	m^3/ha Hardwood pulpwood													
Mak	Kuk	Kok	Lpk	Enp	Raiv	Maanm	Uudist	Taydv	Thoito	Ki1	Mhtyo2	Ki2	Lann	Ojitus	RILm
0	0	0	0	0	0	0	0	0	0		0		0	0	0
0	0	0	0	0	0	0	0	0	0		0		0	0	0
0	0	0	0	0	0	0	0	0	0		0		0	0	0
0	0	0	0	0	0	0	0	0	0		0		0	0	0
0	61	0	0	0	0	0	0	0	0		0		0	0	0
0	0	0	0	0	0	0	0	0	0		0		0	0	0
9	2	7	0	0	0	0	0	0	0		0		0	0	0
21	0	0	0	0	0	530	201	0	0	3	0		0	0	0
0	0	0	0	0	0	0	0	0	0		0		0	0	0
0	0	0	0	0	0	0	0	0	0		0		0	0	0

Appendix III: Quick-start tutorial ArcPad



Quick-start tutorial

3

IN THIS CHAPTER

- **Exercise 1: Exploring your data**
- **Exercise 2: Adding an ArcIMS layer**
- **Exercise 3: Working with geographic features**
- **Exercise 4: Editing features**
- **Sample data acknowledgments**

The best way to learn ArcPad is to try it yourself. This tutorial guides you through some basic ArcPad skills. ArcPad enables you to locate features, update attribute information, and edit layers—live and in the field. With ArcPad your fieldwork is more efficient and immediately productive.

The scenario: Imagine you are a field-worker, and your task is to maintain trees in a city. This tutorial takes you through your day's work and focuses on typical field data collection tasks that you can perform using ArcPad.

This tutorial is designed to let you explore the capabilities of ArcPad at your own pace and without the need for additional assistance. You'll need about 30 minutes of focused time to complete the tutorial. However, you can also perform the tasks one at a time if you wish.

Exercise 1: Exploring your data

In this tutorial, you'll use several layers to complete your work order. The primary layer that you will use is the city trees layer; however, you will also use additional layers to make it easier to locate yourself and to find the trees that need to be identified. The following table provides descriptions of these layers.

Layer	Description
sd_aerial30.sid	Two-foot pixel aerial photograph of downtown San Diego, including the San Diego Convention Center
sd_citytrees.shp	Fictitious trees
sd_convcntr.shp	San Diego Convention Center outline
sd_park.shp	San Diego parks
sd_roads.shp	Roads for the 92101 San Diego ZIP Code

The exercises in this chapter use the sample data distributed with ArcPad. The layers are located under the Samples\San Diego folder on the ArcPad CD–ROM. You may also have these layers on your Windows CE computer or desktop PC if you selected the Sample Data when you installed ArcPad. The San Diego folder is located under the My Documents folder on your Windows CE computer. The exercises require that you have write access to this data. If you don't, you'll need to copy the data to a location that you do have write access to.

The exercises that follow are fictitious, and they do not in any way represent real occurrences in the City of San Diego. For information about San Diego data resources, refer to the end of this chapter.

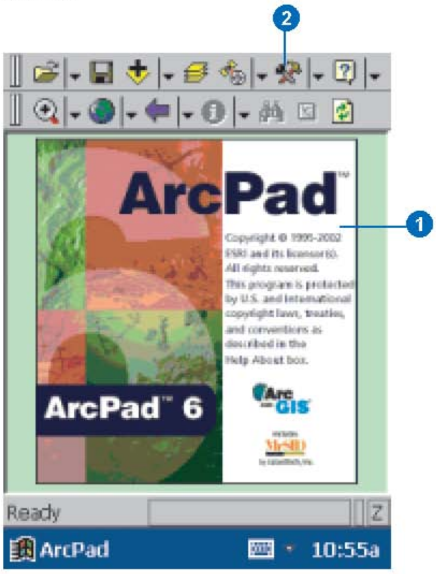
In this tutorial, the word tap is used when selecting an item, as opposed to the word click. On computers that have a touch screen and pen interface, items are selected by tapping the pen on the screen. This performs the same action as clicking does when using a mouse on computers without a pen interface. In the interest of brevity, the word tap will be used, but this should also be taken to mean click.

The San Diego sample data in ArcPad

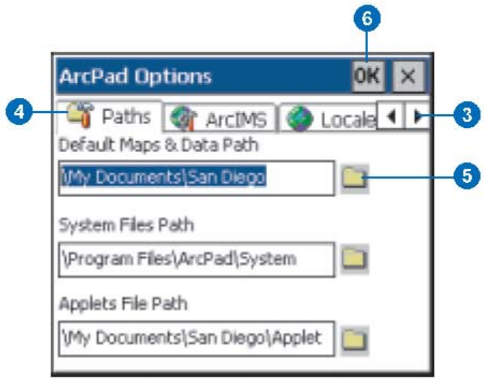
Selecting the appropriate layers

Let's begin by starting ArcPad and setting the default Map Path to where the San Diego sample data is located. You will then add the layers that you need.

1. On your Windows CE computer, start ArcPad by tapping Start, then tap ArcPad. You will see the ArcPad splash screen briefly, and ArcPad will open with a blank Map window.

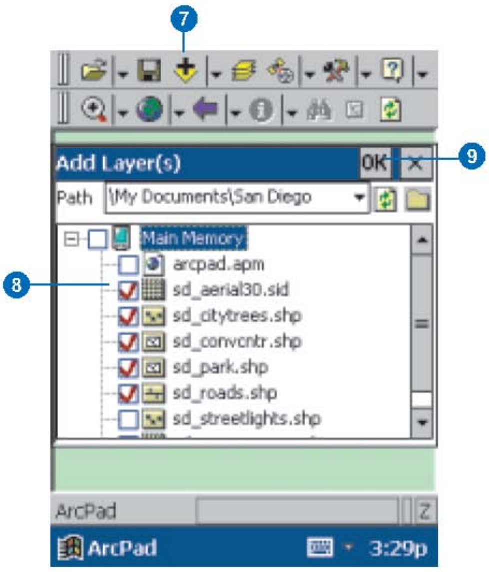


2. Tap the Tools button on the Main toolbar. This opens the ArcPad Options dialog box.
3. Tap the right arrow button.



4. Tap the Paths tab.
5. If the Default Maps & Data Paths include the Samples\San Diego folder, then move on to Step 6. If not, tap the Folder button next to the Default Maps & Data Paths. This will open the Directory Browser. Navigate to the San Diego folder and tap the folder to select it. By default the Samples folder is installed in the My Documents folder on Windows CE computers.
6. Tap OK.

7. Tap the Add Layer button on the Main toolbar. The Add Layer(s) dialog box opens. Notice that the Path is set to the San Diego folder that you set in the previous steps.

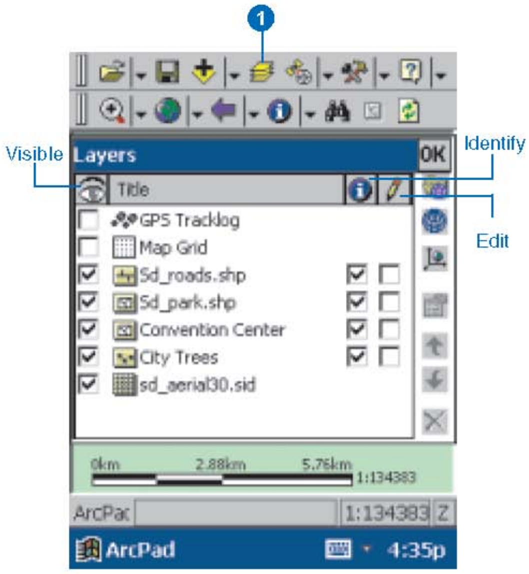


8. Select sd_aerial30.sid, sd_citytrees.shp, sd_convcntr.shp, sd_park.shp, and sd_roads.shp by checking the check box to the left of the layer. A red check indicates that a layer has been selected.
9. Tap OK. The selected layers are drawn in the ArcPad Map window.

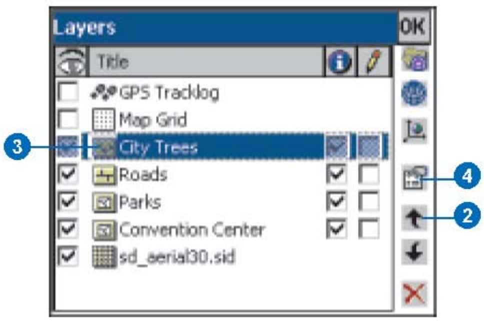
Exploring your selected layers

Explore the San Diego layers provided for this tutorial. Understanding the properties associated with each layer will help you to quickly navigate around the map.

1. Tap the Layers button to open the Layers dialog box. The layers you selected previously are listed, each with a check in the Visible check box and the Identify check box. The Edit check box is, by default, unchecked.

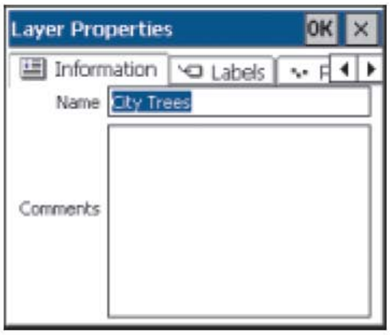


2. You can change the order in which layers are drawn by tapping on the Move Up or Move Down arrow buttons. The layers at the bottom are drawn before the layers at the top. Move the City Trees layer up so that it is drawn after and on top of the Roads layer.

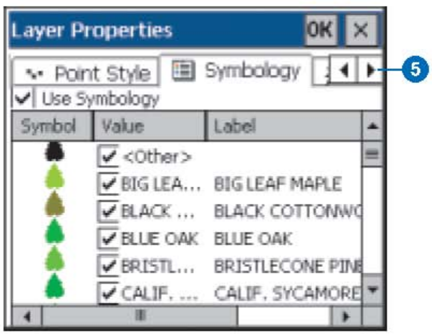


3. Tap the City Trees layer to select it; the layer is highlighted in blue.
4. Double-tap the City Trees layer or tap the Layer Properties button. The Layer Properties dialog box is displayed for the City Trees layer.

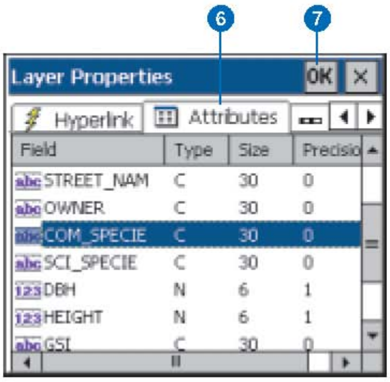
   The Information page is displayed first; you can see that the Title field has the name City Trees in it. This is also the title that is used to name the layers in the Layers dialog box.



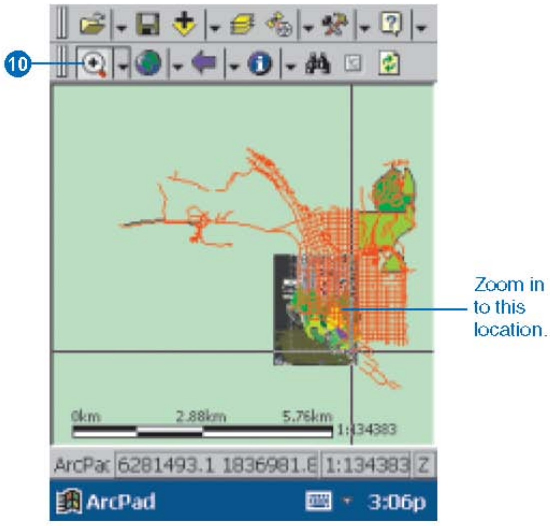
5. Tap the right arrow and then tap the Symbology tab to view the layer symbology. Symbology is created using the ArcPad tools for ArcView GIS 3.x or ArcGIS Desktop. For more information about symbolization, see Chapter 7, 'Symbolizing your data'.



6. Tap the Attributes tab to see the fields associated with the City Trees layer. Later, you will change the values of these fields after you have inspected the tree.



7. Explore the additional tabs to learn more about the City Trees layer. Tap OK when you are ready to return to the Layers dialog box.
8. Explore each of the layers that you will use to help you locate the tree that needs to be inspected.
9. Tap X in the Layers dialog box when you are ready to return to your ArcPad map.
10. Tap the Zoom In button, then tap and drag a box around the area of the image file. The rest of the exercises are concentrated in the downtown San Diego area.

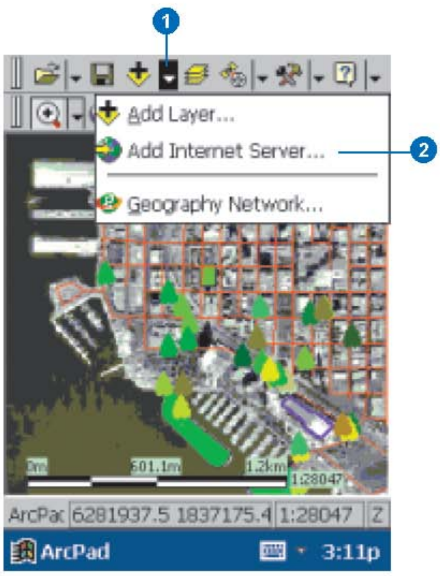


Exercise 2: Adding an ArcIMS layer

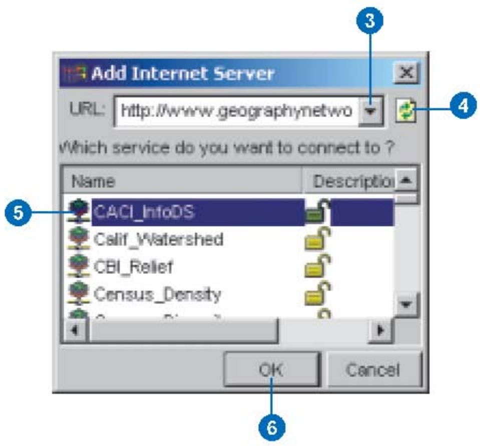
You are out in the field, and you require additional information about the area. The logical choice is to connect to the Internet and retrieve data from the Geography Network (*www.geographynetwork.com*).

To receive data from the Internet, ArcPad requires a valid TCP/IP connection, such as a wireless local area network, cellular phone, or wireless modem.

1. Tap the arrow to the right of the Add Layer button.
2. Tap Add Internet Server.

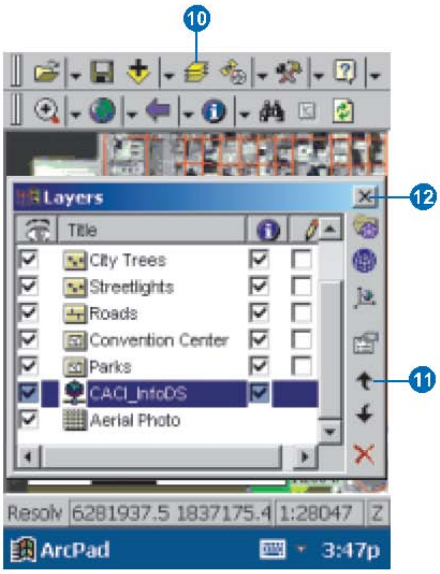


3. Tap the dropdown arrow and select *http://www.geographynetwork.com*.
4. Tap the Refresh button. ArcPad lists the supported services that are available to you.
5. Tap the service you would like to connect to. In this case, tap CACI_InfoDS.
6. Tap OK.



7. Navigate to the location you want to save the file in and tap Save.
8. ArcPad asks you whether or not you would like to add the service to your current map. Tap Yes to add it.
9. Tap Yes to add the layer in the map's current projection.

10. Tap the Layers button. ArcPad added the layer at the bottom of the layer list.
11. Tap the CACI_InfoDS layer and move it above the Aerial Photo layer.
12. Tap X.



Data is downloaded from the Geography Network to ArcPad.

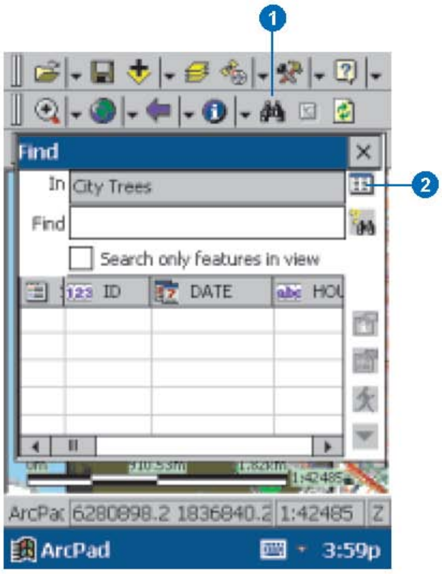
Exercise 3: Working with geographic features

In this exercise you will locate a tree that has been infested by insects and requires spraying. You will locate the tree and then update its attribute information, noting what maintenance needs to occur. Once that task is completed you will select trees neighboring the infested tree and indicate that they are also in need of spraying to prevent the spread of the insects.

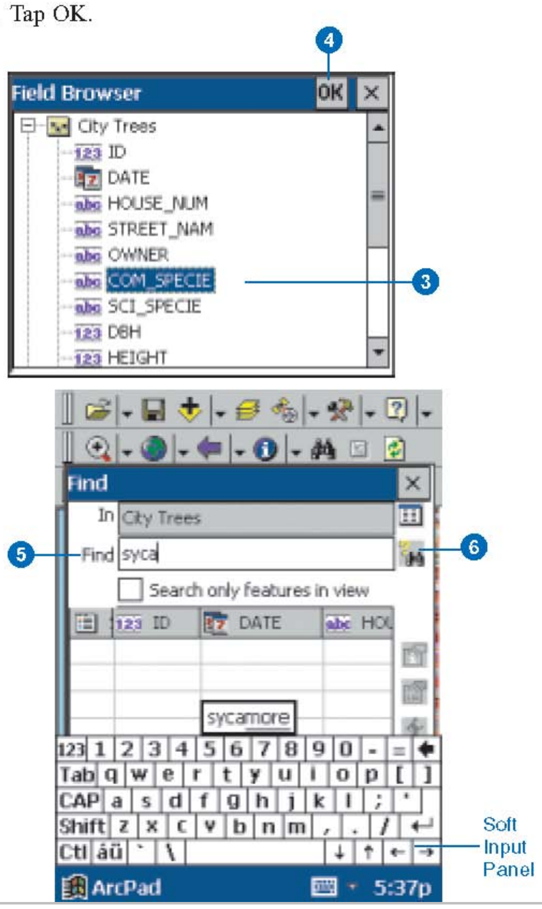
Locating a feature

In this exercise, you will use the Find tool to locate the tree you are looking for. Your work order tells you that it is a Sycamore tree on California Street that needs inspecting.

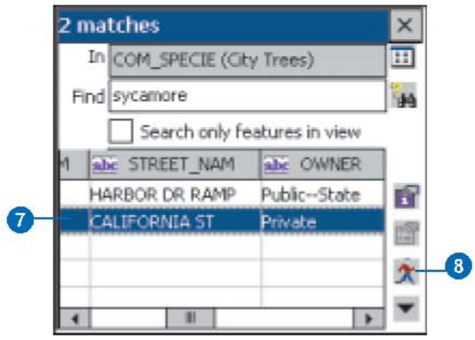
1. Tap the Find button.
2. Tap the Select Layers button.



3. Tap the + symbol next to the City Trees layer and tap COM_SPECIE.
4. Tap OK.



5. Use the Soft Input Panel to type the tree name "sycamore" in the Find box.
6. Tap the Find button to execute the search.
7. Scroll to the Street Name (STREET_NAM) field to make sure it is the Sycamore tree on California Street you have located. Tap the matched feature.
8. Tap the Go To button.

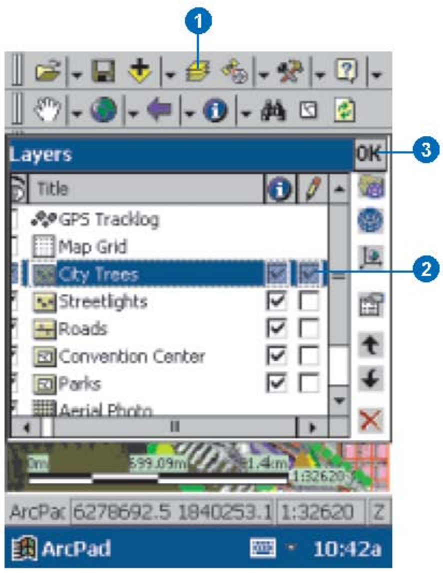


9. ArcPad zooms to the Sycamore tree. The selected tree is highlighted and set as the current navigation destination. The tree is also labeled using the value of the field that was searched on—in this case, the common name of the tree species.
10. Your tree is clearly labeled, and with your ArcPad map you can go to your tree and inspect it.

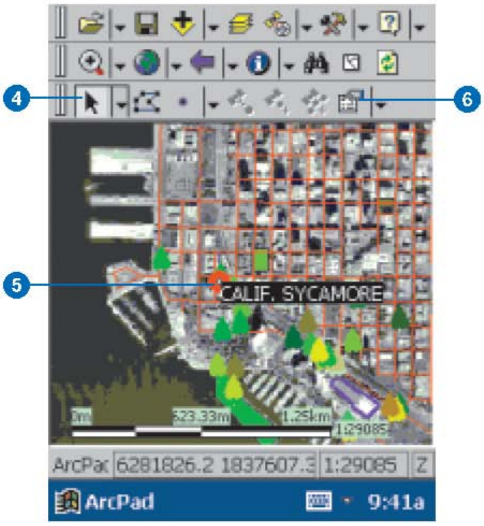
Creating a work order

In this section, you will change the attributes of the tree that you inspected in the previous section and create a work order. It should be noted that although the following forms are included in the Sample Data with ArcPad, the data collection and work order forms used in this section were created and customized using the ArcPad Application Builder. For more information about the ArcPad Application Builder, see Appendix B.

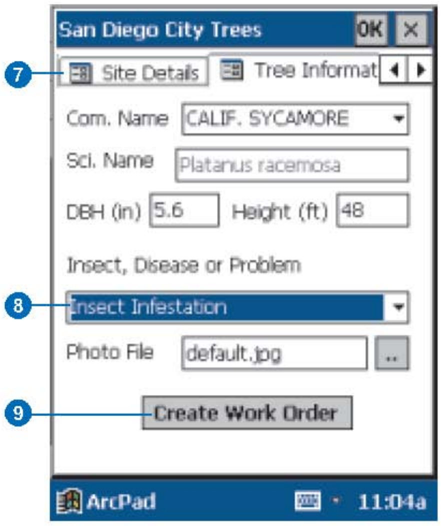
1. You need to make the City Trees layer editable before you can edit its attributes. Tap the Layers button.
2. Check the Edit check box for the City Trees layer.
3. Tap OK. ArcPad automatically displays the Edit/Drawing toolbar once a layer is made editable.



4. Tap the Select button.
5. Tap the Sycamore tree you identified in the previous section to select it.
6. Open the selected features properties by tapping the Feature Properties button.

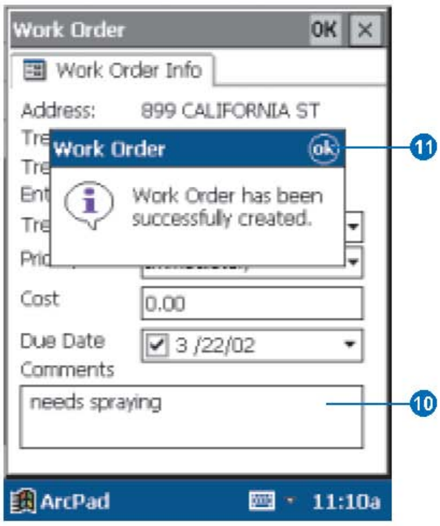


7. Change the form to reflect the inspection. Tap the Site Details tab and use the dropdown calendar to enter today's date under Date Visited.
8. Tap the Tree Information tab. Under Insect, Disease or Problem, select Insect Infestation.

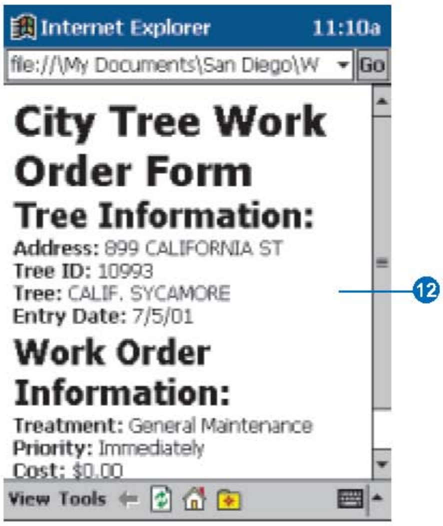


9. Once you have completed updating your form, tap Create Work Order at the bottom of the Tree Information page.

10. Enter any other relevant information using the provided dropdown lists or use the Soft Input Panel to enter your comments about the tree. Tap OK.



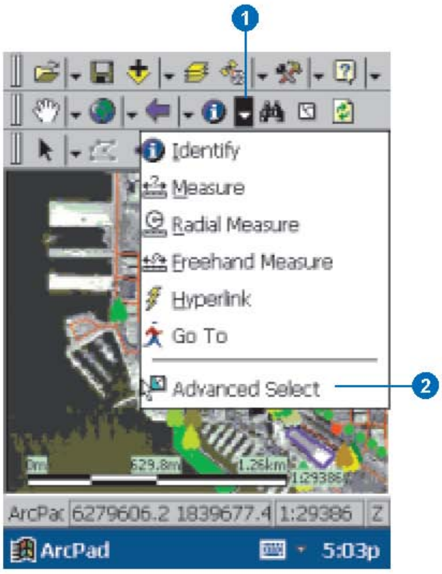
11. Tap OK.
12. The custom work order form creates an HTML page with the provided work order information. You can e-mail it to the office if you have a TCP/IP connection.



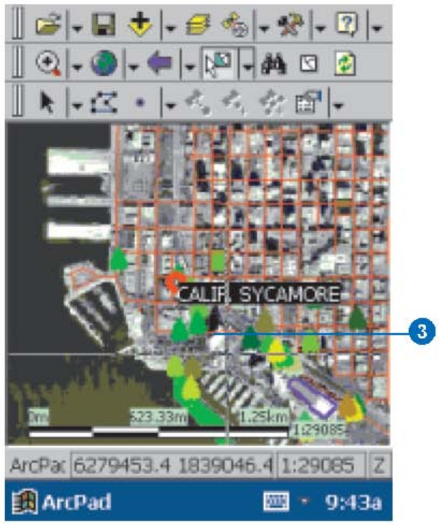
Using the Advanced Select tool

Use the Advanced Select tool to locate all the trees in the immediate vicinity of the infested Sycamore tree.

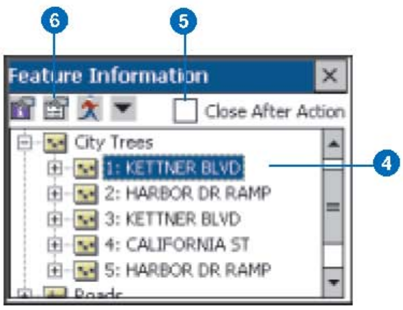
1. With the City Trees layer in Edit mode, tap the arrow to the right of the Identify tool.
2. Tap Advanced Select.



3. Tap and drag a selection box to select all the trees in the vicinity of the Sycamore tree. A list displays the selected features.



4. Tap the first feature.
5. Uncheck the Close After Action check box.
6. Tap the Feature Properties button.



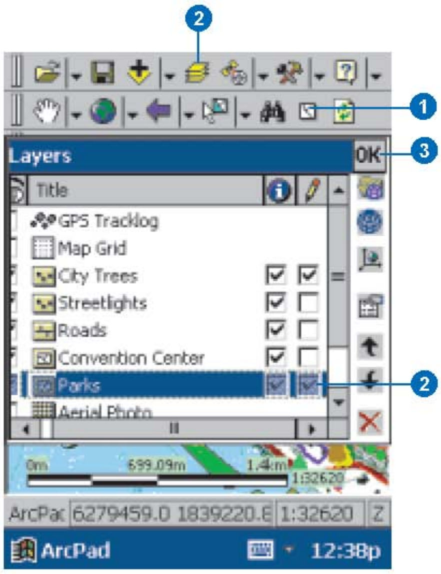
7. The form for the selected feature appears. Make the necessary changes and close the form.

8. Follow the same procedure as outlined above for all the trees selected.
9. Tap OK. You have successfully completed your tree maintenance duties for the day!

Exercise 4: Editing features

Since you are in the neighborhood, the Parks and Recreation Department has asked that you map the potential expansion of Pantoja Park, located in downtown San Diego. The neighboring blocks of the parks have been vacated and turned over to the City. They are deciding whether or not to expand Pantoja Park into this space.

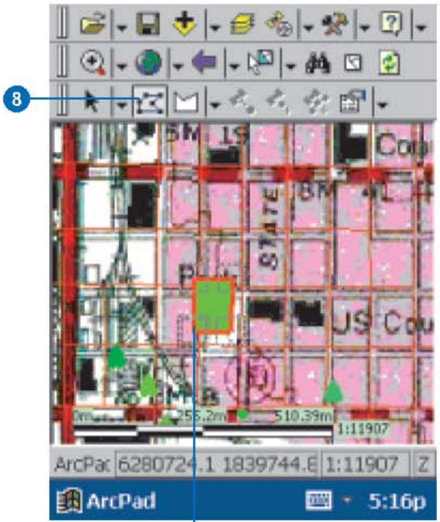
1. Tap the Clear Selected button to clear the previously selected feature.



2. Make the Parks layer editable by tapping the Layers button and check the Edit check box for the Parks layer.
3. Tap OK.
4. Locate Pantoja Park.

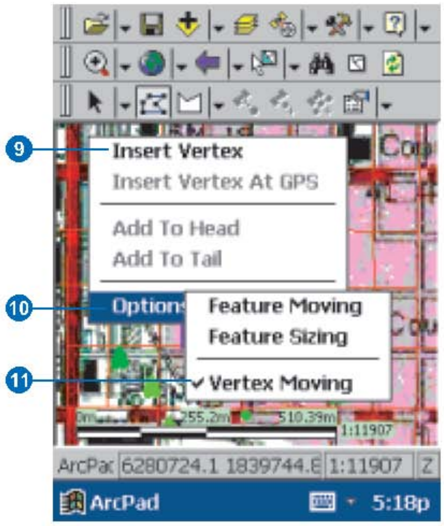
   Tip: Use the Find tool described in Exercise 3.
5. Tap the Select button.
6. Tap Pantoja Park. The park is highlighted, and its extent is outlined using a dashed line.
7. Tap the Zoom In button and zoom closer to the park.

8. Tap the Vertex Edit button.

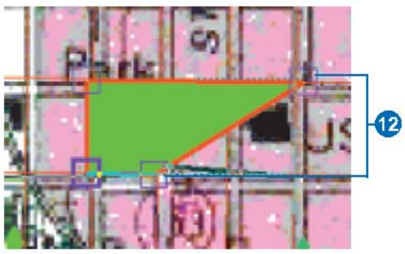


The park is highlighted, and the vertices are outlined.

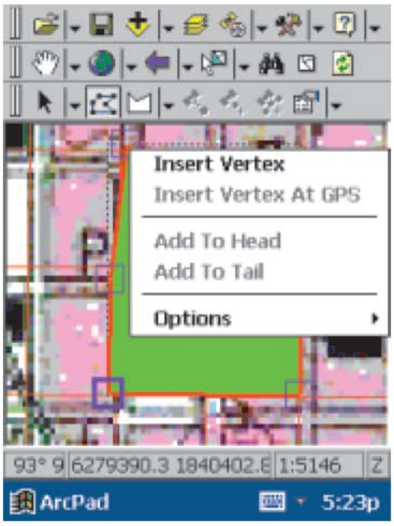
9. Tap and hold anywhere on the map, except within the vertex squares, to display the feature editing menu.
10. Tap Options.
11. Tap Vertex Moving.



12. Tap and drag both the top right and bottom right vertices two blocks eastward.



13. The park is also being extended northwards but for only one block length. Tap and hold at one block north of the top left vertex.
14. Tap Insert Vertex. ArcPad inserts a vertex where you tapped the map. Repeat for the other two vertices that need to be added.



15. Your new park is complete. Exit ArcPad. Your workday is over!

Note: Once a change is made in ArcPad, it cannot be undone. If you exit ArcPad without saving your changes, changes such as changing the shape of Pantoja Park still remain. If you would like to go back to your original park structure, you can use the editing tools to change it back or copy the original files from the ArcPad CD to the Samples\San Diego folder on your device.

Sample data acknowledgments

The San Diego Association of Governments (SANDAG) provided most of the data for the San Diego sample dataset. Other San Diego data layers can be downloaded from the SANDAG Web site at www.sandag.cog.ca.us.

Geographic Data Technology, Inc. (GDT), provided data for the 92101 ZIP Code. You can visit the GDT Web site at www.geographic.com. Map Factory-HJW provided the Aerotopia Photomap, the two-foot pixel aerial photo of downtown San Diego. You can visit MapFactory-HJW's Web site at www.hjw.com. Horizons Technology, Inc. (HTI), provided the Sure!MAPS® RASTER topographic map data for San Diego. You can visit HTI's Web site at www.horizons.com. The data has been simplified by ESRI. ESRI, GDT, HTI, MapFactory-HJW, or SANDAG cannot assure reliability or suitability of this information. Original data was compiled from various sources, and spatial information may not meet National Map Accuracy Standards. This information may be updated, corrected, or otherwise modified without notification. The city trees layer and the exercises in this chapter are fictitious, created for the purpose of this tutorial.

Appendix IV: Export summary

Summary

Output Folder: C:\ThesisProject\ToArcPad
Map Name: Test02.apm

Projection: Finland_Zone_3
Total File Size: (20921 kb)

Total Layers: 4
Feature Layers: 2
Image Layers 2

Label Fonts: Arial
Symbol Fonts: ESRI Default Marker

Feature Layer Name: SampleData
Number of Features: 2
Size of -shp: (1 kb)
-dbf: (1 kb)
-shx: (1 kb)
-apl: (1 kb)

Feature Layer Name: arcview_kuvio
Number of Features: 9
Size of -shp: (4 kb)
-dbf: (4 kb)
-shx: (1 kb)
-apl: (1 kb)

Image Layer Name: image.sid
Size of -sid: (14959 kb)

Image Layer Name: c212312.sid
Size of -sid: (5948 kb)

Appendix V: Map Projection

KKJ – Finland Zone 3 (27°E); Gauß-Krüger; Hayford 1909 Ellipsoid

Name:	GCS_KKJ
Projection:	TRANSVERSE – Gauß-Krüger
Zunits:	NO
Units:	METERS
Spheroid:	INT1909
Xshift:	0.0000000000
Yshift:	0.0000000000

Parameters:

1.00000	(scale factor at central meridian)
27 00 00	(longitude of central meridian)
0 00 00	(altitude of origin)
3500000.00000	(false easting - meters)
0.00000	(false northing - meters)

Angular Unit:	Degree (0.017453292519943299)
Prime Meridian:	Greenwich (0.000000000000000000)
Datum:	WGS84
Spheroid:	WGS84

Semimajor Axis: 6378388.000000000000000000

Semiminor Axis: 6356911.946127946500000000

Inverse Flattening: 297.000000000000000000