The Role of Mobile Geographic and Information Technologies in Optimising Water Quality Monitoring and Management

MSc Dissertation

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Abstract

This thesis explores and reviews both the conceptual and technological issues associated with mobile computing and field data management. Within the context of the study, water quality monitoring is addressed and taken to be the subject of the problem.
The spatial and geographical nature of field campaigns is used as a base to take full advantage of developments in mobile information and communication technologies through integrating these with current monitoring scenarios to ultimately revolutionise the field work and data collection process. The development of integrated data collection systems designed for acquiring, storing, displaying and transmitting the geo positional data during field work campaigns is reviewed and integrated in an attempt to address the problems facing field data management during water monitoring programs.

To conclude a case study is carried out with the water board of Zuiderzeeland in The Netherlands. The case study addresses issues associated with monitoring of a policy for protection of surface waters in agricultural areas.

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Disclaimer

The results presented in this thesis are based on my own research at the Spatial Information Laboratory (SPINlab) in the Department of Earth and Life Sciences, Vrije University, Amsterdam, The Netherlands. All assistance received from other individuals and organizations has been acknowledged and full reference is made to all published and unpublished sources used.

This thesis has not been submitted previously for a degree at any Institution.

Signed:

Kyle Spencer McDonald

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1. Introduction

Motto: *'The Purpose of Technology is to Simplify and Enhance Our Daily Lives'*

The Age of Information, Communication and Mobility

Our society and the way we communicate are changing rapidly. We are currently living in an age of information and communication often referred to as the 'Information Age'. This 'information age' can be described as being fundamentally new because it is fueled by fundamentally new information and communication technologies. These technologies are described as being at the roots of new productivity sources, of new organizational forms, and of the formation of a global economy.

The research in this thesis will show how these focal words of modern technology, can be connected to the problems currently faced within field data management and water quality monitoring systems. The integrated approach to fieldwork is designed to improve the scope of information systems, ultimately helping this new field of mobile Geographical Information Systems (GIS) and what has become known as Location-Based Services (LBS) to emerge into the fieldwork environment.

1.1 Problem Formulation

The Netherlands is a country of 34,000 square kilometres consisting of 12 provinces, each divided into municipalities. Another administrative division within each of the provinces is the water boards, who amongst other things are responsible for surface water management.

Over the last few decades this small country has experienced an array of problems concerning the contamination of its surface water. One of the main causes of contamination has been the negligence and/or lack of awareness concerning environmental matters. Fortunately, awareness is increasing and regulatory actions are now being taken by government agencies to address water contamination issues. However, because the number of regulations is increasing, more emphasis is being placed on the target agencies to effectively manage and ensure adherence. The outdoor nature associated with water quality monitoring means that in order to manage and monitor such issues, fieldwork plays a vital role.

For quite sometime fieldwork and monitoring has been characterized by the "data rich but information poor syndrome" (Ward et al., 1986, Maasdam, 2000). The argument then was that there should be more emphasisplaced on the analysis and further use of collected data, so that the end product of monitoring is information and not only data. This problem has since been addressed, helped by the increased role that geographical information systems (GIS's) are playing in the management and analyses of field data. The dramatic increase in the array of information available for management tasks during fieldwork is, to a large part due to the introduction of Geographical Information Systems (GIS's).

A further problem has since arisen and now needs to be addressed. This problem relates to the initial collection of data during the monitoring process. Due in part to restricted access to geographical and location specific information, resulting from the unconnected nature of fieldwork from the in-office supply of information, fieldwork and data collection is considered to be restricted in its abilities. Until recently the most widely used method during fieldwork had been the use of hard copy, paper maps and forms used to collect information gathered during an inspection. These traditional methods provide limited information to the user, and make the whole process of data collection a tedious task resulting in less informed decisions being made.

Such manual practices have resulted in a certain number of errors, omissions, and illegal entries being unavoidable. Amongst others, this is dueto:

- maps being incorrectly interpreted or outdated
- erroneous or illegible entries resulting from the hardcopy forms that are usedand
- errors arising when procedures require a transcription step.

Worldwide, water boards have placed increasing emphasis on the introduction of GIS into their organizations to improve the planning and analysis of their spatial databases in order to achieve more effective management. The spatial nature and importance of this data has led to a strong call for mobile GIS systems to be used during fieldwork. As a result the department of water quality has called for an investigation to be made into the use of mobile GIS technologies, for exploring new techniques for data management and data handling in the field. Additionally, they are interested to see more generally how mobile GIS can be implemented within their organisations

1.2 Research Objectives

"It seems that change is the only thing that stays constant in the world of information and communication technologies. Just as the mainframe and minicomputers of the 1960's and 1970's, gave way to the workstations and personal computers of the 1980's and 1990's, another revolution is upon us" (Maguire, 2003). This revolution has become known as the 'mobile revolution'.

The purpose of this study is to investigate issues relating to the importance of information used during data collection tasks and understanding what part the 'mobile revolution' is playing a part in this. Furthermore, the associated communication technologies that enable this are reviewed. In the context of a case study, how spatial, and geo referenced data can effectively be used as well as the improved techniques for digital collection of field data, is dealt with. The case study revolves around the central problem of this thesis - poor use of spatial data when carrying out fieldwork in an environment where valuable digital data is usually unavailable. More specifically, the focus is on field control performed at the water board of Zuiderzeeland. With location often defining the kind of information that we need, the importance of knowing ones position in order to provide Location-Based Information (LBI) is addressed.

Objectives

Due to the very componential nature of the information and communication services, as well as the mobile environment, this study takes a componential approach to the investigation. Each of these steps, as reflected in the overall structure of the thesis, will have its own objectives. These steps and their objectives are:

- A description of the current state of water monitoring systems and the techniques and methods used during field data management. The problems facing monitoring programs with regard to field data management and access to, and use of geographical data and information services are also addressed. The objective during this step will be to understand the shortcomings as well as the user demands of current developments in this field. Particular focus is placed in The Netherlands.

- An overview of the state of mobile information and communication technologies needed to provide a more accurate, efficient and robust means for using and collecting information during field data management. The above are the requirements needed to make this fundamentally new information process possible. The many different components involved in the mobile geographic and information services are also described. How these information, telecommunication and positioning technologies can be integrated, in order to provide a complete information service (mobile GIS) are also described. The objective of this step is to understand the technology driven developments and the ingredients necessary for success.

- The last step in this study will be the development of a prototype system during a case study. This is carried out with one of the water boards in The Netherlands. The purpose of the case study is to show the results of what have been described in the previous chapters.

In monitoring and information systems there should be a balance between the data, which is collected during fieldwork, and the information that is generated from that data. Therefore, the success of any monitoring system is dependant on the connection between the data that is collected, and its use in management. This ultimately relies on the information that management is provided with in order to perform its tasks. The research in this thesis presents how, the ability of mobile services, to be both location-based and personalized can revolutionise the fieldwork process. This not only enables the fieldworker to make better use of information leading to more informed decisions, but also the environment in which monitoring can effectively be performed.

1.3 Structures and Layout of the Thesis

Contents of the Chapters

Due to the theoretical, conceptual and technological nature of the subject, the approach that has been chosen for this study has been to take a two directional approach **(part 1 & part 2)**. Ultimately these two parts will be brought together **(part 3),** to show how the current state of the mobile environment, and more specifically location-based geographical and information services, can be used to solve the specified problems.
This conceptual and strategic use of technology and information will then be assessed during a case study, in which a 'tailor-made' monitoring system will be developed for the water board of Zuiderzeeland, The Netherlands. Figure 1, shows a flow chart presenting a graphical approach to this thesis.

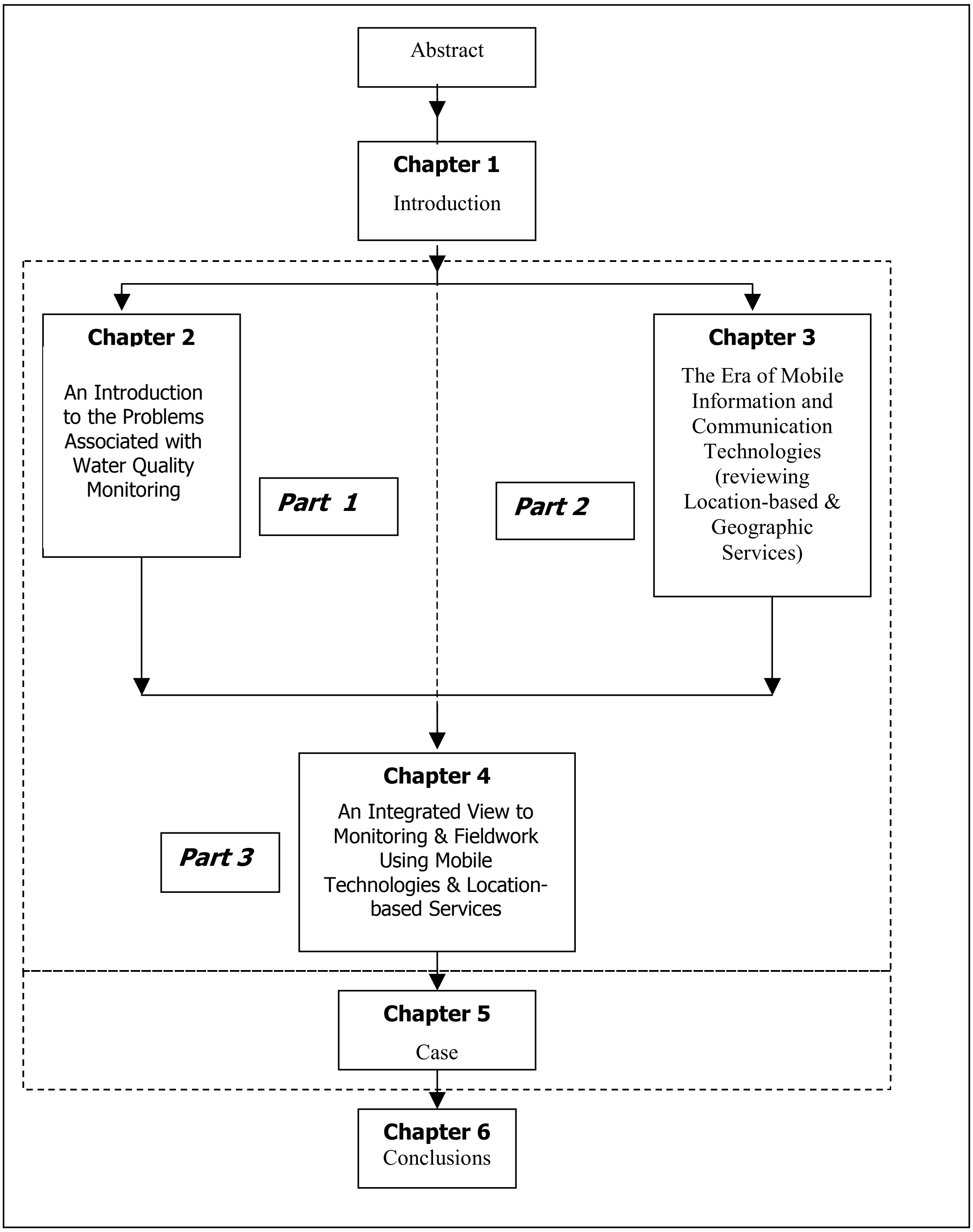


Figure 1.1 The flow chart presents a graphical overview of the structure of the study.

Part 1 (chapter 2), deals with the current state of monitoring in a water quality control environment. The problems currently being experienced are presented and the shortcomings related to fieldwork, due to a lack of access to geographical and location specific information is also dealt with.

Part 2 (chapter 3), probes into the current state of the technologies used to provide such services, as well as the state of mobile information and communication technologies. This part first presents what the mobile revolution implies and thereafter, describes each of the individual protocols that are necessary in order to be mobile. Some of these include:

- Telecommunications (1st generation, through to 3rd generation)
- Positioning technologies (manual, network based & GPS)
- The necessary hardware (mobile devices & accessories)
- Software

Part 3 (chapter 4 & 5), combines the results of the research in Part 1 & Part 2 to discuss an integrated view to fieldwork and monitoring systems. In this part the knowledge gained beforehand, will be used to discuss how the problems identified in Part 1 can be solved with the technologies discussed in Part 2.

Included in Part 3 is a case study. The case study was performed with the aim of showing that the research was not only conceptual but could in fact be implemented in a working environment. The results of the research are put into practice with the design and development of a 'tailor-made' prototype for the water board of Zuiderzeeland, in the province of Flevoland, The Netherlands. The prototype was designed for the control of a local policy concerning the protection of surface waters from pollutants originating from agricultural practices.

2 Perspective of the Problem

2.1 Introduction

Water boards in The Netherlands are largely responsible for the essential aspects of water management. "Nowadays this goes further than laying dykes and building pumping stations" (Waterschap valley & Eem). The activities of a modern water board are closely related to land use planning, nature conservation, environmental protection and recreation, etc. They are responsible for balancing the different and sometimes conflicting interests of water users. This is done in co-operation with central government, the provincial and municipal authorities and other interested parties.

Introducing and describing the subject of monitoring in water management programmes and describing the problems and constraints that are being faced are necessary before further investigation into the relevant solutions can be discussed. This chapter briefly introduces the field of water quality monitoring, and summarises the relevant problems associated with regard to field data and its management. Ultimately this chapter places the problem facing this thesis into perspective. The future perspectives to monitoring and water management with regard to mobile and digital technologies are briefly addressed.

The acquisition, processing, and management of data can require a substantial portion of the resources allotted for an investigation. Performance of these tasks in an efficient and reliable manner can be of considerable value.

2.1.1 What is Water Quality Monitoring?

Definition: The Oxford Dictionary defines a monitor as being a 'person or device for checking or warning and maintaining regular surveillance over…..'. (1978)

In the subject of this thesis the role of the monitor is to maintain regular surveillance over the quality of water.

Water quality monitoring is a means of getting information on the condition of streams, lakes, estuaries, and coastal waters (water systems). The results are used to help determine whether these waters are safe enough to swim in, fish from, or be used for drinking or irrigation purposes. The purpose of monitoring is to help provide this basic information.
Regardless of if and how water gets polluted we need to monitor it. Therefore the purpose of a water quality-monitoring program is to determine quantitative cause and effect relationships in water quality and obtain sufficient data for updating water quality management plans. Additionally, the monitoring program is to set priorities for establishing or improving existing pollution controls and determining whether additional

water quality management strategies may be required to further identify impediments to the natural resources.

In Ruurd Maasdams thesis headed "Exploratory Data Analysis in Water Quality Monitoring Systems" he noted that monitoring in the broader sense can be placed in the information-cycle (figure 2.3). He goes on to state that the guiding principle is that monitoring (and assessment) should be seen as a sequence of related activities that starts with the definition of information needs and ends with the use of the information products (2000, p.18). This cycle of activities has become known as the "monitoring cycle" seen in figure 2.1.

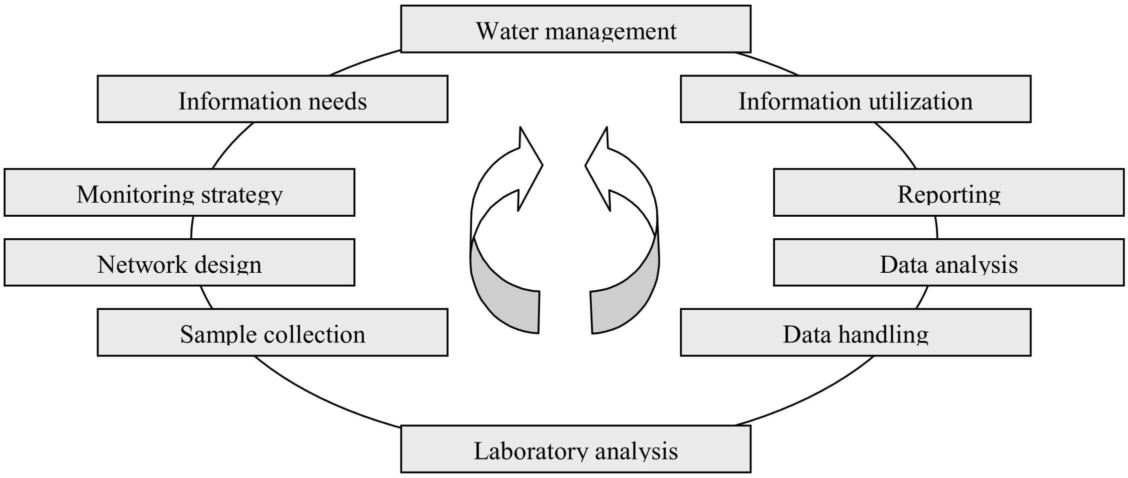


Figure 2.1 The Monitoring cycle (Source: Task Force on Monitoring and assessment, 1996).

Monitoring of water conditions is a very complex field, and as a result there is no easy way to evaluate the constituents in water. Although for simple water tests a sample can be analysed with a small hand kit, for a proper evaluation of larger water bodies or natural areas it may be necessary to take samples from a wide range of factors including sediments and fish tissue. The physical measurements of other general conditions such as temperature, flow, watercolour, and the condition of stream banks etc, are also important and need to be placed into a spatial context.

2.1.2 Responsibilities of the Water Board

A water board has one primary concern and that is the water management of a given area. The water board is therefore characterized as a functional administrative organ, whereas provincial and municipal bodies are general administrative organs.

'A Dutch water Board may be charged with the following tasks:

- Water control: flood protection by means of dunes, dykes and canals;
- Water management:
    - **Water quantity:** managing the amount of water and ensuring that it is kept at the right level;
    - **Water quality:** combating water pollution by means of sewage water treatment and improving the quality of the surface water;
- Management of inland waterways and roads.'

'Like provincial and municipal authorities, the water boards are de-centralized government bodies. They are independent and have their own areas of authority. They can draw up regulations that citizens must observe and they can levy taxes'. (Colofon, 2003)

2.2 Developments in Water Monitoring Systems

Water quality management has changed dramatically over the last few years. Water data programmes have been described as being 'fragmented, often collecting the wrong type of information, and are inefficient both in information and in cost' (Ongely, 1993). Worldwide governments and organisations are realising the importance and value of clean, fresh potable and drinkable water. Developing countries that have never before placed much emphasis on the protection of their surface waters are now investing in ensuring the survival of this vital commodity. Over the last few years Europe in particular has placed an enormous emphasis on protecting this often shared and scarce resource. European countries are sharing an interest in working together to prevent deterioration of water quality in transboundary waters.

In the case of Dutch water management, the management of regional water (small streams and polders), is performed by the regional water boards whilst the national waters (larger rivers and lakes) is done by the Directorate General of Public Works and Water Management (in Dutch: Rijkwaterstaat) within the Ministry of Transport, Public Works and Water Management.

The data that is collected by state or local agencies and private entities are then used to build the assessments that are necessary to make better pollution control decisions with. Without data, it is impossible to know where pollution problems exist, where we need to focus our pollution control energies, or where we've made progress.

2.2.1 The Need to Monitor

The reasons water needs to be monitored varies considerably, this may include anything from drinking and recreation to agricultural use and irrigation. These reasons often depend upon the context in which the monitoring is being performed.

The purpose of a water quality monitoring program is to determine quantitative cause and effect relationships in water quality, obtain sufficient data for updating water quality management plans, determining effluent limits, identifying non point sources of pollution and classification of stream segments throughout the watershed. Additionally, the monitoring program sets priorities for establishing or improving existing pollution controls and determining whether additional water quality management strategies may be required to further identify impediments to the natural resource.

In most cases the need for monitoring is laid down by laws or other regulatory actions (directives, water quality standards, action plans) that have been set in place, and aim at assessing the state of the environment as well as detecting trends. In these instances the purpose of the monitoring is to gather and supply information on the quality of the water, which will be used for comparison with these regulatory actions.

Five major needs that apply to all water monitoring systems are to:

1. Characterize waters and identify changes or trends in water quality over time;
2. Identify specific existing or emerging water quality problems,
3. Gather information to design specific pollution prevention or remediation programs,
4. Determine whether program goals, such as compliance with pollution regulations or implementation of effective pollution control actions, are being met,
5. Respond to emergencies, such as spills and floods.

(US Environmental Protection Agency, Dec 2003, p.1)

Some types of monitoring activities meet several of these purposes at once; others may be specifically designed for one reason only. But ultimately the aim of monitoring is to collect data that can be used for further assessment (information generation).

2.3 Water Management Needs Information

Monitoring does not only involve the collection of data but it includes the entire systematic process by which the data is collected, handled, managed, analysed and presented. Therefore, when the collected data is stored in the computer, one is only a portion of the way towards being able to provide complete and accurate information about a water system. However it cannot be ignored that, in order to kick-start the whole process of having information about water systems, the process of data collection is one of great significance. The focus in this thesis is on the data collection side of monitoring systems and shows how this very important process can be optimised through the use of new mobile technologies.

As a result of the ever increasing number of uses and functions for water, which often have conflicting requirements, water quality management is becoming ever more complex as time goes on. Although the information age now allows us to use and handle large amounts of data, the "data rich but information-poor syndrome" described by Ward et al. (1986) led to the "Monitoring Tailor-made" workshop to investigate the importance of information during water management.
"The international workshop was organised in 1994 to provide a forum for experts from many countries to exchange experiences in monitoring and obtaining better water information." One of the major conclusions of this workshop was that "monitoring is justified by the value and use of the resulting information." These systems require interrelation of various disciplines in the form of integrated (and in the future comprehensive) water management. (De Jong et al. and Raskin et al. (in Timmerman et al, 2000: 2))

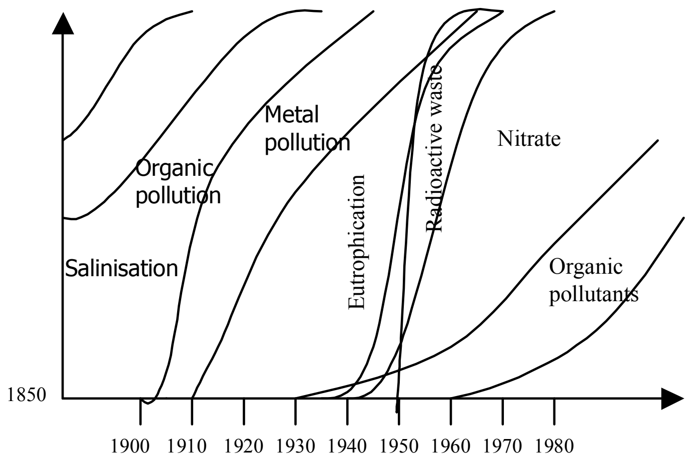


Figure 2.2 The sequence of water quality issues arising in industrialised countries
(Source: Meybeck and Helmer, 1989 - Timmerman, Adriaanse, Breukel, 2000)

As discussed in the initiative Making Monitoring Tailor-Made, water system problems have become increasingly complex over recent years. Water quality monitoring (information) systems should be a balanced combination of data collection and information generation. This is shown in the information cycle (figure 2.3), which illustrates that monitoring is a sequence of related activities that begins with the definition of information needs and ends (and starts again) with the use of information products (Maasdam, 2000). The problem arises in that water quality programs tend to suffer from traditional approaches, both of methodology and legal/administrative. This has ultimately resulted in many of the water quality programmes being inaccurate, inefficient and providing information that generally is not useful for making informed decisions.

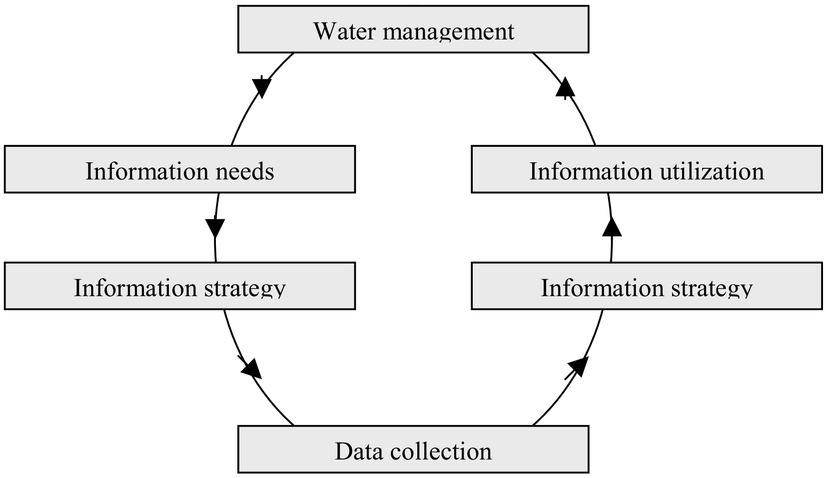


Figure 2.3 The information cycle (Source: Timmerman and Hendriksma, 1997)

Mans response to these problems has been his realisation of the need for modernisation. Program modernisation is essential to achieve greater efficiency and meeting data needs for water quality management purposes. (Ongely, 1993) claims that modernisation will reduce costs, may reduce the amount of equipment and infrastructure required and often reduces the amount of data collected. Although the use of modern technologies and techniques will apply across the wide range of water management processes (illustrated in 'Making Monitoring Tailor-Made'), this thesis focuses on the field data collection process.

The Directorate General of Public Works and Water Management in The Netherlands started with a project to create an inventory of the information needs among the water-policy makers within Rijkswaterstaat, focussing on new information that would be needed after the fourth national policy document on water management, that was accepted by parliament in 1998. This policy emphasised the information needed for water management, and consequently on the monitoring networks. Figure 2.4 shows the five-step method for specification of information needs that was used within the project.

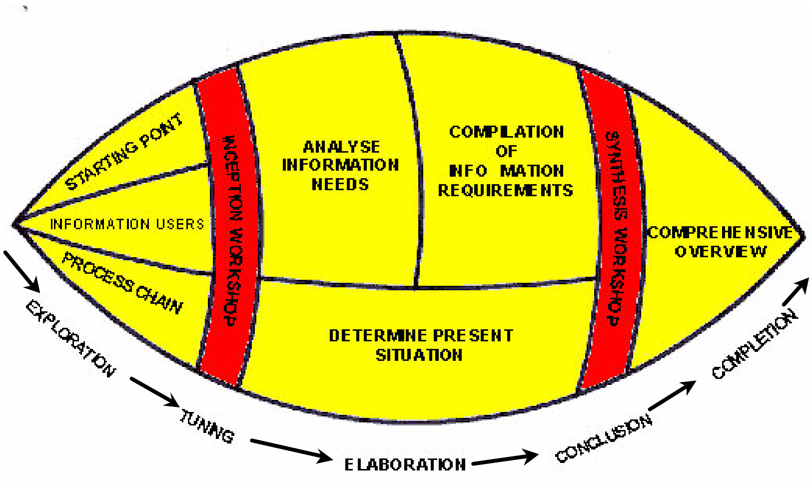


Figure 2.4 The five-step method for specification of information needs
(Source: Timmerman and Mulder, 1999)

2.4 Data Management Concepts

Monitoring does not end at the collection of data, hence much of the water management process occurs back in the office. Once there, it becomes a complete water management process rather than a monitoring process. With the introduction of specific software programs that allow for further analysis and interpretation of the collected data, it is possible to make more improved and informed decisions within the context of water management.

The components of a data management system that can be used in a water resource study are illustrated below in figure 2.5. The diagram shows the different components of the system including on the right an "application" module that is used for entering data into the management system program that is used to read information from and write information to the data storage module. Furthermore, "utility" programs are used to perform functions such as data editing, displaying data in graphical and tabular form as well as mathematical transformations of data. The benefits of such a system are that data can be loaded into the storage module, reviewed, and perhaps edited with the utility programs. Furthermore, an external interdependent program can be used to perform any required analysis operations

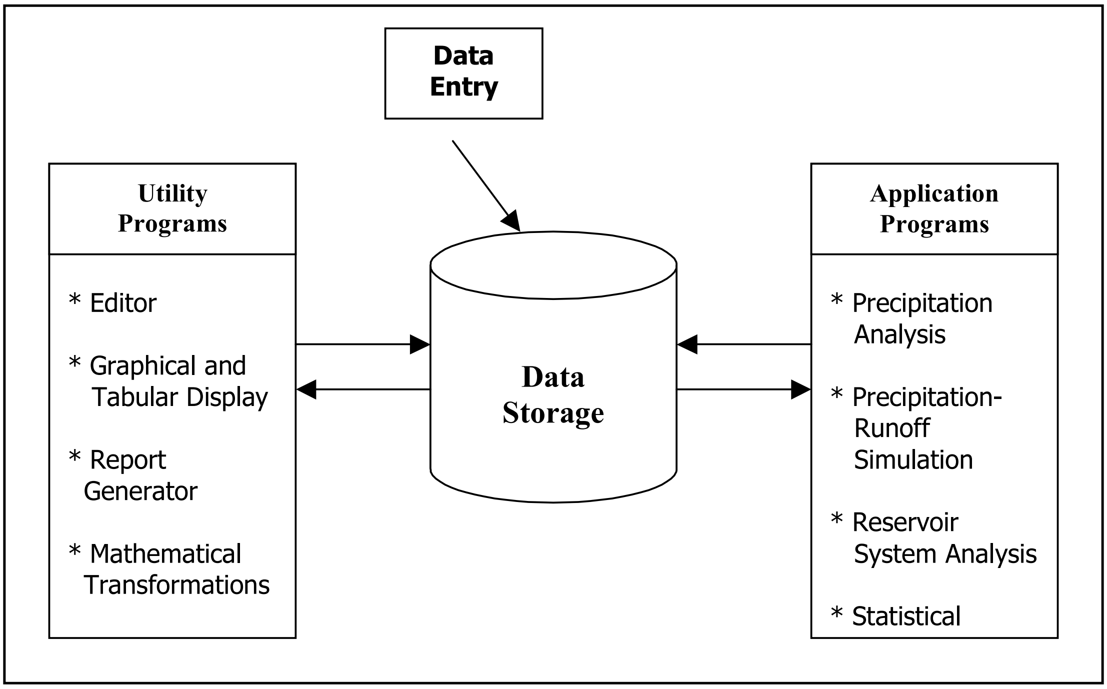


Figure 2.5 Data management (Source: Engineering & Design, 1994)

Using new digital mobile GIS applications, Chapter 4 introduces a new meaning to the idea of data management when collecting field data. As the user will be making use of more data than previously it is important that this data is managed in a better and proper way. Furthermore, it is important to ensure proper management of all collected data otherwise it becomes difficult for this data to be effectively used for the necessary further analysis and assessment.

2.4.1 Geographic Information Systems

"A G*eographic Information System* (GIS) is a computer-based information system that enables capture, modeling, manipulation, retrieval, analysis and presentation of geographically referenced data" (Worboys, 2001).

The geographic information system can be described as a powerful data management tool for spatial (i.e., geo-graphically oriented) data. Such systems enable the storage and retrieval of information that is associated with spatial elements such as rectangles, triangles, or irregularly shaped polygons. Variables such as slope, orientation, elevation, soil type, land use, average annual rainfall, etc. can be stored for each element. The data may then be retrieved and tabulated, displayed graphically, or used directly by application programs. (Engineering & Design, 1994).

The purpose of a GIS in water management is to help manage the data but also to use the data to generate important information for the management process, using GIS functions.

Much of the resultant data collected after monitoring is used to help maintain computerised data systems that are used to store and manage the water quality data they or others collect. Such computerised data systems are increasingly including some form of GIS system due to the enormous benefits such systems bring to help manage and analyse different forms of spatial data.

Ruurd Maasdam focused on the point that 'the ultimate goal of monitoring is to provide information, not data and that in the past, many monitoring programmes have been characterised by the "data-rich, information poor syndrome' (DRIP- syndrome; Ward et al, 1986). He used this point to explain how explorative analysis can be used to improve the effectiveness and efficiency with which data is used. GIS specialises in being able to take spatially referenced data and generate useful *information* to help with improving the effectiveness and efficiency of decision-making and management plans.

2.4.2 Data Collection

Many different data sources can be collected and used to generate spatial data sets. These data sources help to determine the validity and usefulness of spatial data and as a result, data collection is considered to be an important processing step when developing spatial data.

Field data capture still largely depends on the traditional pencil and paper notebook for the collection of data, although there has been some use of modern mobile technologies, this is still relatively unexplored in this area and in many cases still needs to be proven. The traditional method with which field data is collected involves using specially designed paper forms containing fields or blocks within which the necessary information can be filled in using a pen or pencil. Depending on the application, the method with which the data collector receives information varies. If the monitoring process involves going into the field and collecting information according to tests on the chemical properties of the water, then the values would be obtained from the measuring equipment used in the tests. However, other monitoring might require interviews and questions aimed at the responsible persons using the land.

Whether it be for cartography, engineering, surveying or monitoring, field collection of data dependant on location has until recently been problematic. This is partly due to the difficulties associated with obtaining accurate positions as well as the difficulties associated with referencing collected data against its specific position. The tools that have been available to the field worker have been bulky in size, hard to become familiar with and relatively expensive. However modern devices such as the digital GPS (Geographic Positioning System) have made this much easier.

'Water Quality monitoring can be an effective way to determine quantitatively the impacts of various management activities on water. However collecting useful data requires a commitment of resources to collect adequate information on baseline conditions' (Norman, 1996). It is this baseline data that forms the building blocks for the further steps of management and decision making. As a result this data collection process is necessary to ensure effective and accurate collection of useful field data.

After the field data capture process there is a second process of data capture which involves automatically extracting information from forms utilizing scanning equipment or specially trained data capture staff. In a data capture environment, the information that is collected and stored on the form is the primary deliverable to a database. In the in-office phase there are 3 stages involved. These are:

- Scanning and importing
- Recognition
- Verification.

The new generation of lightweight hardware and mobile software systems along with positioning technologies have made data collection for the field more feasible. This new generation of Personal Digital Assistants (PDA's) and handheld GPS receivers that evolved after the introduction of small mobile devices and operating systems such as Microsoft's pocket PC operating system are discussed further throughout this thesis.

2.4.3 Data Quality

The cliché, 'garbage in, garbage out', means that when you put poor quality data into your system, you will output poor quality results. Data collected must be reliable and accurate otherwise the outcome of the entire database may be inappropriate when displaying, storing, analyzing, or manipulating spatial data. The quality of a database is as only as good as the data sources used to create the database.
Due to the two fold nature of the data capture process, providing good quality data in the initial collection phase avoids any poor quality data from being passed further into the whole management and analysis process.

In order to ensure that spatial data integrity is maintained regardless of the type of data that is collected and used it is important that several factors are identified before the collection of data starts. Although not only applicable to field data capture, listed below are some issues which need to be considered when the quality of data originating from different sources is unknown.

- 'Positional and attribute accuracy
- Geographic extent of a data set

- Completeness and correctness of data
- Scale
- Projection and coordinate information
- Drafting accuracies
- Mixing source documents
- Classification
- Sampling techniques
- Boundary definitions
- Cartographic interpretation
- Data input'

(U.S. Army Corps of Engineers, last accessed Feb 2004)

It is possible that these errors may originate in any of the sources of data used during a project, these may occur within documents or as a result of poor fieldwork amongst many others.

Adopting good practice in terms of data capture and analysis should, in most instances, be sufficient to ensure errors are kept to a minimum. The problem arises when inappropriate techniques are used. There are many factors, which can affect the quality of the data that is collected, the most common problems are equipment related and field data collection techniques being incorrectly used.

2.4.4 Data Acquisition and Use

The meaning of data acquisition can vary considerably depending on the context in which it is being used. The general understanding of the words '*data acquisition*' means the acquiring and movement of data. Probably one of the most important aspects of data acquisition that needs to be considered is that of data input. Data input usually involves the input of data from one format to another, usually from hard copy to digital. In the field of geographical information there is a need to have tools to transform spatial data of various types into a usable digital format. Data input into a GIS involves encoding both the locational and attribute data. The locational data is encoded as coordinates whilst attribute data is often obtained and stored in tables. This process of data input is a major bottleneck in the application of GIS technology and often results in:

- 'Costs of input often consuming as much as 80% or more of project costs
- Data input being labour intensive, tedious and error prone
- Danger that construction of the database may become an end in itself
- The project not moving on to the analysis of the data collected

It is therefore essential to find ways to reduce costs, maximise accuracy' (Goodchild et al, 1991).

As a result of these points there has been a realisation that there is a need to automate the input process as much as possible, which has unfortunately led to problems of it's own. Some of these problems may include that:

- 'Automated input often creates bigger editing problems later on
- Source documents (maps) may often have to be redrafted to meet rigid quality requirements of automated input.' (Goodchild et al, 1991)

Due to the enormous costs involved and the difficulties that may arise a lot of emphasis has been placed on trying to improve the methods used during data input. There have been some significant improvements, although data input is still a problem within the GIS industry.

Data can be used for a wide array of reasons depending on the scope and purpose of a study. In order to determine the use of data it is important to understand the types of data that are required, where the data can be obtained from (source), acquire the data and ensure it is usable and to perform the necessary analysis so that the results can be documented.

With the costs of data input often consuming 80% or more of the total projects costs it can be seen what benefits such future mobile applications will bring to the field of monitoring and issues of poor quality data. There is a need to develop, integrate and start implementing mobile systems.

2.5 Characteristics of the Mobile Monitor

Although the last few years have produced rapid developments in mobile communication and information technologies, the majority of field work is still conducted using traditional techniques and is not changing at the same rate as technology. "A basic characteristic of fieldwork has always been it's wireless nature and it's remoteness from all office equipment like telephone, fax, PC, databases and printers" (Wagtendonk, 2004). This applies to both traditional and modern means. The traditional pencil and paper notebook have remained the norm in the field of monitoring and collection of field data.

2.6 Integrated Water Quality Monitoring

2.6.1 A New Perspective on the Future of Monitoring

The motto for this thesis, 'the purpose of technology is to simplify and enhance our daily lives', becomes applicable at this point.

There have been major developments occurring in the field of water management, water monitoring and how these are incorporating information and communication technologies into their operations over the last decade. Water management is embracing and making use of such technologies on an increasing basis. Over the years there have been many technical devices that have been used to try to improve the registration and measurement of field observations like tape recorders, camera's and binoculars, etc.

'The development of software applications for mobile computers has been recently spurred by the availability of more powerful operating systems and the transfer of standardised programming languages to ever smaller computing platforms'. 'For disciplines with an active fieldwork component, providing tools that improve the accuracy, efficiency and quality of the data collection process can significantly improve current practices. In addition the technologies described in this [thesis (chapter 3)] will allow users to link real-time field data collection from various devices to a centralised data server located at a remote location.' (Vivoni et al, 1998)

The objective of a mobile software application is to streamline the collection process and improve the accuracy of field data as compared to current practices. The integrated system includes automated control of a handheld computer and a global positioning system reciever, mobile geographical information system software, an internal database and manual input for other parameters through customised user interfaces. In addition, wireless and Internet technologies are used for transferring and displaying collected field data.

The new generation of lightweight hardware and mobile software systems along with positioning technologies will make data collection in the field a lot more feasible.
Some of the advantages of these new generation data collectors are:

- Economically priced
- Familiarity with Palm, Pocket PC and Windows results in quick and easy GPS/GIS integration with these devices
- Longer battery life
- Lightweight
- Touch screens and colour displays
  (Wadhwani, 2001).

Another advantage of using digital input of field data into a computer is that the user is able to spend more time focussing on the subject at hand rather than problems that may be associated with data input.

2.6.2 A Brief Introduction Into – 'Tailor-Made Monitoring'

In order to bring monitoring programs into the information age there is a large concern to 'making monitoring tailor-made'. Using the latest mobile ICT technologies (described in chapter 3) it is now possible to optimise the way fieldworkers use and collect data that is often of a spatial nature.
With the further developments in the mobile information and communication technologies there have recently been great advances in how a user in the field is able to collect, manage, process and deliver field data. In these types of applications a wireless network connection is used to provide geographic data and processing dependant on a location as a type of service to a user in the field.

Although Adriaanse, 1997, states 'tailor-made' as implying providing the right information to make management decisions' this thesis takes the word 'tailor-made' as being a means of customising the way in which monitoring is carried out in the field. This customisation involves the personalised design of an application program to suite a users needs (seen in chapter 5).

The personalised application is designed in specific software and contains specific buttons and tools allowing for the collection, use of, processing and transfer of both attribute and spatial data to and from a mobile device and a central system. These technological and conceptual advances over recent years have, as yet, not been fully enhanced and integrated into many of the monitoring programs.
One such field in which exploration is being made with regard to mobile field applications involves making use of what is known as Mobile Geographic Services.

2.6.3 Mobile Geographic Services

People who are always busy and on the move are increasingly under pressure to use their time more efficiently. People do not want to be restricted merely because of their location and as a result they are requesting access to geographically sensitive data and services.
The current revolution that is going on with regard to hardware size, performance and power consumption, as well as the improvements in network bandwidth, have helped to produce a new breed of mobile geographic applications. These new forms of geographic applications promise to change the way we use geography in home and professional life for ever.
A mobile geographic service can have a variety of different forms depending on the type of application for which it has been developed. "Mobile geographic applications are characterised by their ability to support itinerant, distributed and biquitous computing.

- Itinerant – providing computing capability while moving with a person, in a vehicle, or on an aircraft or ship (in this context in the field)
- Distributed – integrating functions that are performed at different places in a way that is transparent to the user
- Ubiquitous –delivering the same functionality independent of a user's location."

"It must be noted that a mobile GIS is not a conventional GIS modified to operate on a smaller computer but is a system built using a fundamentally new paradigm" (Maguire, 2002).

In the context of this study the service is a server based application that delivers data and/or processing to clients on demand. Although not the case in all mobile geographic services, in server based applications requests are made from a mobile client who requires geographic data and/or processing (creating a map, supplying data for a region) afterwhich, the necessary query, analysis and mapping operations are performed on the server and sent back to the user. In other instances all processing can be performed on the device itself. Whatever the case the results are displayed on the clients device. The results could be a map, a list of geocoded addresses, or a data file. In the case of a mobile geographic service or LBS the majority of applications are likely to be server based, meaning that most of the processing is done on the server side and not the client side.

2.7 The Need for Mobile GIS at the Water Board

A mobile GIS utilises the latest information and telecommunication technologies that enable GIS to be used out in the field often on small handheld computing devices. Utilising mobile GIS often cuts out several steps in the work process and, in all instances, reduces excess paper work. Eliminating these extra steps greatly reduces the possibility for errors. Rather than repeating the data capture process, from paper in the field, to digital in the office, fieldworkers of any sort can enter data directly into a handheld computer integrated with GPS whilst in the field. This not only means that the data is digital from the first moment of collection but it is now also referenced with an exact location of existence on the earths surface. It is these cuttings out of extra steps that can dramatically reduce mistakes and save money during the field data management process.

There are many different utilities who are already reaping the benefits of GIS within their organisations. It is fair therefore to say that a small initial investment in mobile GIS can go a long way. Up until this point water boards have not used GIS in such a manner and almost all data collection has been performed using traditional pen and paper methods.

"Having more timely and accurate data translates directly into more efficient operations for the many organizations currently taking advantage of mobile GIS" (Chivers, 2003). It must be noted that water boards are already using GIS in a variety of aspects, however these are all desktop based and primarily used for mapping. Desktop GIS systems that have been specifically built for the water boards includes the Intwis and the AquaGIS systems (described further in section 5.9).

2.8 Conclusion

This brief introduction has provided a glimpse into the complex world of water quality monitoring, its developments, problems and future. Efforts are currently underway to improve how monitoring is conducted, how information is shared, and how decisions based on monitoring are made. The challenge of the next decade will be to rethink how water quality data are collected and used, and to take advantage of new capabilities that can revolutionise the information effectiveness and cost efficiencies of data and assessment programmes (Ongely, 1993).

3 An Era of Mobile and Wireless Technologies

3.1 Introduction

Mobility is currently one of the most discussed subjects in the field of information and telecommunication technologies. The integration of mobile devices, the Internet and wireless connectivity provides an exciting opportunity for organisations to extend the reach of their information and services to mobile professionals. The potential results include improved productivity, reduced operational costs and increased customer satisfaction. The wireless connectivity element is relatively new and expanding rapidly. This chapter moves away from the rest of the thesis and explores the options available for mobile and wireless configurations, providing a brief description of each of these technologies.

3.2 Wireless - Not Connected?

Being wireless ultimately means – not being connected. The Oxford dictionary defines wireless as: "Without wire (s), telegraphy, radio transmission of signals…". (1978)

With access to the latest technologies that enable always-on, wireless and broadband data telecommunications, mobile computing and communications are augmenting the user's ability to function in professional and social settings by providing supplemental information gathering, processing, and storage functions, which to a large extent will be cued to the user's geographic or locational context.

3.3 Wireless Protocols

Most mobile devices (particular those powered by Windows) are enabled for personal, local and wide area network (PAN, LAN and WAN) connectivity. Because they are built on open standards, it has become big business for companies to provide add-on hardware, software etc that is able to support and be integrated with the various wired and wireless connectivity methods. The following 2 sections provide a brief overview of the different protocols associated with being wireless.

3.3.1 Wireless topologies

How will the device need to be connected to information or applications (i.e., PAN, LAN, WAN)? Will the user be within 10 to 30 meters (PAN), 165 meters (wireless LAN with walls) or three-quarters of a mile (wireless without walls) of a wireless connection, or will a wide area cellular network be appropriate? These are all important questions to know the answers to before deciding on the kind of configuration that will be used in a mobile application.

In the case of the Windows Powered devices, they are enabled for personal, local and wide area network (PAN, LAN and WAN) connectivity. These are built on open standards, and as a result there are various hardware, software and drivers to support the various wired and wireless connectivity methods available today.

There are the three wireless network topologies available, namely the WPAN, WLAN & WWAN

3.3.1.1 Wireless Personal Area Networks – WPAN's

A wireless PAN or wireless personal area network makes use of synchronisation technologies enabling personal connectivity. PAN's, which can also be referred to as 'cable replacement Bluetooth technology, are suitable when connectivity will be relatively short distance. These work ideally between 10-30 meters (e.g., to LAN hubs, other mobile devices, cellular phones, PC's, and other devices such as cameras) depending on the power of the Bluetooth technology.

3.3.1.2 Wireless Local Area Networks - WLAN's

A wireless local area network (WLAN) uses radio frequency (RF) technology, wireless LAN's to transmit and receive data over the air, minimising the need for a wired connection. A wireless LAN' therefore combines data connectivity with user mobility. Wireless LAN's provide all the functionality of wired LAN's without the physical constraints of the wire itself.
Depending on the penetrability of walls and floors, LAN's operate well in buildings or structures with a range from anywhere between 175 meters to almost a mile

3.3.1.3 Wireless Wide Area Networks - WWAN's

The wireless Wide Area Networks (WWAN) provides access to information anytime and anywhere that there is cellular (data) coverage. WANs are able to provide connectivity between Local Area Networks and network addresses. Very often WWAN use local telephone company lines to connect geographically dispersed locations.

There is another method for data transmission known as Universal Mobile Telecommunication System (UMTS). UMTS has often been described as the third generation of telecommunications. 'The report, commissioned by mobile Internet platform provider 3G Labs, predicts that third-generation (3G) UMTS services will represent about one-third of the total mobile subscriber base in 2006.'
(*Howell-Jones, 15th Dec 2000*)

3.4 Towards the Third – Generation (3G)

3.4.1 "2.5G" – An Intermediate Technology

Second generation technologies (2G) have recently been developed into "2.5G" technologies such as GPRS. At the time 2.5G were intended as a stop - gap measure, giving operators time to develop 3G networks. 2.5G provides faster, more convenient data facilities, which are being increasingly supported by new mobile devices. 2.5G lets the user experience 'always on', high speed, wireless access without the service providers needing the costly system wide upgrades needed by 3G. (Mitchell, 2002)

3.4.2 3G Mobile Networks: Faster Access Speeds and "Always On"

'Faster access speeds'

3G networks are currently the latest form of networking available for wireless users. 3G are even faster than GPRS with speeds that enable the mobile networks to support many more subscribers who can download data much faster than was possible before.

'Always on'

A 3G network promises seamless mobility support, but is built on a complex connection-oriented networking infrastructure. 3G has basically enabled the mobile device to stay connected to the network through an 'always on' connection. Being connected continuously means that the mobile operators will bill you according to the packets you download instead of the amount of time online – or else they will make a single monthly charge for everything. Furthermore, being always connected means that e-mail and a variety of other web based resources are always accessible.

Using 3G services such as I-Mode (section 3.6.2), means your mobile phone becomes a multi-purpose device that can be used, for example holding train tickets, discount vouchers or acting as a key to unlock your house. (Mitchell, 2002)

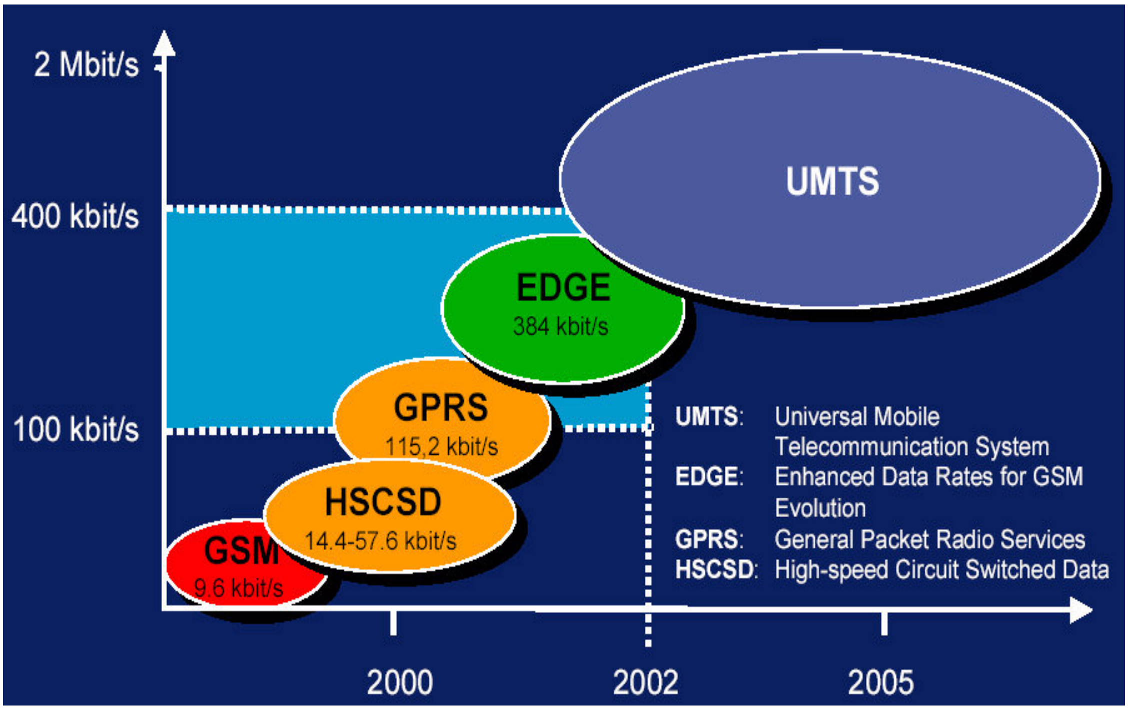


Figure 3.1 Shows the different means of communication with their times of development and relative speeds for data transfer (Source: Harkey et al, 2003)

3.5 Modes of Connection

There are basically three connection options that exist for linking mobile devices to the different networks: two-body, detachable and integrated.

As the name states, ***the two-body connection*** requires two pieces of equipment. These may be for example a pocket PC and a cell phone. In this scenario an external modem (e.g. the cell phone) is used for the connection.

Figure 3.2 The two body-body connection requires two pieces of equipment. (Source: Microsoft, 2003)

When using the two-body connection it is necessary to consider one more factor and that is the kind of connection that will be used to 'connect' the two devices. This can be done via a cell phone with a cable, infrared-equipped cell phone *(figure 3.3)* or the Bluetooth-equipped (PAN) cell phone.

Figure 3.3 Infrared & bluetooth equipped cell phones can connect wirelessly to a mobile computer.
(Source: Microsoft, 2003)

Detachable clip-on and plug-in modules provide connectivity for many types of wireless networks: These may come in the form of

- cell phone, CompactFlash or Pccards which plug into either a CompactFlash or PCMCIA card slot providing connectivity to cellular or paging networks.

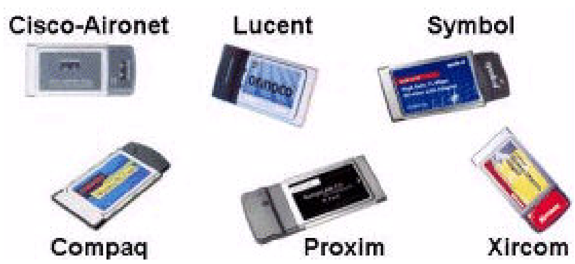


Figure 3.4 Different types of compact flash or PC cards able to provide connectivity to a cellular network.
(Source: Microsoft, 2003)

- Wireless LAN PC card
- Wireless LAN CompactFlash card
- Clip –on-modem

Figure 3.5 Slip-on jackets which in turn provide support for CompactFlash and PCMCIA cards. (Source: Microsoft, 2003)

- Slip-on-jacket- Compaq for example, provide jackets that the device slips into, which in turn provide support for CompactFlash and PCMCIA cards. The advantage of Compaq's PC card jacket is that it contains an additional battery. This results in the PC cards not drawing power from the Pocket PC.
- Bluetooth CompactFlash card.
- Wireless WAN card.

Lastly, probably the most beneficial and biggest indicator of the advancements in the technology is the ***integrated*** approach to wireless connectivity, in which everything is sealed within one device. Some examples of these are:

- Rugged, integrated bar code and wireless devices.
- Integrated GSM Pocket PC. For example Sagem developed a dual-band GSM/GPRS phone-enabled Pocket PC. So has O2 with their XDA.

Figure 3.6 Some mobile devices offer integrated wireless connectivity. (Source: Microsoft, 2003)

3.6 Wireless Communication Technologies Considered for Monitoring Systems

There is currently a vast selection of wireless devices available, these may use WAP, GPRS and I-mode. As discussed throughout this chapter all of these differ in the kind of wireless network they use as well as the method with which they access information. "High speed communication becomes necessary if complex raster data or a broad variety of different vector data layers have to be transferred. Therefore the user has to choose between a slow data connection but simpler handling or a fast data connection (up to 11Mbit/s) but expensive handling" (Simonis, 2002).

3.6.1 Wireless Application Protocols (WAP)

Wireless application protocol (WAP) is a protocol that has successfully established a de facto standard for the way in which wireless technology is used for Internet access. WAP technology has been optimized for information delivery to thin-client devices, such as mobile phones. (Nokia – The Wireless Future)

The number of WAP users throughout the world has increased dramatically over the last few years. In part, this growth is driven by the introduction of General Packet Radio Service (GPRS), WAP 2.0, Bluetooth and Mobile Commerce.

3.6.2 I-Mode

Similar to GPRS, I-mode is a packet based information service for mobile phones. I-mode is able to deliver information (such as map services) to mobile phones as well as the exchange of email from devices on the PDC-P (personal digital cellular) network. It is a relatively new technology launched in 1999 by NTT DoCoMo, a Japanese company and hence i-mode is very popular in Japan but not yet elsewhere.

3.6.3 Bluetooth

Bluetooth is based on a Radio Frequency (RF) specification for short-range, point-to-point and point-to-multi-point voice and data transfer, and can connect many types of digital devices without a single cable needed. It enables users to connect to a wide range of computing and telecommunications devices without the need for proprietary cables, giving the user more freedom to roam. And that, after all, is what mobility is all about.

"This 2.4 GHz radio technology is designed to work over short distances, most of them up to 10 meters" (Anderson, 2001) and acts as a method of automatic synchronisation. Furthermore Bluetooth offers synchronisation for your desktop, portable PC, notebook (PDA), mobile phone and many other devices.

Together with other industry initiatives, such as wireless application protocol (WAP), Bluetooth will have tremendous effects on everyday life. Bluetooth has for the first time enabled wireless communication and data transfer of such an extent thereby cutting down boundaries that previously existed because of the need for wires in order to access and transfer data of a considerable size.

3.6.4 Infrared (IR)

IrDA is yet another means of wireless communication that is already well established. IrDA is already extensively used within notebook computers and other devices. With IrDA now available on many cellular phones there is the potential to expand use of infrared as a cable replacement on other devices. The advantage is that it will still maintain a speed advantage over initial Bluetooth products (i.e. 4Mbps versus 1Mbps).

3.6.5 General Packet Radio Service - GPRS

A General Packet Radio Service (GPRS) provides a wireless connection to data networks allowing users to access information and services. GPRS is a GSM data transmission technique that transmits and receives data in packets and does not set up a continuous broadcast between the device and the provider. GPRS technology allows mobile phones to be used for sending and receiving data over an Internet Protocol (IP)-based network. GPRS enables wireless access to data networks like the Internet as well as the transfer of data through these networks.

- No permanent link
- Data is encapsulated in individual packets
- ‘Always on’
- Transfer capacities are shared between users of one cell
- Theoretically 128kbps

3.6.6 Short Message Service (SMS)

It was not that long ago that short message services, more commonly known as SMS were considered to be the new ‘killer application’.

SMS is relatively new feature in the world of mobile phones and wireless communication that enables users to send short text messages to other users. These messages are usually limited to a certain number of characters, however as technologies improve so do the size of the messages.

The above sections (namely 3.3 and 3.4) have given an insight into the different types of networks and means of communication available in the wireless environment. There is a choice available to potential users and as a result there are factors that need to be considered when planning an end-to-end mobile, wireless solution. These are:

- The kind of application i.e. the kind of data flow and connectivity requirements of the specific application.
- Connection type - (WPAN, WLAN, WWAN).
- Coverage – What type of environment does the connectivity need to be available?
- Throughput - how much and what type of data needs to go over the air-link?
- Security - e.g. authentication and encryption of the data are two key security areas to evaluate.
- Cost – What costs will be involved in using the air link?
- Power management – where does the modem that provides the wireless connectivity draw its power from (device or externally)?
- Notification – is it necessary that the users be notified of information that is received during the day?
- Form factor - what size characters suite the mobile device?
- Service - what are the requirements/service that the users need?
  (Microsoft, 2003)

Each of the different connectivity options, which have been described so far in this chapter allow for different quantities of data to flow to the devices. The different data transfer speeds also affect the types of work or application that can be performed.

The chart below illustrates some of the applications that become feasible as the data flow to a mobile device increases.

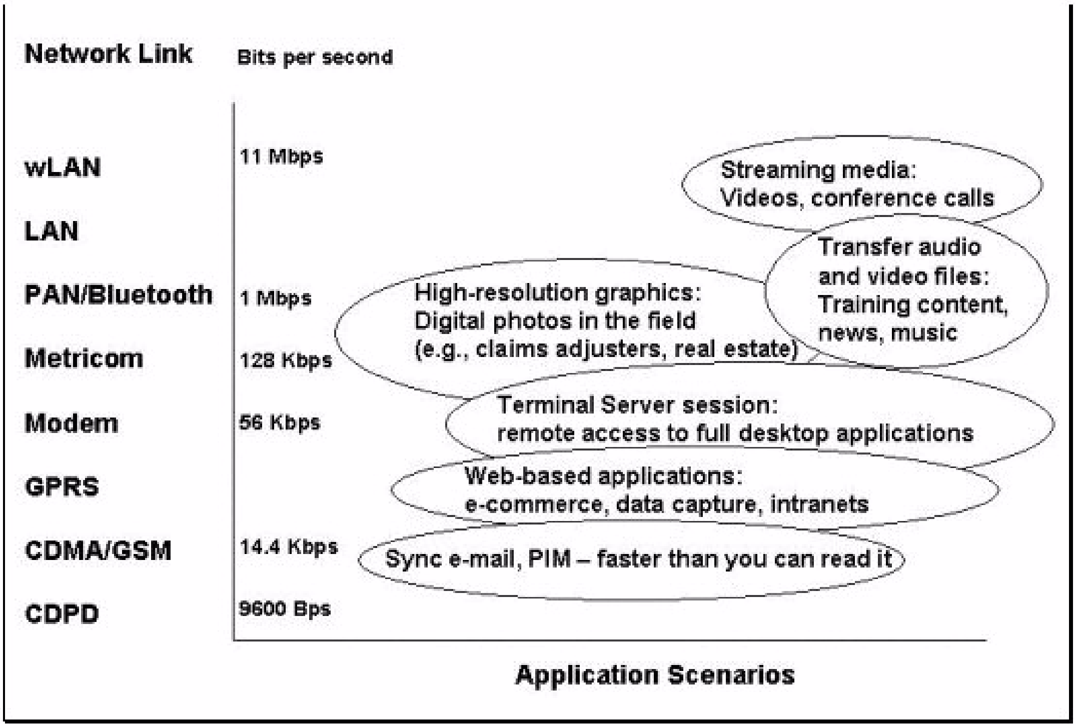


Figure 3.7 Different network links, their speeds and the types of different application scenarios in which they can be applied. (Source: Microsoft, 2003)

3.7 Knowing Your Location and Position

Knowing your location is of prime importance to man.

> "Man has used stars, landmarks and verbal queries since ancient times to find his location. During the middle ages man used compasses and maps and nowadays we are using the latest digital technologies." (Magon et al, 2002)

There are various means for determining position. These are:

- Manual
- Network Based Positioning
- GPS

3.7.1 Manual

Emergency response services such as the AA (Automobile Association) frequently use manual methods for relaying the location of their users. It is the advancements in wireless communications and the mobile Internet that have given a new meaning to the term location service.

3.7.2 Network Based Positioning

Network based positioning uses the location of the mobile device in relation to its cell site to figure out its location. Triangulation of the signal from cell sites that serve a mobile phone are used to calculate the position of the user. At least three cell sites are needed for triangulation to work.
Differing techniques like:

- 'Cell of Origin
- Time of Arrival
- Angle of Arrival
- Enhanced observed Time Difference
- Assisted GPS' (Mehta et al, no date)

are used to find the geographical position of device.

3.7.3 Global Positioning System - GPS

"The Global Positioning System a gift of the arms race has changed navigation and position forever" (Magon et al, 2002)

GPS is a worldwide radio navigation system that consists of 24 satellites orbiting the earth and their ground stations. The method GPS uses to find a location is known as Trilateration. Trilateration uses the basic geometric principle that states that as long as you know the distance from other already known locations it is possible to calculate a current position. Trilateration can be described as being the very root of GPS. Of the 24 satellites that are orbiting the earth, no fewer than five of these are in view of a point on the earth at any time. However for the formula used in trilateration it is only necessary for three of these satellites to be in view of the receiver. The GPS receivers position is then calculated from the information that is transmitted from the satellite to the receiver. The receiver is able to recognize it's exact distance from a satellite by using the time that it took for the signal to travel from the satellite to the receiver. Using the signals from three or more satellites the receiver is able to compute it's own spatial relationship between itself and each satellite in order to come up with it's precise position on the earth. Therefore the technique used for trilateration is relatively simple and for the GPS receiver to locate itself only two requirements are needed, these are:

- View of at least three satellites orbiting the earth
- The distance between the receiver and each of those satellites.

Without a doubt GPS is of an extremely high standard and offers very high quality data. But as good as GPS is, it to does have its limitations. The main limiting factor for the methods used by GPS are the line of sight criteria, this can especially be a problem in urban areas or when in a gorge or canyon during fieldwork. Other limiting factors include the added costs involved and the time it takes to obtain the signal.

> " A combination of network and terminal based solutions is often a good way to go. A GPS solution gives high accuracy and can be backed up by, for instance, CGI-TA at times when it is not available." (Anderson, 2001)

3.8 Developments in the Mobile World

3.8.1 The Mobile Internet

> "It seems like only yesterday when the Internet hype first grabbed the world's attention. However, today the plain old Internet is almost history, compared with the newest sensation: the mobile Internet."
>
> Bangkok Post, Focus Is on M-Commerce, December 15, 2000

There are many features of the Mobile Internet that give it an advantage over existing services of the fixed Internet. The biggest advantage of the mobile Internet is the very mobile/wireless aspect of it. You can now have access to any of this data from your mobile phone, PDA etc. You can take these terminals anywhere you want to, allowing them to act as mobile personal computers.

One of the most important and newest features of the Mobile Internet is its ability to provide location-based services (described in section 3.11). The services that you select will now be able to filter their content or change their behaviour, based upon your location.

Mobile Internet has had a troubled history. Throughout the 1990's numerous attempts were made to make wireless Internet access ubiquitous (e.g. through WAP). However, none of these efforts were considered a success. It is now clear that the third generation of telecommunications is going to be focusing on the important and difficult aspect of data transmission at wide band rather than towards the services of voice communication. This will require that handsets have a display of quality, at an image resolution sufficient to be able to benefit the best of the services, which are offered.

"Much of the reason that wireless Internet has not reached a critical mass is that the available bandwidth is typically inadequate for the desktop network applications which users have grown accustomed to, and few new custom applications designed for the mobile Internet users have emerged." (Townsend, 2000).

3.8.2 Spatial Data Infrastructures

"A new wave of technological innovation is allowing us to capture, store, process, and display an unprecedented amount of information about our planet…. Much of this information will be 'georeferenced', that is it will refer to some specific place on the earth's surface."

(Al Gore, 1998)

Spatial Data Infrastructures have arisen from the need for cooperation between data users when dealing with spatial information. The SDI is a tool that assists with the decision making and spatial analysis problem solving. Whilst there are many definitions for SDI's relative to their contexts, Rajabifard and Williamson (2001) explain their underlying principle as providing an environment, which enables a variety of users to access and retrieve complete and consistent data sets easily and securely. Due to the mobile context of Mobile GIS there is a strong need to be able to access and retrieve necessary data easily and securely and hence the SDI should be a vital component to mobile applications.

3.8.3 Mobile GIS

Caduff, 2002 describes a mobile GIS as being a high tech equivalent of paper maps. Traditionally desktop based GIS's have been static, but, using the recent mobile related technologies described in this chapter, mobile users are able to use their geographic information system in new environments.

The advantages that mobile GIS has over traditional techniques are very evident. In many utility companies for example, paper maps were used to help their workers repair, maintain and extend geographically deployed assets. As with many technologies, GIS has not led to the need for these services to disappear but what is changing is merely the medium with which it is done. The main advantages that mobile GIS and it's use of handheld computers has over using paper maps is that:

"In a Mobile GIS one is able to store vast amounts of data on a small notebook that:

(1) Can provide all the information, not just the minimum that is typically annotated on maps and plans.
(2) Is a much more durable/robust computer-based medium than paper maps, which tend to deteriorate in the field due to wear and tear.
(3) Can easily pre-package/organize daily job tasks into work order packets for field execution.
(4) Has much more flexibility in viewing your data with standard GIS features of pan, zoom, filtering and many searching/browsing features both attribute and graphically based.
(5) Has much more flexibility of object representation (symbology) allowing real-world objects to be easily highlighted for field activity, ensuring corporate-wide drafting standards, and
(6) Has additional data sets available to assist operators to make decisions in the field such as access to the topologically connected network for tracing and analysis and other types of data such as geo-coded schematic and image files."

(Spencer, 2002)

It is therefore clear just how more beneficial using mobile GIS is over using paper based maps when in a mobile, out of office environment.

3.8.4 Hardware

As the hardware capabilities of these mobile client devices continue to improve, software applications become more advanced. The bandwidth limitations are alleviated and greater focus and interest will be placed on developing the existing protocols such as HTML and XML as well as making them more widely accepted, and usable for mobile devices. HTML is concerned with data presentation, whereas the more extensive XML supports data content description and structuring (Maguire, pg 4). The demands and use of both of these are likely to increase substantially in the near future.

Mobile Devices

The advancements in the small handheld client devices have also been enormous over the last decade. It has not been that long that the mobile phone has been in use and look at how they have developed and changed over the last few years. Computers then became mobile with the advent of the portable PC's or laptops. These have now become so miniaturized that we are now using handheld PC's.
Although these handheld PC's do not have the same functions and storage capabilities as larger PC's, this is proving to be less of a limitation with the state of the mobile internet. It is no longer necessary to have the same storage capabilities in your hand held PC or PDA as was necessary on a wired PC. With the capabilities of transmitting and making information available through a wireless connection, a mobile device has access to as much information as a wired up device.

Advancements in the hardware performance market have allowed the development of small, low-powered, devices that are capable of being held in the hand and used on the move. These hardware devices are commonly known as mobile devices and are available in many different forms. Some examples of these devices include:

- Pocket PC running Windows CE
- Palm PDA running Palm OS
- Smartphone running EPOC
- Pager with proprietary OS

Figure 3.7 An example of a PDA (O2's XDA).

The choice of operating system may also vary depending on the device in question. Some of the different operating systems include Windows CE, Palm OS, EPOC, JavaOS and Linux amongst others.

It is however becoming important that these devices, as mobile geographic clients, be geographically aware (Maguire, pg 5). This basically implies that the mobile device must now be continually tracked and that its location must always be available. Knowing a devices location can play an important part in a project, as it is often necessary to know the exact location that a sample is taken from. The methods with which a location is determined vary. These alternatives were discussed in section 3.7.

3.9 Client Centric versus Server Centric Scenarios

In the mobile domain, the use of handheld computers means that the computer is, by necessity, much more limited in its capabilities. This derives primarily from the need for lightweight, the small form factor and the need for longer battery life. All of these leads to an issue when developing applications that will be used on

a handheld computer that is based on the question - How much of the application should I put on the handheld computer? (Technology crafters, 2002)
This is where the debate of whether to design a system as a client-centric or server-centric scenario arises.

Another way of referring to whether something is client centric or server centric is whether it is a thin-client or a thick-client. A client is classed as thin or thick depending largely on how much of the processing takes place on either the device or the server.
There have been shifts from thin client to thick client and back again, the rationale for the shifts is typically the same. Clients become thicker with increasing bandwidth and processor power and become thinner as new transmission media decreases bandwidth and portability of devices decreases processing power.

It is widely thought that the thin client scenario best suites data collection in the field.

> "Emergence of the World Wide Web, "pre-emergence" of the wireless application protocol (WAP), a need for titanic storage volumes and the introduction of spatially aware databases has given rise to the notion that "thin" is "in" again."
> (Reid et al, no date available)

There are several names for the architecture that allows a client device to exchange data with a host with minimal processing at the client level, some of these include, centralised computing, controller based computing, server based computing. Thin client applications are developed for speed, simplicity, minimal keystrokes and minimal training thereby speeding up the whole process of data collection. However both the thin client and the thick client has its advantages and disadvantages. These are listed below:

Thin client advantages

- No download or installation necessary
- No installation conflicts, versioning or environmental issues
- Available from any PC with a browser – thin clients can run on any system that supports a browser
- Instant updates and revisions form a central location.

Thin Client disadvantages

- Low level of interactivity
- Limited access to services on users machines – the browser sets up its own "sandbox" environment for the thin client, which limits the access to services on the users PC.
- Requirements of always on connectivity – must be connected to the server at all times.

Thick client advantages

- Rich screen functionality, high level of interactivity – since the client is a program installed on the device, it can be made to perform virtually any functionality desired.
- Required client adds security, persons with out client cannot access system
- No "sandbox", client is able to access peripherals – application based clients have more access to the clients peripherals, allowing more elaborate print functionality, storage access, multimedia display, etc.
- No requirements of always on connectivity.

Thick client disadvantages

- Updates, new features, and bug fixes requires users to download and install client side software
- Server must account for multiple versions of clients, increasing complexity
- Cannot access system from "ad-hoc" locations unless client is installed. (Harada, 2002)

3.10 What are Location-Based Services?

A recent development that has captured the attention of those interested in GIS has been the topic of Location-Based Services (LBS). These systems, which are designed to add location-awareness to the delivery of services provided to users, have invigorated the interest that information systems researchers have in location-based problems and issues (Mennecke, 2003).

"Location-Based Services are projected to rise more than 100-fold in the next four years, making it one of the fastest growing sectors in the mobile field." (Beinat, 2001)
The science of mobile information services have evolved rapidly over the last few years, one of the reasons for this is the added dimension of knowing a persons location. This has resulted in what has now become known as '*Location-Based Information Services' or LBS.* LBS can be described as the capability of finding the geographical location of a mobile device and then providing services based on this location information. LBS arose as the result of the convergence of a number of different components. Information systems, wireless communication mechanisms and positioning technologies, shown in figure 3.8 are the main ingredients that have helped make LBS possible.

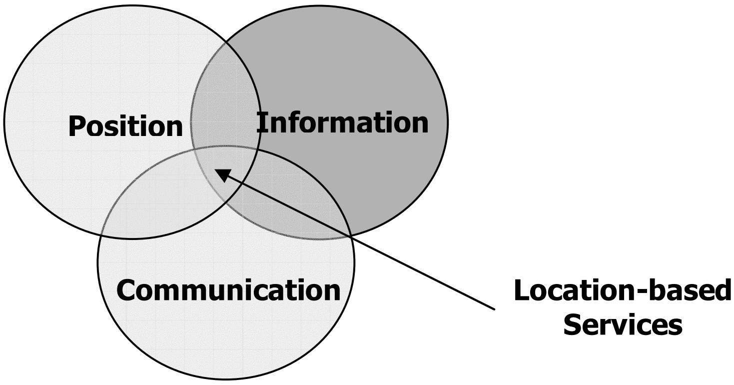


Figure 3.8 The convergence of technologies enables Location-Based Services (Source: Smith et al).

Some of the diverse applications that LBS have been applied to include fleet tracking, emergency dispatch, sensor monitoring, customer location for target marketing and advertising, roadside assistance, stolen vehicle recovery, navigation, directory services, and many more. LBS has the potential to facilitate the delivery of spatial data along with providing routing and direction finding information.

According to a poll by Integrated Data Communications, Inc. (IDC), two-thirds of all Americans want wireless location-based services in the near future.

3.10.1 Components of LBS?

LBS have evolved from a combination of a few technologies. As the name states a Location-Based Service is an information services with the added component of '*location*'. It is this union of GIS, Internet, wireless communication, location finding techniques and mobile devices that have given rise to the exciting world of Location based services. Although still in its infancy LBS is certain to make a major impact on the way navigation is done and businesses are conducted in the future.

"Three technological trends are converging to strengthen and reinforce the link between databases, computation, and day-to-day management.

1. The expansion of terrestrial wireless communications networks for voice and data
2. The widespread use of geographical data and geographical information systems
3. Advances in positioning technologies such as the Global Positioning System" (Townsend, 2001).

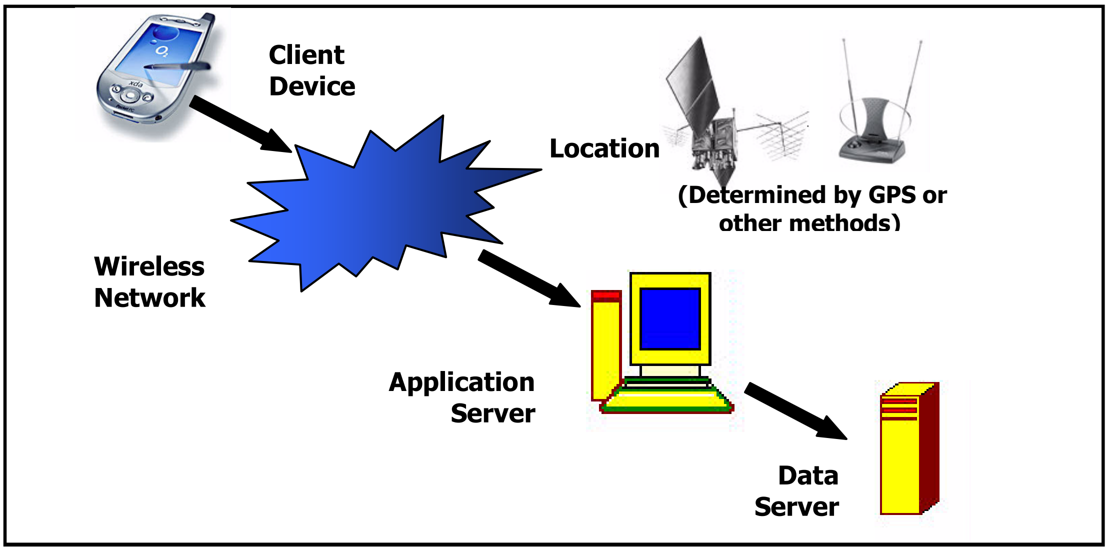


Figure 3.9 Key elements of a mobile information system.

A mobile information system such as LBS is not a conventional GIS modified to operate on mobile devices such as PDA's. What makes LBS what it is, is the fundamentally new paradigm that is used when building the system and is based on the key elements shown in Figure 3.9 above. It must be noted that the location component to LBS is not only limited to the use of GPS but includes a wider range of techniques including the mobile antenna network (triangulation) etc. Further methods for finding ones location are better described in section 3.7.

The architecture behind LBS is based on the thin client or server centric scenario. Because information is based on location, large amounts of data have to be stored in a data server and only upon request from the user is selected data transferred to the mobile device via wireless data transfer techniques.

"Mobile geographic applications are characterized by their ability to support itinerant, distributed and ubiquitous computing.

- Itinerant – providing computing capability while moving with a person, in a vehicle, or on an aircraft or ship
- Distributed – integrating functions that are performed at different places in a way that is transparent to the user
- Ubiquitous – delivering the same functionality independent of a user's location.

(Maguire, 2002)

A service such as LBS delivers data and /or processing to clients on demand. As can be seen in the figure above there are a number of steps involved in getting information to the user. Requests from the clients may come from, pagers, phones, Pocket PC's, PC's etc (as described in section 3.8.4). These requests may involve geographic data and or/ processing (e.g. make a map, geo-code an address, download data for an area).

Any queries, analysis and mapping operations are then performed on the server and in some of the more advanced clients these can be performed on the clients mobile device itself, depending on the thin or thick client scenario's chosen. Whichever option is chosen, the results will be displayed on the client. One of the important components of the modern technology is the ability to service multiple clients at the same time, they are maintained centrally in secure facilities and these multiple clients have the ability to interact with each other.

The last component of LBS is the data that is going to be made available to the end users. "Data management and high throughput for large databases is enabled by the use of commercial off the shelf relational database management systems. The same software can be used to store and manage both the geographic and associated attribute data" (Maguire, 2002)

The application server is a vital aspect of an LBS / mobile GIS and acts as a management system for all the data involved. In order for LBS's to be successful it is important that there is an advanced geographic application server that is able to provide many of the capabilities listed below:

- "Rich functionality: The range of applications listed earlier must be supported. At a minimum the following services must be available: high quality mapping, geographic and attribute queries, data downloads, proximity analysis (i.e. find closest object of a given type), geo-coding, and routing.
- Good performance: Performance is critical for application servers of this type because they must be able to process many requests simultaneously and potentially millions of requests per day.
- Scalability: This includes the ability to deal simultaneously with both very large data sets and very large numbers of application requests. It must also be possible to add processing capability without interrupting operations. As a rough guideline a medium sized database is approximately 200 Mb – 1 Gb, a large data base is 1 – 10 Gb and a very large database is greater than 10 Gb.
- Extensibility: For all organizations the transition to mobile applications is very new and no one can foresee long-term future requirements. It is essential, therefore, that application servers can be extended to support new services and increased numbers of users.
- Reliability: Because geographic services need to be available 24 hours a day they must be robust and reliable. The use of commercial off the shelf technology such as standard hardware, GIS and DBMS software configurations provides this reliability.
- Standards-based: Although wireless systems are still immature and are developing rapidly, standards such as XML are beginning to emerge. Building systems based on these standards will help ensure compatibility with future systems and applications." (Maguire, 2002)

With wireless communication and information access methods expected to continue to evolve and play an increasing role in society, and the strong focus on mobility that wireless communication implies, it is critical for the spatial information industry to develop an infrastructure that meets the needs of the new user base. The SDI, (*described in section 3.8.2*) is used to help ensure easy access and retrieval of information from a database.

There are definitely challenges for the market of LBS in the years to come. Some of the challenges that may be experienced include deciding on what applications need to be developed (the technologies now exist but what can we do with them), how to generate revenue from the applications, overcoming acceptance hurdles and how to protect user privacy.

4. Integrating Mobile Technologies and Location-Based Geographic Services for Monitoring & Fieldwork, 'Tailor-Made Monitoring'

4.1 Introduction

This chapter reviews some of the conceptual and technological issues related to mobile geographical information systems and digital field control. Integrating the latest developments in mobile computing and mobile GIS technologies (*described in chapter 3*), the bottlenecks and problems facing monitoring (*described in chapter 2*), are addressed. The intention of this chapter is to give an overview of the state of the art developments, existing, conceptual and technological, regarding the use of handheld computing devices during fieldwork. Due to the nature of monitoring, emphasis is placed on data collection and use of spatial and tabular data in a mobile context, focus is also placed on the importance of *knowing ones location*.

4.2 Developments in Mobile Computing Within Field Monitoring

"A basic characteristic of fieldwork has always been it's wireless nature and remoteness from all office equipment like telephones, faxes, PC's, databases and printers" (Wagtendonk, 2004). Until recently it was felt that a notebook and a pencil together with the human knowledge (experience) and senses were all that were needed in order for effective monitoring and fieldwork to be conducted. With the development of mobile and digital tools for fieldwork, the wireless element is now more applicable than ever.
Developments and the technologies mentioned in the preceding chapters have brought about a new revolution regarding field data management. These communication and simulation sectors offer new options to realise a fast and cost effective method for field data management and data collection processes.

Mobile device development has often been driven by frequent advances in hardware components and protocols, rather than by the needs of those who use the technologies. This surge of development regarding these technologies has meant that mobile mapping and computing has been incorporated into monitoring programs. Mobile computing is now being used as a means of using and collecting digital, spatial, geographical and attribute data with a lot of emphasis placed on the locational component to this data. Furthermore mobile protocols such as the wireless Internet connection (*described in chapter 3*), have enabled users to share data by communicating between each other in ways that until recently were not possible.

4.3 'Tailor-Made Monitoring'

'Tailor-Made' monitoring in the context of this thesis implies personalising the way in which monitoring is performed and information is used in the field. Recent technological developments have brought about a new revolution regarding field data management. These communication and simulation sectors offer new options to realize a fast and cost effective method for field data management and collection. These have resulted in higher productivity and less data handling errors.
'Tailor-Made' monitoring described in this thesis, attempts to be a forerunner to the concept of 'Making Monitoring Tailor-Made'. "Making Monitoring Tailor-Made" was an initiative in Europe created to find an answer to the question of how monitoring could provide more effective information to end users, and decision makers. The emphasis was on providing the right information to make management decisions, thereby addressing the further analysis of information after the data collection process. In 'tailor-made' monitoring however, we try to focus on how the data collection process can be improved by optimising the way in which information is used and data is collected in the field. The aim is to provide more accurate and usable data to the end users.

Customisation of software and mobile ICT configurations to suite specific projects, so that the user can optimise the way in which he collects and uses geographical data, is not new to fieldwork. For many years systems and programs have been custom designed and built around specific applications. These have varied from the collection of water chemical properties to the recording of electricity meter readings. However, what is revolutionary is that the developments in information and communication technologies are allowing new doors to be opened in terms of what can be accomplished with mobile fieldwork tools.

'Tailor-Made' monitoring covers a relatively broad scope. This means that it is possible to combine a number of different technologies and techniques into different configurations to suite a specific application's needs. This largely centres around configurations used when combining technologies (hardware & software), but what makes the system truly 'tailor-made' are the tools and interface seen by the user. Just as with traditional monitoring, forms are designed within the program with tools and buttons enabling simple, consistent input through the use of drop-down list boxes, check boxes, yes-no selections, and the automatic acquisition of GPS coordinates from a GPS receiver (figure 4.1). Furthermore the 'tailor-made' element to the PDA input, automates some of the data entry by using logic that has been programmed into the input forms i.e. particular input into one form will dictate the input required for subsequent forms.

Figure 4.1 Different GPS devices that can be attached to PDA's.

4.3.1 The Digital Fieldwork Assistant (dFA) – 'Context-Aware Data Collection'

Why use digital field data capture?

"The main reasons and benefits for considering digital field data capture include:

(1) data validation during collection,
(2) reduce data transcription errors,
(3) control of the quality of positioning,
(4) speed of data collection,
(5) faster field data distribution during and after the field season "

(Source: Nykanen (in: Wagtendonk, 2004))

These benefits combine to maximise field worker productivity, drive down the cost of field operations, improve the accuracy of enterprise data and enhance customer service.

A potential solution to many of the problems faced during fieldwork with regard to data collection presented itself in the form of digital Fieldwork Assistants (dFA's) based on small handheld computers. The dFA was based on an earlier project of Leusen & Ryan (2002), who developed the 'FieldNote' system as part of a PhD study at the Oxford University in England.

The dFA is based on small handheld computers linked to GPS receivers that can be used to aid the process of context-aware data collection. A context-aware system uses a GPS receiver to supply a hand-held computer with a continuous 'awareness' of its location, and this is used both to tag recorded data and to select and display contextually relevant information from a database. In a context-aware application the computer monitors, and responds to, various aspects of the user's environment.

In order to characterize the mobile fieldworker it is necessary to understand what the objectives and goals of their work are.

Pascoe, et al. (1998) defined four main characteristics of the mobile fieldworker:

1. **Dynamic User Configuration**. The fieldworker wants to collect data whenever and wherever they like, whether they are standing, crawling, or walking.

2. **Limited Attention Capacity**. Data collection tasks are oriented around observing a subject. Depending upon the nature of the subject the user will have to pay varying amounts of attention to it. In most of these situations it is important that the user has to devote minimal time to interacting with the recording mechanism.

3. **High-Speed Interaction**. The subjects of some time-dependant observations can be highly animated or, more commonly, have intense periods or 'spurts' of activity. During these spurts of activity they need to be able to enter high volumes of data very quickly and accurately, or it will be lost forever.

4. **Context Dependency**. The fieldworker's activities are intimately associated with their context. For example, in recording an observation, its location or the location of the observation point will almost certainly be recorded too. In this way the data recorded is self-describing of the context from which it was derived. Further applications of the data often involve analyzing these context dependencies in some form, e.g. plotting observations on to a map. (Pascoe (in: Wagtendonk, 2004))

"Mobile computing and communications will augment the user's ability to function in professional and social settings by providing supplemental information gathering, processing, and storage functions, which to a large extent will be cued to the user's geographic or locational context." (Townsend, 2001) Knowing the users geographic or locational context is very important within mobile GIS and plays a vital part in providing location specific information or location-based services. The importance of context - awareness is further discussed in (section 4.8.1).

4.4 Streamlining the Efficiency and Accuracy of Field Work Procedures

The three primary components necessary for mobile field data collection have been dramatically improved over the recent years. GPS (receivers) have become more accurate and smaller and the data collection hardware (PDA's) and software (for example ArcPad) have become considerably improved in terms of compatibility, usability and cost. These improvements have resulted in GPS/GIS data collection tasks being much easier, more effective and more efficient for average consumers. No longer is the thought of mobile yet interactive use of technology for field data capture and management a daunting task, the knowledge and infrastructure has been developed to such an extent that it is now a realistic option.

4.4.1 The Needs of Data Collection Clients

Current practice with hardcopy forms cannot prevent input errors, therefore 'procedures based on independent self-location and direct digital data entry should prevent most types of errors from being made' (Leusen & Ryan, 2002).
Data collection is a highly specialized application that benefits greatly from the use of wireless radio frequency (RF) clients to increase worker productivity. Such wireless, digital clients offer instant, real-time access to data, improved data input accuracy and allow for total mobility across a wireless network.

The advantage of the digital element of PDA data collection is that the device can be synchronized with a central database. This helps to ensure that only the latest records are retained. The database can be added to a geographic information system as a data warehouse, allowing normal GIS functions such as, queries and analysis to be performed on the collected data. The GIS also allows the user to browse and edit the data to verify correctness (Wagtendonk, 2004).

4.4.2 Minimal Attention User Interfaces (MAUI's)

Usability from the users perspective is vital when designing such systems. Users do not want interfaces that are confusing, intimidating and that may slow them down or even put them off from using the digital devices altogether. The applications must be designed to minimise the amount of written input. In some instances large buttons and other controls are incorporated so that most interaction can be performed using the fingertip, making the pen almost redundant.

The Minimal Attention User Interface is another way of streamlining and improving the collection of field data. The MAUI model attempts at increasing the speed at which data can be collected by minimising the amount of time the user has to spend concentrating on the screen and increasing the amount of time that is spent focussing on the job at hand. As a result the purpose of the MAUI is that the user needs to place less emphasis and time on operating the device.

Pascoe describes the MAUI as 'providing interface mechanisms that minimise the amount of user attention, though not necessarily the amount of user interaction that is required to perform a particular task' (Pascoe et al, 2000). During many monitoring programs the operator needs to place as much of his attention as possible looking at the subject of study, they cannot afford to be distracted, having to look at the mobile device too often. In order so that the operator is still able to record information while at the same time observing the subject, the MAUI simplifies the user interface enabling an easy grip on the device. Shown in figure 4.2, the operator can still record data with the use of his thumb and/or other fingers.

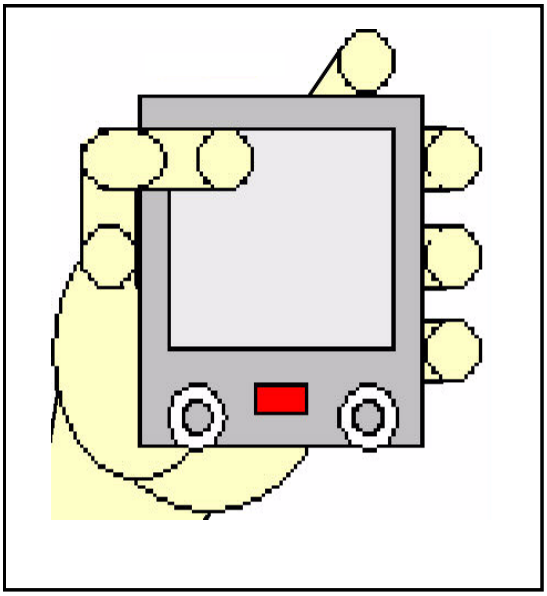


Figure 4.2 The most comfortable grip on a PDA for one-handed operation.

Within the 'tailor-made' scenario the user-interface is designed with the goal to minimise the necessary user interaction with the PDA, however it is the minimal amount of user attention needed, which ultimately allows the user to spend as much time as possible focused on the subject at hand.

The traditional MAUI is limited to rather simple data collection tasks, due to small screen sizes. Examples that best suite the MAUI are those when items require counting, the user is then able to focus on the object, whilst using their finger to make recordings.

With the first MAUI prototypes the screens sizes tended to limit the number of buttons to not more than four, intended to ensure easy use. The team at the university of Kent at Canterbury are building a prototype where they use layered sequential screens in order to provide even better MAUI's.

4.4.3 Mobile Mapping and the Mobile Internet

During traditional field practice, collection units are mapped directly onto large-scale topographic or cadastral maps of the survey area, using existing landmarks for orientation, a series of forms are preferably used to record information about the collection unit (Leusen et al 2002). However as described in section 3.8.1, we are presently witnessing the collision of the worlds two fastest growing sectors, mobile technology and the Internet. This revolution is known as the Mobile Internet. The Mobile or Wireless Internet has enabled mobile users much easier access to maps and other representations whilst in the field.

The key to mobile mapping is the ***Internet Map Server.*** The map server acts as a large database that contains and manages a huge repository of digital maps. The user of the mobile device sends a request, through the browser so that a particular .html page containing the map can be selected and displayed to the user with the browser.

This ensures that during fieldwork, any maps that cannot be stored locally on the device (due to limited storage capacity) can be obtained through the Internet map server and used in a variety of ways. The user may want to compare, correlate or use the maps for navigation. Furthermore, with the launch of Geographic Information System (GIS) capabilities on the World Wide Web, middleware programs such as Internet Map Server (IMS) from ESRI have been launched as the next generation Internet GIS. An Internet map server is also a very efficient way to make live GIS products available to a large population at minimum cost.

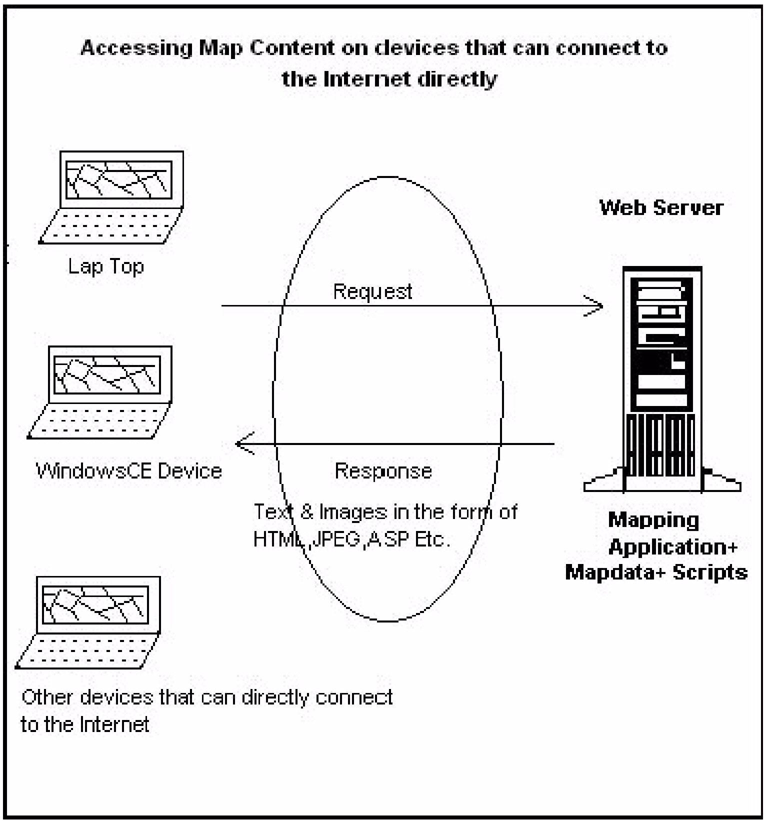


Figure 4.3 Accessing map content on devices that can connect to the Internet. (Source: Srinivas et al, last accessed March, 2004)

There are a number of advantages associated with mobile Internet mapping. The most obvious of these is that the user requiring the information now has access to both maps and the related information from anywhere and at anytime, saving both time and money. Secondly the central nature of the server means that the data can be kept up to date and changed with relative ease. This private medium of dissipating the information means that it is both convenient and secure for others to use.

This means that as long as there is a wireless connection, the user will have access to the map server and hence a repository of maps. There are of course both advantages and disadvantages to accessing maps in this manner. The advantages of mobile mapping are obvious as the user no longer needs to carry around files full of large paper maps. They can now just choose which one they require and download this into the GIS where it can be used in a variety of ways. The disadvantages include the fact that if the connection to the server is lost, whether it be from the server or in the field then the user no longer has access to the required maps, which may ultimately lead to failure of the task. Other disadvantages are that due to the large nature of digital maps, download times can be very long and with storage capacity of mobile devices being relatively limited the users are often limited to how many maps they can use.

4.4.4 'Thin is Better'

Thin client computing as described in chapter 3, is an architecture that allows a client device to exchange data with a host with minimal processing at the client level. Thin-client architecture is often thought to be best suited for data collection applications, particularly when in mobile environments because of the limited capabilities of mobile devices and the need for collected data to be available for processing soon after collection. At the same time though, when relatively simple data needs to be collected and the infrastructure is not available for thin-client computing the thick-client scenario can also be suitable.

There are many important differences between thin and fat client scenarios that offer compelling reasons to select thin client architecture for data collection applications. Some of the more inviting reasons are that wireless clients offer instant, real-time access to data (providing the connection is not lost), data input is available for processing directly after input, and it allows for total mobility across the Wireless LAN.

"A growing desire to distribute data and analytical tools to a broader user community has a lot of corporations looking to "get thin." (Reid et al)

It is often claimed that during data collection emphasis must be placed on collecting the data as quickly as possible and that there should be little emphasis placed on how the processing is done. This is true only to a certain point, and is very dependant on the type of application that is being used. When the application/program is large and involves a lot of processing to be performed on the data then it is often more suitable to use the thin-client scenario due to limited memory and processing power that is available on current mobile devices. For smaller applications however, where for example the main purpose is to collect data (such as in the case study), and there won't be any major changes to the program itself, it may be more suitable to make use of the fat-client scenario. In these applications the program can easily run on the device and for the type of data that is being collected the devices are more than suitable in terms of memory and processing power. Furthermore being online all the time as is often the case in thin-client architectures consumes a lot of battery life, as the modem may need to run directly off the devices power supply.

The advantages and disadvantages of both thin and fat client computing can be seen in section 3.9.

'The benefits of this are that the client simplifies device management for end-users and at the same time the central controller optimizes the data stream, and minimizes data traffic over the wireless link, resulting in fewer collisions and congestion.' (Harada, No date)
Other benefits of using the thin client as opposed to the thick client scenario include:

- **Supportability** – depending on the application there may be many devices to support at the same time: the simpler the client devices are the easier they will be to support.

- **Flexibility** – in a centralized system, changes that are made at the controller (central system) will occur across all client devices or groups of devices. With thick clients, each client would have to be reprogrammed.

- **Reliability** - centralized based architecture has often been critisised for having a single point of failure that affects the entire system. However modern systems employ controller redundancy to reduce the risk of failure. With centralized controller based systems, the ability to isolate and diagnose problems is far greater than with decentralized thick client systems.

- **Programmability** – because in a centralized system all processing is done on the host system, any changes made can be rolled out to all the clients instantly instead of making the changes to each individual client. (Harada, No Date)

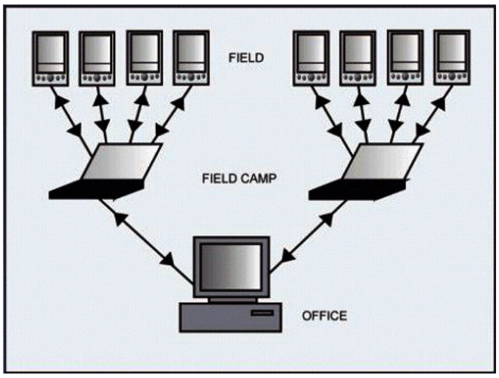
4.4.5 Multidisciplinary Data Sharing

Is it possible for mobile computers to enrich the outdoor field experience by supporting team collaboration during fieldwork? - With the benefits that modern information technologies have brought to our everyday lives, we have become a lot more comfortable with accessing and sharing information.

Modern monitoring can be classified as being multidisciplinary, this means that there are many different components and aspects associated with monitoring. The monitor cannot merely walk into the field and start collecting data, during water quality monitoring it is often necessary that field walking takes place in conjunction with the monitoring in order to get an understanding of the land and its surroundings. Due to this multidisciplinary nature of monitoring it would be useful to the different field crews if they could incorporate on-line communications into their projects making it possible for the data collected by one crew to be available to another crew working in a completely different area. In many circumstances it would be useful for improving the decisions that are made, if participants could communicate between not only the fieldworkers, but also the base camp (this may be a vehicle) and the central system. This has been a limiting factor, and only recently have fieldworkers been using mobile phones as a suitable communication medium assuming there is sufficient network coverage in the area.

There are however, other possibilities, and although GSM (Global System for Mobiles) are limited because of a high cost, the GPRS (General Packet Radio Service) and third generation networks (discussed in chapter 3) e.g. UMTS (Universal Mobile Telecommunications System) are already proving to be more affordable. "There will be and always on' IP connection to a network server, and charging will be by data volume rather than usage time" (Leusen et al, 2002).

The type of data sharing that can be used, ultimately depends upon the available connections between devices and the different users involved. Depending on what is available, the chosen configuration could provide a many-to-one synchronisation, in which the data collected on the devices is uploaded on to a mobile computer (laptop) and later to the main database back in the office. The other option is the wireless synchronisation where wireless means of communication are used to transfer the collected data directly from the devices to the central system.



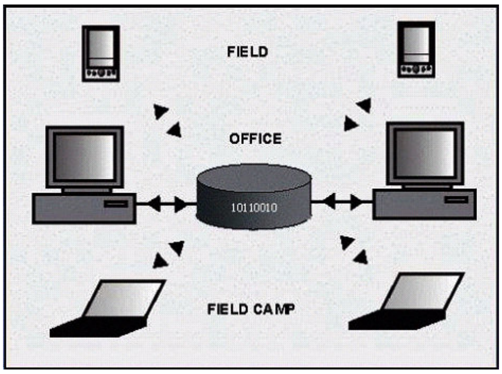


Figure 4.4 Synchronisation: Many-to-one Synchronisation: Wireless (Source: Schetselaar, 2002)

Leusen & Ryan (2002) stated that other benefits of on-line communication between personnel, are that 'if newly recorded data is rapidly mirrored on a remote server, we can overcome the ever-present fear of losses arising from device failure in the field'. Furthermore, messages and other data like maps can be transmitted to the user in the field in almost real-time, as they are produced.

4.4.6 Geographic Data

A rather under reported fact over the last decade or two has been the explosion of computer and geographical data that is spatially referenced.

> "It is estimated that 80% of the information on the web is or can be geographically encoded. (Townsend, 2001)

Geographical data is a key component of 'Tailor-Made' monitoring. Just as in any geographical information service, the client must be provided with the correct data. The Database Management System (DBMS) is therefore very important in a centralized system, as it handles the data that must be delivered to the client upon request.

The second form of data is that which is collected during the data capture process. Depending on the scenario chosen, this data will be stored either locally on a removable memory card or else it will be sent back to the central system where it can be processed for further use.

4.5 Location-Based Services and Mobile GIS for Monitoring

Fieldwork and monitoring does not only comprise data collection, but includes the entire decision making process. Depending on circumstances, the fieldworker may require information about an area in which they are working. The type of information may vary from the users details and past records, to the type of soil, and land use upstream of a river. With the advent and success of location-based services a fieldworker is able to request, receive, update and send back maps and attribute information, all in real time.

The geographic application server is key in providing good quality, up to date and timely geographic data and services. It enables a range of mobile geographic applications, ultimately saving the fieldworker time. Incorporating added GIS functionalities on the mobile devices enables the user to perform queries on the data resulting in geographically sensitive data and services. The types of areas that such technologies can benefit, include:

- Maximising field worker productivity
- Driving down the cost of field operations
- Improving the accuracy of enterprise data
- Enhancing customer service
- Browsing and editing of collected data
- Verifying correctness.

4.5.1 The Importance of Knowing Your Location

"Just as laptops and PDA's have given legs to a generation of computer applications that previously were restricted to the desktop, GIS is the latest technology to pack up its data and take its capabilities on the road" (Harrington, 2003).

Regardless of the application, location is a critical element in mobile GIS. A mobile device's knowledge of its position will allow it to automatically relate the correct GIS data to it's environment (Harrington, 2003). Described in an article written by Andrew Harrington for geoworld, there are three types of mobile operations benefiting from accurate and timely location information, these are:

1. **'Accessing relevant datasets**: The mobile device's ability to know precisely where it is enables it to automatically retrieve datasets, or slices of data, relating to it's current position. For example, a utility technician arriving at the site of a pipe leakage wouldn't have to search through a menu of addresses or serial numbers to find the section of the water pipe network map relating to the problem. The device would pull the necessary information from it's hard drive memory.

2. **Enabling spatial definition of data**: As mentioned previously, one of the current uses of mobile GIS is to take existing data into the field, in order to update it onsite. At some point, the data must be loaded back into the enterprise, and this requires a spatial identifier. The location of each feature serves as the tag that links the updated attributes with the original data in the enterprise GIS. Precise location ensures that correct data elements are updated.

3. **Navigation to a feature**: A technician can't update attributes of a feature if the feature can't be found in the field. Mobile GIS applications will provide navigation capabilities to varying degrees of sophistication. This could vary from a simple map-viewing capability, allowing users to display their locations directly on a map, to sophisticated routing that provides turn-by-turn instructions for a street network to reach a designated spot. This ability to use location for navigation by making use of position finding technologies is already in use, and allows users to see their exact location and point of destination on a map.

With mobile GIS certain to become commonplace in the near future, these location-enabled devices (LBS) are sure to be used in more circumstances and in more places. This incorporation of location into mobile devices has enabled data to be managed efficiently and seamlessly, resulting in higher productivity and less data handling errors'. (Harrington, 2003)

4.5.2 Geographic and Location Based Services for Decision Support

'A decision support system (DSS) is an interactive, computer-based system providing easy access to decision models and information to support decision making' (Duffy et al, 1989)

Everything we do occurs within a spatial context and therefore has a location associated with it. Furthermore, most data that we use, both in business and for personal use include spatial criteria. It is therefore important that we are able to answer location-based questions as we carry out our respective activities. "The recent development that has captured the attention of those interested in GIS has been the topic of location-based services (LBS). These systems, which are designed to add location-awareness to the delivery of services provided to users, have invigorated the interest that information systems researchers have in location-based problems and issues. What makes GIS a relevant topic is that geographic technologies provide the infrastructure that can be used to not only deliver LBS, but also to support various operational and managerial control and decision making activities". (Mennecke et al, 2003)

4.6 The Need for Open Standards LBS

Open standards in GIS have been a big talking point regarding development over the last few years. The same is applicable to mobile GIS. With these Open Standards evolving in both GIS and wireless technology there is now a scope for viable Open Standards in Location-based Services.

The three components of LBS as noted before are:

- Mobile Computation Services (Communication and computations using mobile devices)
- Location Enabling Services (User Location Providing)
- Location Aware services (IP based applications)

(Sengupta et al, 2002)

As a result of the need to consolidate in an effective way a number of technologies in order to make LBS work effectively, it is important that we have standards for the 'interoperability between technology components' (Sengupta et al, 2002). Without standards different technologies are unlikely to be able to work together effectively. For these technologies to integrate in a seamless and error free way, open standards for data exchange and application interfaces are necessary.

It was only acknowledged in the later stages of LBS development that standards are very important. The two proposed standards, which were developed in order to improve integration and stimulate application development, are:

- The Location Interoperability Forum-Mobile Location Protocal (LIF – MLP) API for location
- The Open GIS Consortium (OGC) Open LS API for spatial processing.

The Location Interoperability Forum-Mobile Location Protocol (LIF-MLP) API describes the request / response that gathers x,y coordinates from the mobile positioning centres and gateway mobile location centres (MPC/GMLC). In the new architecture model, the location – enabling middleware effectively acts as an LIF-MLP pass-through and subsequently passes on requests from the LBS application to the MPC/GMLC for location gathering. The OGC's Open LS APIs are XML schemas that describe a finite, invariant set of spatial processing function interfaces for geo-coding, reverse geo-coding, spatial querying, mapping, and routing." (Spiney, 2003)

Jonathan Spiney noted that the OpenLS objective is to provide a standardized solution for carriers/operators that allows them to choose and implement standard interfaces and components into their LBS systems. This ensures that application developers have standard tools and/or services to use when building LBS applications. (Spiney, pg 6) The main reason for this is because the industry was plagued with an abundance of non-standardized proprietary interfaces to closed systems that were neither extensible nor portable.

"Conventional methods of proprietary data and components have distinct disadvantages in terms of interoperability and integration, and do not allow much flexibility in cost and scalability". (Sengupta et al, 2002)

4.6.1 The 'Geographic Application Server'

The application server as mentioned previously, is a vital part of LBS and mobile GIS, and acts as a management system for all the data involved. For a successful LBS it is important that there is an advanced geographic application server that is able to provide many of the capabilities listed below:

- **Rich functionality**: The range of applications listed earlier must be supported. At a minimum the following services must be available: high quality mapping, geographic and attribute queries, data download, gazetteer, proximity analysis (i.e. find closest object of a given type), geo-coding, and routing.
- **Good performance**: Performance is critical for application servers of this type because they must be able to process many requests simultaneously and potentially millions of requests per day.
- **Scalability**: This includes the ability to deal simultaneously with both very large data sets and very large numbers of application requests (e.g. thousands of users requesting routing across the whole US street database of 37 million streets). It must also be possible to add processing capability without interrupting operations. As a rough guideline a medium sized database is approximately 200 Mb – 1 Gb, a large data base is 1 – 10 Gb and a very large database is greater than 10 Gb.
- **Extensibility**: For all organizations the transition to mobile applications is very new and no one can foresee long-term future requirements. It is essential, therefore, that application servers can be extended to support new services and increased numbers of users.
- **Reliability**: Because geographic services need to be available 24 by 7 they must be robust and reliable. The use of commercial off the shelf technology such as standard hardware, GIS and DBMS software configurations provides this reliability.
- **Standards-based**: Although wireless systems are still immature and are developing rapidly, standards such as XML are beginning to emerge. Building systems based on these standards will help ensure compatibility with future systems and applications. (Maguire, 2003)

4.7 Configurations – What to consider!

There are many factors that enterprises need to consider when planning an end-to-end mobile, wireless solution:

"Application. What are the data flows and connectivity requirements of the specific application? Does the usage model require the device to connect intermittently and synchronize data such as e-mail or e-commerce transactions? Where is the data located, on a PC or a corporate server? Does the device need to remain connected while using an application (i.e., one with a thin-client or Web-based architecture)?

Connection type. How does the device need to be connected to information or applications (i.e., PAN, LAN, WAN)? Will the user be within 30 to 100 feet (PAN), 500 feet (wireless LAN with walls) or three-quarters of a mile (wireless LAN without walls) of a wireless connection, or will a wide area cellular network be appropriate? Is satellite connectivity necessary for remote or devastated environments?

Coverage. Where connectivity needs to be available: in an office environment, regional environment, nationally or globally? Which air link is most appropriate given the geographic location of the mobile professionals? Does the organization's wireless carrier offer the appropriate air link?

Throughput. How much data needs to go over the air link? WAN solutions such as CDMA and GSM provide throughput up to 14.4 Kbps, CDPD provides up to 9.6 Kbps. The next-generation WAN, GPRS and will support between 28.8Kbps and 128Kbps throughput in different regions. The third generation (e.g. UMTS) will support throughput between 300 Kbps and 1 Mbps. For PAN and WLAN technologies, throughputs range from 720 Kbps to 11 Mbps between Bluetooth, 802.11FH systems and 802.11b high-speed DS systems.

Security. Authentication and encryption are two key security areas to evaluate. Is there a power-on password on the device? Is the secure sockets layer (SSL) technology supported for accessing secure Web sites? Is strong encryption (e.g., 128-bit or elliptical curve) supported over the air link? Is the connection between the device and either a Web server or a corporate data server encrypted over the entire end-to-end route? Is there software that helps ensure that viruses don't pass through the device into the organization's network (e.g., attached to e-mail)?

Cost. Based on the data usage model, what is the expected monthly cost of the air link? Packet-based networks that charge based on the amount of data transmitted can be expensive. Rate plans that provide a flat monthly rate for all the data to be transmitted are preferable. If connectivity needs are localized to a permanent site, WLAN technology should be considered because there are no per-minute or monthly charges. The reduction in monthly fees quickly offsets equipment costs.

Power management. Does the modem or peripheral that provides wireless connectivity draw power directly from the device's battery? Based on the usage model, how much power does it draw during a normal working day? Is there time to recharge the unit when the device isn't being used? Is it possible to maintain two batteries per device that can be switched when work shifts take place?

Notification. Do users need to be notified of new information during the day? Can notification be sent to a device when it is powered off? Can a cellular phone or pager be used to notify a mobile professional of new information instead of sending it directly to the mobile device?

Form factor. What size characteristics are important for the mobile device? Does it need to be rugged (e.g., able to sustain a drop without breaking, withstand broad temperature ranges, operate in rainy or dusty environments), look business like or have an integrated keyboard? Does it need to be the size of a phone, personal digital assistant (PDA) or Handheld PC?

Services. What types of services do the mobile professionals need? Do they need Internet access for Web-based applications, e-mail, remote access to client/server applications, thin-client application access, and remote synchronization for updating a personal information manager (PIM), or instant messaging?" (Microsoft, 2003).

The above are all important considerations to make before beginning development of such a mobile system, whether it be for fieldwork or business purposes.

4.8 Application Development

4.8.1 Analysis

The analysis phase of prototyping involves a description of the problem and specification of all of the requirements. "To facilitate the process there exist several different modelling languages and methods, however the main objective for any analysis tools should according to Hojdalsvik and Sindre (2000), be problem orientation, i.e. a tool that helps focus on the problem and not the solution."(Thompson, 2003)

4.8.2 Design and Prototyping

Design

One of the most important stages when developing software is during the design phase. It is during this time that all the necessary details regarding the requirements, structure and actions are dealt with. During the earlier analysis phases much of the software is still in the imagination of the designer however during the design phase imagination becomes reality. Due to misunderstanding this is often the point where many problems arise.

Described in the Delta method, the *Analysis* and *Design* processes contain the following phases: (Delta Method, 2002)

- System definition
- User profiling
- Task analysis
- Design preparations
- Setting usability requirements
- Conceptual design
- Prototype design
- Usability testing and evaluation
- User Interface Implementation

Each one of these steps has it's own purpose and plays a major part in the effective design of any system.

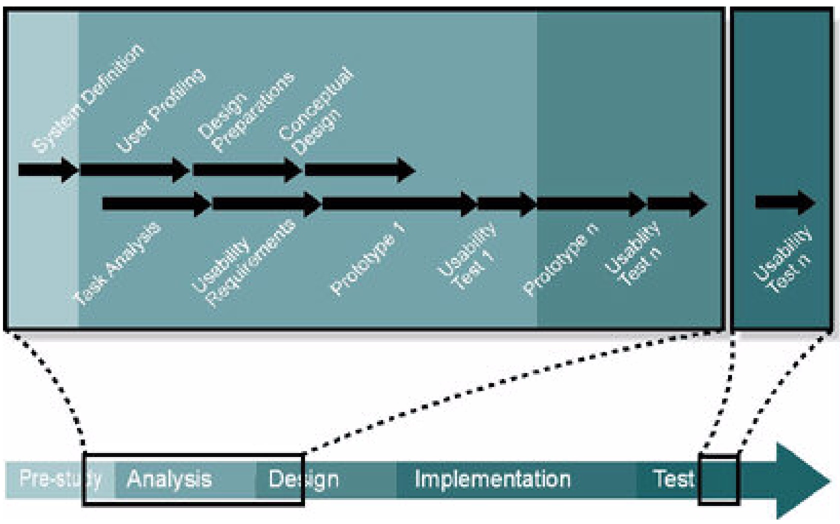


Figure 4.6 Shows the integral steps that should be used during the design of any system. (Source: *Delta Method, 2002)*

According to the Delta method this involves performing a detailed analysis of the system's planned functions in relation to the users' needs. Furthermore, it is important that one or more prototypes of the system describing the interface should be designed.

Prototyping

A prototype is a simplified model of a system or parts of a system. This can be described as an iterative process that facilitates the communication between designer and user. It should be able to provide both parties with a concrete model of the systems capabilities. This iterative process of prototyping is shown in figure 4.7.

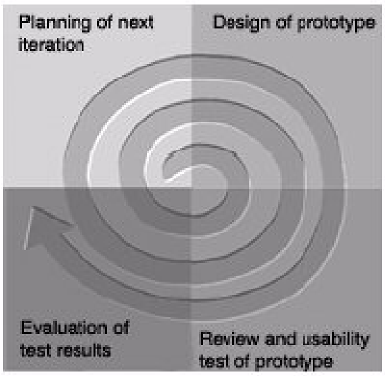


Figure 4.7 Model that shows the iterative process of prototyping design (Source: Delta Method, 2002)

'The purpose of prototyping is to eliminate the possibilities of uncertainty and misunderstanding, to achieve unity, or to verify a solution at an early stage of design.' (Delta Method, 2002) A prototype is designed to show the intention of what is being developed and is a first best guess of what the system might be. The more limited the scope of the prototype, the less formal the methods need to be thereby keeping costs to a minimum. This was a key motivation for building the prototype for the case study described in chapter 5.

Sommerville, 2000, defines prototyping as the rapid development of a system. As he states, in the past the developed system was normally thought of as inferior in some way to the required system, so further development was required. However, the boundary between prototyping and normal system development is blurred and many systems are now being developed using an evolutionary approach. Prototyping can be classified into two main categories, either 'evolutionary' or 'throw-away'. In evolutionary prototyping an iterative approach is taken. During this an initial prototype is produced and then refined through a number of small stages until a final system is reached. Although this option has the advantage of not wasting time, it also runs the risk that the developers may fix on a particular solution rather than exploring alternatives. With throw-away prototyping the main aim is to produce a prototype which is a practical implementation of the system. This is then used to help discover requirements problems and thereafter it is discarded. The system is then developed using some other development process.

The ultimate objective of evolutionary prototyping is to deliver a working system to end-users, whilst that of throw-away prototyping is to validate or derive the system requirements. The two different approaches to prototyping are illustrated in figure 4.8.

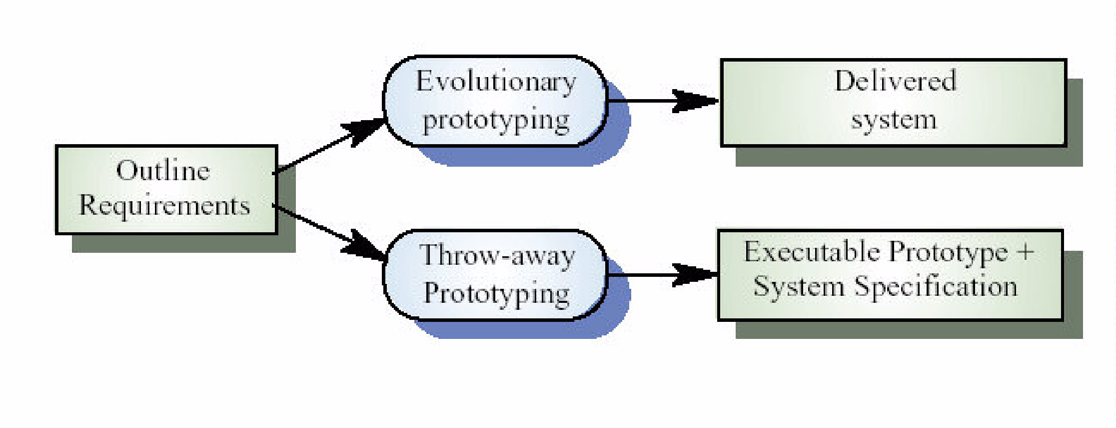


Figure 4.8 Shows the 'Evolutionary' approach compared to the 'Throw-away' approach to Prototyping. (Source: Sommerville, 2000)

4.8.3 Hardware and Software Components

Hardware

The mobile field client is faced with a variety of challenges and problems in the field, these ranging from its need for robustness to its battery life. Robustness is one of the major challenges facing data collection tasks in the field, because as soon as the user is in the field he is exposed to a range of environmental and hazardous factors, which could damage the device. Handheld computers have not yet been designed to be hardy and rugged enough to withstand the knocks and bangs faced in the field.

The new generation of light-weight hardware and mobile software systems along, with positioning technologies, will make data collection in the field much more feasible and easier to use. A problem that is likely to arise however is that due to the pace at which technologies are moving and add on hardware components are being developed for mobile devices, the devices themselves are likely to run out of ports that can be used to plug the add on hardware into.

Software

Not only have the data collectors become smaller, lighter, and less expensive, the software has become cheaper and easier to learn. This new generation of software has become significantly more affordable and offers various options that can be used for their applications. Furthermore, most of the new generation software allows the user flexibility to utilise any type of GPS engine, and has the capability of reading from 2 serial ports, allowing the user to use a GPS receiver as well as an additional sensor. The latest software applications can also accept digital camera input.

‘Once the location, features and attribute data have been collected, all of the data can be exported in different GIS formats, such as ‘shape files’. Because most of the latest software applications have a version available for Windows as well as a Pocket PC operating system, this results in a much shorter learning curve’ (Wadhwani, 2002).

4.9 Conclusion

Combining the concepts and technologies of mobility with the mobile-Internet and positioning systems, as well as the new paradigms with regard to monitoring and the information age, has created exciting new opportunities for location-based technologies and services (LBS). With the knowledge that this is a new and exciting exploratory field with so many applications still open for exploration, man’s imagination is the biggest limiting factor with regard to what can be accomplished.

In this chapter the idea of an integrated data collection system designed for acquiring, storing, displaying and transmitting environmental and geo-positional data during field campaigns was presented. The purpose was to highlight the possibilities of customizing configurations and user interfaces (tailor-made) to be specific to an application’s needs as well as to eliminate the time consuming process of using paper forms and maps in the initial stages, only to recapture the data in a digital format at a later stage. The importance of location and context awareness has shown how valuable location specific information can be in a mobile field environment.

This type of approach provides a time saving solution that assists in conventional data collection tasks (automating some aspects of data entry and assisting in others). It also adds some novel utility to the field-workers job (e.g. a map display showing current location and data collection sites).

All of these advances have made the GPS/GIS data collection tasks easier, more economical and faster to complete.

5. EXPLORATION INTO THE USE OF MOBILE GIS DURING FIELD CONTROL: A TAILOR MADE MONITORING APPLICATION FOR THE WATER BOARD OF ZUIDERZEELAND.

Keywords: monitoring, mobile, handheld computing, GPS, GIS, data capture.

5.1 Introduction

Modern field walking surveys and controls have become increasingly labour intensive because more stringent demands are now placed on the precision and accuracy of field recording techniques (Leusen & Ryan, 2002). Field measurements for water quality control still largely depend upon the pencil and paper field notebook for data collection. However, recent advances in scalable wireless telecommunications and the proliferation of hand-held computing devices have enabled the development of software tools to assist fieldworkers in the collection of spatially referenced field data.

This chapter first describes a case - the role of control related and geo-location data collection at one of the water boards in The Netherlands. The chapter then examines the processes involved in developing a relatively inexpensive 'Tailor-Made', data collecting prototype with a simple interface that enables users with an average level of IT knowledge, to easily set up field runs used to collect field data.

All of the steps, from design to implementation of a custom built (Tailor-Made) water quality data collection and analysis prototype are documented. The prototype was integrated with GIS software on a handheld computer for easy use in the field. Also documented is the analysis and testing phases, during which further functions are investigated with an aim to expand the list of tasks to which such applications could be applied to within the water boards general administration structure.

The structure of the thesis is reflected in the structure of this chapter. The first part (Sections 5.1-5.5) provides an overview of the study as a whole. Stage 1 (Sections 5.6 – 5.9) takes a comprehensive look at the context of the study. It explains the role and tasks of a Dutch water board and how these tasks could be aided by the use of mobile GIS. Stage 2 (Sections 5.10-5.17) reviews the design and development of the prototype, describes all of the processes that were involved, and concludes.

5.2 Context of the Case Study

Over the last few decades The Netherlands has experienced an array of problems concerning the contamination of its surface water. One of the main causes of contamination has been the negligence and/or lack of awareness concerning environmental matters in agricultural practices. Much of the contamination caused by agriculture originates from pesticides and fertilizers that are incorrectly applied to farm lands. Fortunately, awareness has increased over the last few years and regulatory actions are being taken by government agencies to address water contamination issues. The Lozingenbesluit Open teelt en Veehouderij policy (described in section 5.7) is one of the new regulatory measures implemented by the Dutch government to control water contamination issues and has been chosen as the target problem for this case. The investigation focuses on the use of mobile GIS and mobile ICT technologies for improved control of the policy by the water board of Zuiderzeeland. The prototype system aims to improve current control techniques by optimizing the use of spatial data and maps in the field and by streamlining the process of data capture using tailor made data collection forms.

5.3 Brief Description of the Problem

This case study revolves around the central problem of the thesis - poor use of spatial data when carrying out fieldwork in an environment where valuable spatial data is usually unavailable. Field measurements for water quality control, and more particularly agricultural control, still largely depend upon the pencil and paper field notebook for data collection. In current practice hard copy forms are used to log the findings through the various pre-processing steps. The information is later transferred from the forms into a database management system (DBMS). It is at this stage where a certain number of errors, omissions and illegal entries is unavoidable because maps may be incorrectly interpreted or outdated and hard copy forms cannot prevent erroneous or illegible entries. Further errors may arise where the procedure requires a transcription step.

The primary aim faced by the water board is to become more effective and efficient with their collection of geo-referenceddata, resulting in more efficient and time saving procedures at both control and administrative levels.

5.4 Objectives of the Case Study

The case study is carried out with the Regional water board of Zuiderzeeland, Flevoland in The Netherlands. The activities of the government Service for Land and Water Management and their responsibilities for controlling the Lozingenbesluit Openteelt en Veehouderij decree are the primary focus points for the case study.

The Mobile GIS will ultimately improve the ability for field workers to have access to spatially geo-referenced data and allow the input of valuable spatial and tabular information into a database while in the field using a handheld device and positioning technologies (GPS).

The case studies main objectives are to:

- **Develop a prototype based on PDA, GPS and GIS technologies for the mobile collection of water quality information during field control programs.**
- **Investigate the need for further functionalities of the system in order for mobile GIS applications to benefit control procedures even further.**

The objectives of the mobile software application to be developed are to:

- **streamline the data collection process,**
- **allow for more efficient and reliable data to be collected whilst in the field,**
- **allow for simpler and less expensive data collection and analysis procedures that can be made position specific,**
- **improve the accuracy of quality control during field control programmes,**
- **optimize the use of spatial data whilst in the field.**

The integrated system will include automated control processes for the control of agricultural regulations implemented to improve surface water quality as well as mobile geographic information software. In addition, wireless Internet technologies for allowing users to share data as well as have access to and transfer of useful data in the field is incorporated. This is seen as both a conceptual and realistic method of working with spatial data in a mobile environment.

5.5 Methodology

As is the case with any prototype-development project, it is important to try to solve a problem that exists in the real world. It is only through a process of activities and their associated results that this can be achieved. "There are four fundamental phases or activities common to all software processes.

Software specification. The functionality of the software and constraints on its operation must be defined.

- **Software development**. In order to meet the requirement of the specification the software must be developed.
- **Software validation**. The software must be validated in order to ensure the users requirements are met.
- **Software evolution**. The software must evolve in order to meet changing user needs." (Sommerville, 1995)

The scope of this thesis involves the development of two different prototypes. One is based on a working PDA application that users will be able to take into a working environment and test. This prototype is PDA based and used for the collection of spatially referenced and GPS data in a mobile environment. The other prototype is purely conceptual and offers all of the functionalities that the PDA application does, however it also shows some potential added functionalities such as the integration of wireless communication for the transfer of data when in the field. The PDA based prototype however, is the main focus of this case study. Presently this prototype has full performance but limited functionality compared to the conceptual prototype. The conceptual prototype on the other hand has full functionality but only has potential performance.

STAGE 1

5.6 Background to the Water Board of Zuiderzeeland

The water board of Zuiderzeeland is one of many water boards in The Netherlands. It is located in Lelystad, the capital of the province of Flevoland and is responsible for the management of all water related issues on both the Flevopolder as well as the Noordoostpolder. Figure 5.1 below illustrates the extent of the area that the water board of Zuiderzeeland is responsible for administrating.

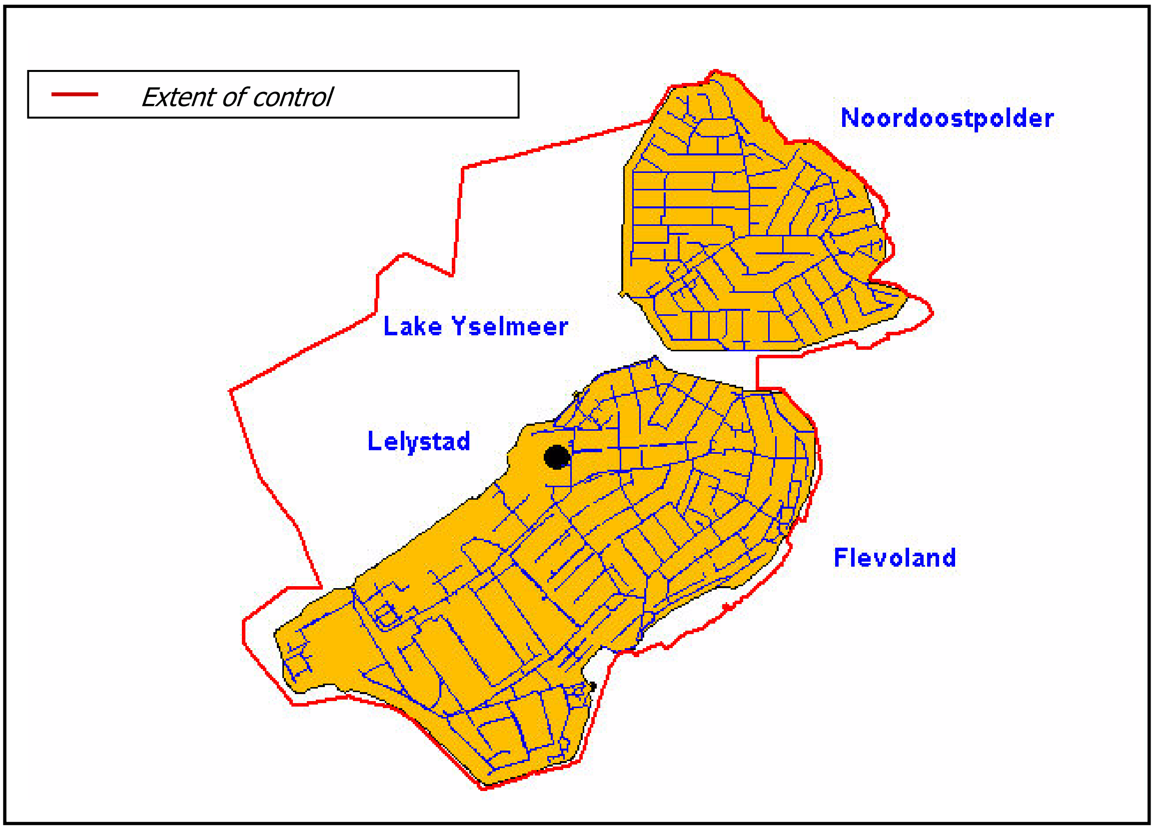


Figure 5.1 Shows the area administered by the water board of Zuiderzeeland

5.6.2 Current Control Structure Within the Water Board of Zuiderzeeland

The water board shares the task of ensuring water quality together with the General Inspection Service (AID). Together they are responsible for the enforcement and observance of the Lozingenbesluit policy.

Specially trained staff from the emission control and water quality departments of the water board have been responsible for field control for many years. Until recently these staff have been responsible not only for performing field controls but also many of the necessary administrative tasks once back in the office. As shown in table 5.1 below, this can result in a lengthy and time consuming process. Control prior to the development of this project consisted of a number of steps, including the preparation, collection, digitising and processing of the collected field data. Each water board is responsible for their own involvement and order of work relating to their responsibilities with regard to control.

Table 5.1 provides a description of the steps taken by the water boards for administrating the Lozingenbesluit policy.

Step 1: Gathering of Data
The first step is the collection of information or data. ***Address Collection*** The collection of addresses is necessary for, *inter alia*, record keeping, duty to report and/or licensing duty. Addresses are entered into the system once and thereafter are only occasionally changed. ***Crop Data Collection*** Crop information is necessary for laying down the rules that apply to the teeltvrije zone as well as to spraying techniques. This is data that will change on a yearly basis.
Step 2: Field Controls
Once the most necessary information and data has been collected it is possible to carry on with the field controls. There are many water boards who have worked in combination with other water boards in this initial stage of field control and data collection. In this first phase informal household visits are made, during which the report forms are explained and/or filled in together with the farmer. Through these inspections and/or household visits, maps of all of the known areas can be created. The frequency with which this data changes, is dependent on the frequency of the visits by the water board.
Step 3: Updating of data
Depending on the results of the field visits, the existing data gets changed/updated or collected. Because this data was collected on paper in the field it has to be recaptured digitally in the office.
Step 4: Printout results
It is often necessary to produce a letter after completion of the data collection. This letter may be a fine or it may just contain the information necessary to inform the farmer of the measures that still need to be taken with regard to the water board's rules. It is also necessary that this information be printed for the management of the AID.

Step 5: Set Priority for the Maintenance Plan
Once all the data has been obtained and the necessary information has been issued to the farmers, it is possible to begin with the necessary maintenance. A maintenance plan must be set up. The priorities of the plan depend on the water board.

Table 5.1 Current process during control of the Lozingenbesluit, (Buschgens, 2001).

5.7 Background to the Lozingenbesluit Open teelt en Veehouderij

Man's use of land for his many needs is placing ever increasing pressure on freshwater resources. This has led to increased demands on policy and decision makers at international, national, regional and local levels to develop sound fundamental strategies and solutions (Maasdam, 2000). It is for this reason that the Lozingenbesluit decree was created.

During recent years water boards in The Netherlands have started pursuing many measures with regard to surface water quality and the pollution of water bodies. One area where the effects of human use on surface water are strongly evident is in the agricultural sector, including cattle farming. Investigations carried out by local government authorities have led Dutch regional water boards to conclude that the concentrations of chemicals (pesticides) and manure fertilizers in many bodies of water strongly exceed the water quality standards.
In particular, high concentrations of plant pesticides can have very harmful effects on aquatic life. It was thus decided that it was necessary to set out rules and regulations which could be implemented in problem areas in order to reduce the amount of pollution reaching surface waters.

On 1 March 2000 the Lozingenbesluit Openteelt en Veehouderij decree was set in place. This policy aims to reduce the amount of plant pesticide and manure matter in surface waters. The main purpose of the policy was to improve the overall quality of surface waters in the Netherlands. The Lozingenbesluit is based on the Dutch Law on the pollution of surface waters (Wet Verontreiniging Oppervlaktewateren (Wvo)) and the Bestrijdingsmiddelenwet (Bmw), a set of general rules based on pesticide emmissions that need to be adhered to.

5.7.1 The Nature and Cause of the Problem

Contamination of surface waters by pesticides and manure matter arises from, *inter alia* washout, run off, and mis-spraying of land bordering canals. "In areas where fertilizers are used intensively, leaching of nitrate into the groundwater can rise to over 30% of the total added nitrogen. When manure is used instead of artificial fertilizers, the washout of nitrogen will be even greater, due to the washout of both mineral nitrogen and organically bound nitrogen (Vellinga, et al, 2001)". The volume of these emissions is not great relative to the overall flow of nitrogen and pesticides into surface waters, but they can very often be the causes of temporarily high concentrations in the surface water. It is these peak concentrations that can lead to harmful effects on aquatic organisms as well as the continuous loading of these substances on the land and the resulting modification of the ecosystem that is the main problem. Aside from the harmful effects on aquatic organisms and changes to their ecosystems, emissions of agricultural pesticides and fertilizers lead to great expenses for many of the water purification companies responsible for making water suitable for drinking. It is this pollution of surface waters that led to the creation of the Lozingenbesluit Openteelt en Veehouderijpolicy .

5.7.2 Process Description of the Lozingenbesluit Open teelt en Veehouderij Decree

The Lozinginbesluit is directed at trying to prevent the high concentrations of pesticides and nitrogen that have been experienced in the past from recurring in the future. As a result together with the interests of the agricultural organizations and the water boards, a number of measures have been created to restrict pesticides and manure emissions reaching surface waters. The Lozingenbesluit contains several rules that apply to all agricultural activities and the water boards have thus been entrusted with the observance and control thereof. It is for this reason that the possible benefits that GIS could bring towards helping with the implementation of the Lozingenbesluit that the water boards are interested.

5.7.3 Description of the Regulations

In summary form, the Lozingenbesluit regulations aim to:

- Ensure a zone (teeltvrije zone) between fields and the water surface within which no growing or spraying of crops occurs.
- Prevent and limit various discharges of agricultural wastewater.
- Prevent the spraying of small canals and ensure a 90% rate of safe spraying, i.e. spraying on land only.
- Prevent manure dressing of small canals and limit the run off of manure matter.
- Prevent and limit the runoff of polluted rain water from buildings and/or hard surfaces.

This project focuses on the teeltvrije zone. According to the Lozingenbesluit, if a parcel of land borders on any surface water (typically a ditch) it is necessary to ensure that there is a teeltvrije zone between the point of entry of the bank and the outside of the crop edge. According to the Lozingenbesluit it is this teeltvrije zone that should not be, either sprayed with pesticides or dressed with manure. The width of the teeltvrije zone is dependent on the kinds of crops that are grown and the spraying techniques used. Figure 5.2 shows an example of such a teeltvrije zone. Furthermore, spraying is only permitted with certain types of spraying nozzles, thereby minimizing the possibility for mist spray to go adrift and settle on any water surfaces.

Figure 5.2 Shows the 'teeltvrije' zone which must occur between the edge of the crops and the top-edge of the canal bank (on the left). No growing may take place in this zone (Source: Heuser, 2003).

The water board serves to ensure that the wash off and release of unwanted matters from agricultural businesses remains within fixed borders. It is for the maintenance of these regulations that the water board would like to make use of mobile GIS.

5.7.4 The Land Users

The 'Lozingenbesluit, Open teelt en Veehouderij' applies to the following land users:

- Crop farmers
- Flower bulb producers
- Vegetable producers
- Businesses involved in the production of flowers
- Tree growers – permanent trees, fruit producer,
- Cattle farmers

5.8 Introduction to the Basic Registration Parcel (BRP)

This project makes use of the Basic Registration Parcel System (BRP). Created by the ministry of Agriculture, Nature Management and Fisheries, the BRP is a spatially referenced database system created as an automated process for the registration of land parcels. This spatially referenced database has made control and access to up to date, parcel related information much easier resulting in minimized administration required by the water boards. The spatial and geo-referenced nature of the BRP data makes it suitableto be used in Geographical Information Systems.

5.9 How Mobile GIS and the Lozingenbesluit Open teelt en Veehouderij Can Work Together

In a strict sense a Geographical Information System (GIS) is an automated system for the input, management, analysis and export of spatial data. One of the characteristics of a GIS is the relationship between administrative and spatial data. This relationship offers the opportunities to perform extensive spatial and administrative analyses and queries independent of the extensiveness of a GIS's capabilities.

While mobile GIS are relatively new, desktop-based GIS have been used for some time with the water boards. One example of this is a GIS system, known as GISis that was developed specifically for use within Dutch water boards. Another more advanced of these systems known, as INTWIS is a GIS based system currently being used by several of the involved water authorities in The Netherlands. Its primary purpose is as a water management system. The modular and open architecture of INTWIS is based on technical (ArcGIS, Oracle and business objects) and the spatial technical standards (Adventus) of the water managers. The INTWIS database acts as a water resource centre and contains all kinds of data related to water resources (including geographical data).

Until recently the water boards involved with the maintenance of the Lozingenbesluit were performing many of their tasks via e-mail, telephone or through orally interviewing the farmers. However, many of the water boards are now showing an increasing interest in going active with mobile GIS to implement the Lozingenbesluit. In an attempt to get GIS incorporated at some water boards there are many small-scale experiments with GIS projects already underway and many of the water boards in the Netherlands are already using GIS in one form or another. In these initial stages most potential is seen through improving the data collection process as well as optimising the use of spatial data while in the field through projects similar to this one. This interest derives from the benefits that mobile GIS systems convey and benefits that are being experienced at other utilities.

STAGE 2

5.10 Development of a Digital Fieldwork Assistant

The aim of this project was to develop a prototype that could be presented to and tested by the intended users. The project was from the onset strongly focused on design and implementation.

It can be difficult to specify adequate requirements on such an application in advance. Often the customer is not really certain of what they want until the real system is presented. With the aid of a prototype the intended users are provided with a better understanding of the intended functionalities of the system and consequently are capable of making better decisions on design improvements regarding the usability and function of the end result. Therefore using a prototype is a good way of decreasing the complexity of, and uncertainty concerning a problem as well as illustrating how we attempt to meet requirements.

We are mainly interested in prototypes for measuring the usability of a system, but the same prototype can very often be used for several purposes during a systems design. For example, one prototype can be used for testing the function and usability, and later on for marketing and training of the system.

The basic structure for this application is based on a previously developed test application (prototype) created by ESRI, The Netherlands. Both the existing applet and the developed application were developed in the 'ArcPad Application Builder'. The remainder of the application involved further developing the ESRI prototype to meet functionalities including the design and implementation of specialized forms used for the digital collection of data in the field.

Due to the enormous extent of the water board's administration area, a test area was selected within which this project was carried out. The test area known as 'section J' can be seen in figure 5.3 and consists of 87 parcels of land. Section J is located in a northwesterly direction from the city of Lelystad.

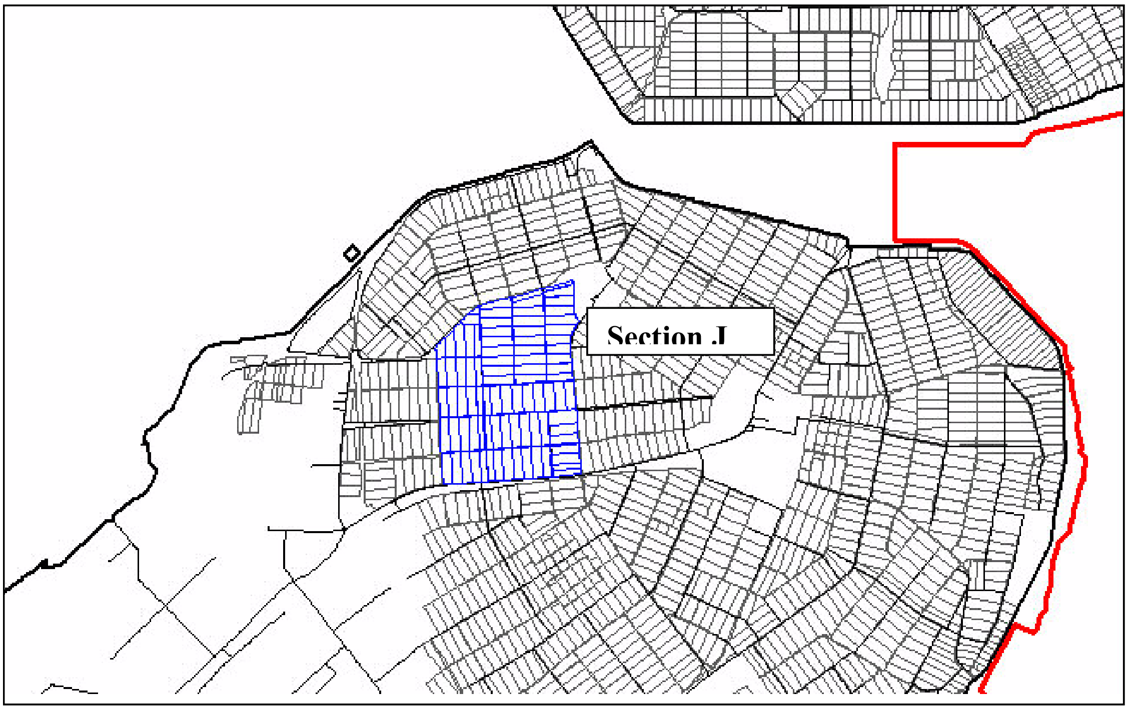


Figure 5.3 Test areas, 'section J', located North West of Lelystad.

5.11 Requirements Analysis

The requirements analysis aims to complete the overall system requirements specification by providing usability information. Unlike the system definition, in which the demands of the customer are analysed, *User Profiling* entails forming an understanding of the users, their present work situation, tasks and most importantly their needs. This was accomplished by going into the field with the inspectors and getting a feeling as to how they carried out their work.

5.11.1 Requirements of the System

It is vital that the necessary information for enforcement of the Lozingenbesluit policy is obtained in order for enforcement to be effective. Throughout this project the information needed during a field visit can be classified into two main categories within the organizational structure, these are:

- The information that is needed at a field control level;
- The information that is needed at a company control (administrative) level.

During a field visit, multiple actions need to be performed. To be able to make the right choices at a place of violation, license and maintenance-information is required. There is a certain amount of information that a controller needs to know when in the field and at the moment this information is not directly available.

Most of this information relates to the parcel that is being monitored. The most necessary data at field control level includes:

- Who is the user and the owner of a parcel (part of or whole);
- Which licenses and/or releases are given and/or further requirements are set;
- What is the maintenance history of the offender;
- Is the parcel checked? If yes, was the area where no cultivation should occur in order?
  What is the lot number;
- Is the ditch next to the parcel dry or wet according to concept wet/dry ditches map;
- Where are the discharge/draining points.

It is these types of questions that are so important to the controller in the field and having the answers available during field visits would considerably improve the whole process.
In terms of the regulation regarding the teeltvrije zone, which is of prime importance to the water board, the following information is required during field controls:

- Is the watercourse wet/dry? And in the case of wet:
- Is the teeltvrije zone 1.5 meters wide?
- Which crop is growing on the land?
- What was the date of the previous visit?

The next requirement of the system involves the ability for the user to generate a fine (boete) directly on the mobile device while in the field. This fine can then be given to the farmer who is responsible for the offence at the time of inspection.
This form can be printed from a vehicle-based printer or else e-mailed (conceptual prototype) to the farmer using wireless communication.

5.11.2 Hardware Requirements

Further user requirements centre more on the **hardware** that would be used in the field. Fortunately similar projects had recently been performed in which the same/similar hardware was used during other fieldwork programs. Some of the requirements that needed to be considered, included:

Pen User Interface – Using pen-based interfaces on a pad-like device with handwriting recognition would act as a substitute for writing notes on paper forms. And speed up the data collection process.

Small form-factor – It is necessary to use a small form factor on the device as the field worker may be burdened with a lot of other equipment. Ideally the device should be small and fit in a pocket or as close to that as possible.

Battery-life – Due to the timely nature of field work and data collection the user may be in the field for some time without being able to recharge the battery on the device. Therefore, the battery should last a day in the field (although battery packs can easily be replaced).

Robustness – Although it is not thought that the nature of the fieldwork will involve to much exposure to the environment, it is necessary that the device be able to cope with small knocks and bangs in the field. Protective covers can be used.

Connectivity – Regardless of wireless possibility of uploading of data, the device will have to be synchronised with a desktop computer. Therefore, a device that can be easily connected to a PC is necessary.

Screen-size – it is necessary that the screen on the device is not too small. It must be adequate for the user to view maps as well as forms. The screen should have a non-reflective surface enabling easy viewing outside.

Predetermined data entry field templates can be put together and then implemented in the field almost instantly.

Automated PDA input – Program logic that has been programmed into the input forms can automate some of the data entry; particular input into one entry block will dictate the input required for subsequent forms or entry blocks.

This application focuses on the digital collection of data on a handheld device through custom designed forms. The GIS aspect to this part of the application involves the geo-referencing of these forms to parcels of land stored as a map. Location is therefore an important aspect of the application.
GPS integration needs to allow for a number of functions, including:

- Navigation
- Track-logging
- Logging the exact co-ordinates of a problem for re-inspection

In order to meet these requirements it will be easier to integrate a connected GPS device to the handheld than to have a separate GPS device requiring manual entry of coordinates.

During the early planning stages many questions were asked and multiple options explored. Some of the key questions are listed below.

- What are the possible configurations?
    - PDA with GPS and possibly GPRS?
- How will the needed data be taken with into the field?
    - Off-line through synchronization or on-line, perhaps with GPRS?
- How do I process mutations in the data?
    - Off-line through synchronization or on-line through the use of GPRS?
- Is an Ipaq (or alternative PDA) sufficient or is there a need for a tablet PC?

5.11.3 Configuration

For practical reasons and due to time constraints, it was decided that the working prototype would incorporate the following technical aspects:

- The configuration did not require GPRS incorporation. A mobile device and GPS would be sufficient for the users' needs.
- A tablet PC was selected for this project because of the larger screen size and easier visibility in the field. The general usability of a tablet PC is better than that of a PDA, although beyond this the devices did not differ to much.
- Because it was decided not to incorporate GPRS, data would be taken off-line through means of synchronization. This meant that any mutations or changes to data would be stored locally on the device and thereafter downloaded to a desktop computer via synchronization (see Figure 5.4).
- For the time being this prototype focuses on the data capture process although allowing for increased use of the spatial digital data whilst in the field.

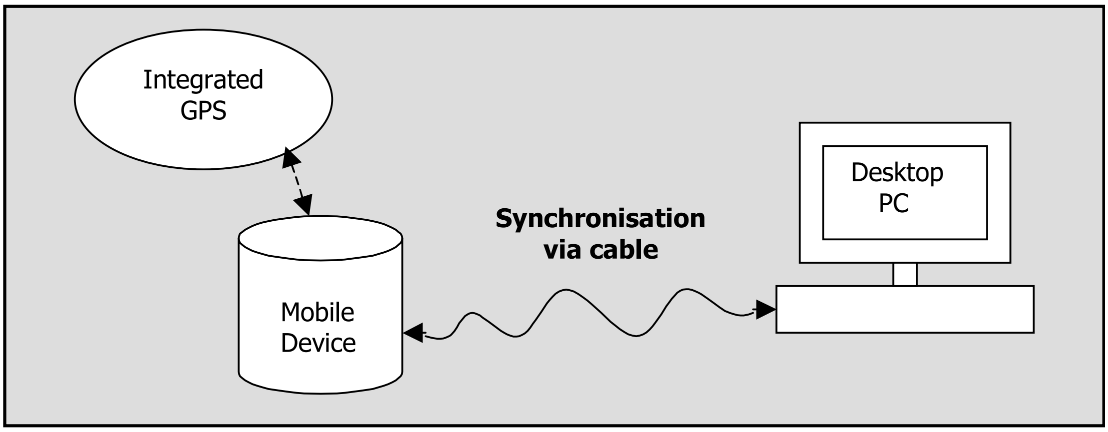


Figure 5.4 Shows the basic configuration that was used within the main prototype.

5.12 Development of the Mobile Geographic Information System

5.12.1 Database Manipulation

Mobile GIS implementation usually takes place on a PDA (personal digital assistant). Although a PDA is a cheap and convenient device for the open field, it has drawbacks: limited data capacity, 32 or 64 megabytes of memory, and low display resolution (320 X 240 display - preferably a colour screen). Databases that can be implemented in the open field have to be downsized and categorized on personal computers and then downloaded onto a PDA.

The data that was to be used in this system was obtained from both the water boards internal administrative database (MRPP+), as well as the BRP dataset obtained from the Ministry of Agriculture, Nature Management and Fisheries. Also loaded onto the PDA were a number of other layers or map files that may be useful to the user when in the field. For example, some of these include watercourses and roads. It is possible to include these as added layers and thereafter compare, analyse or even use for aided navigation, thereby making the whole decision making process easier.

5.12.2 Software and Hardware Integration

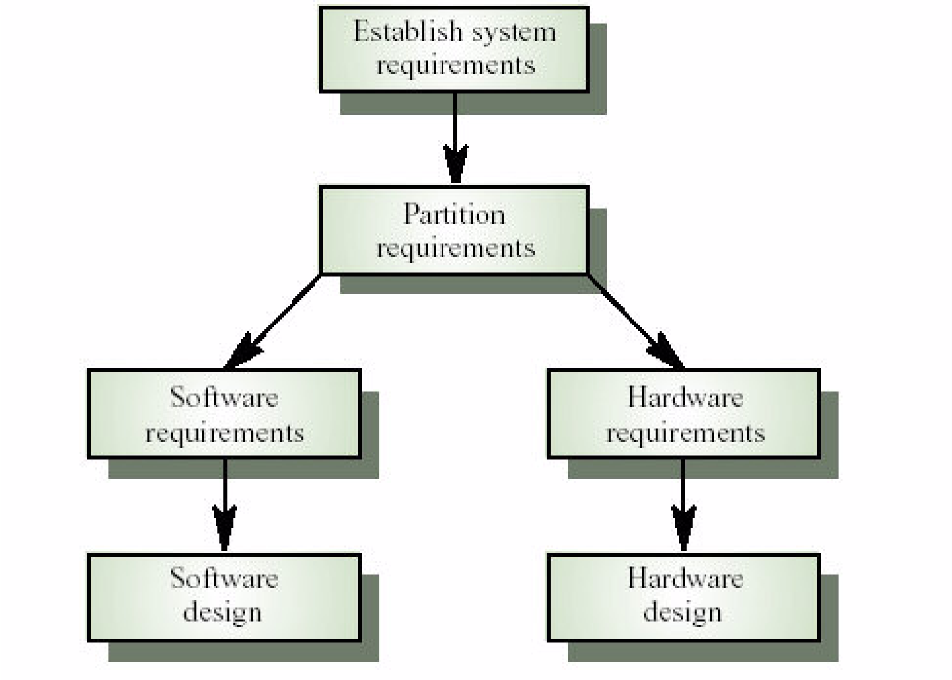


Figure 5.5 Hardware and software design.
(Source: Sommerville, 2000)

5.12.2.1 Hardware

The Siemens SIMPAD SL4 tablet PC, running Windows CE, was chosen as the preferred handheld client device. The reasoning behind this choice was purely trial basis. The device was provided in order to evaluate it's usability in the field. Field tests showed that the screen size on this device better suited usability in the field because forms and maps were substantially clearer on the larger screen as compared to the smaller PDA's. For general aesthetics, it must be noted that a colour display was used. Colour was also needed for display of colour photographs and in order to differentiate between different features on the device.

The SL4 came with a wireless connection (GPRS) card, which could be used in order to make a wireless internet connection, facilitating data transfer. This however was not incorporated into the main and final prototype. The device offered 64 MB of memory which, although could be insufficient in many circumstances the option for adding extra memory cards (up to 1 GIG) are available.

For positioning purposes a GARMIN 12 GPS (Global Positioning System) device was used.

Lastly a desktop PC with a cradle and data cable was necessary for the preparation and transfer of data between devices.

5.12.2.2 Software

The PDA devices used Microsoft Windows CE version 3.0. There are many different software packages available on the market for mobile GIS. ArcPad 6.01 software was chosen for the PDA, with this it was possible to integrate GPS and GIS in the open field. The main reason ArcPad was chosen was because of familiarity with this package during development of other applications. As a result it was felt that ArcPad was well proven and it would not be necessary to learn different software.

ArcPad 6.01 was installed on the PC and the mobile device. Synchronization software, such as Microsoft ActiveSync 3.0 or higher, must be installed on the PC in order to get data from the PC to the mobile device and visa versa. ESRI's ArcPad Application Builder was installed on a PC running with Microsoft embedded Visual Basic. This is the main program language for data base manipulation and paper works in a PDA device. The ArcPad Application Builder runs with ArcPad and is used to build the applications which, are later deployed to ArcPad. The data base management program for the device was Pocket Access. It is easy to convert an Access file with MDB extension into a Pocket Access file with CDB extension.
The data base file format implemented by ArcPad is DBF. The main databases were stored in Microsoft Access MDB format and SQL Server. DBF files can be converted directly to a pocket PC.

5.13 System Architecture

Figure 5.6 shows the system architecture behind the design and development of the final application. This application is based on two components, these being the *central system* and a *mobile client*. The central system contains all of the map data as well as an internal database (MRPP+). The internal database contains the administrative data as well as the BRP data set. The map data consists of .shape files derived from the BRP data set. In this diagram all arrows indicate some form of data transfer.

Due to several constraining factors, a client centred scenario was chosen. In this type of scenario the majority of the processing and storage is carried out on the mobile device (client) side, so the amount of information that a client can take into the field is limited. This is a result of limited memory on the devices (32 or 64 MB). It must however be noted that it is possible to store data on replaceable/removable memory cards capable of storing up to 1000 MB of memory.
Due to the limited memory capacity on the devices internal memory, a selection from the larger central system was necessary. The central system in Figure 5.6 refers to the central server. Only necessary data is taken into the field. Preparation is performed in the office prior to field work. The following paragraphs

provide an explanation of the technical aspects as well as the information transfer within the chosen architecture.

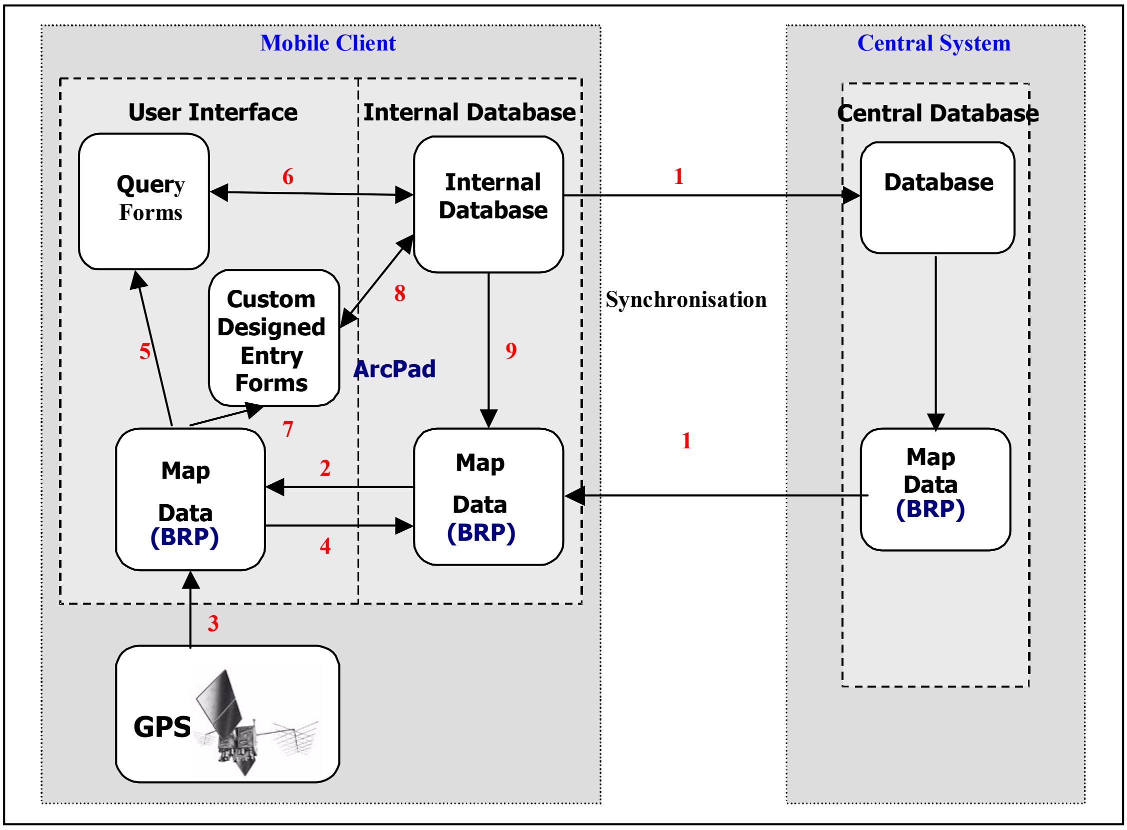


Figure 5.6 Shows the architecture that was used for the development of the prototype. All arrows are used to indicate some form of data transfer.

In the first step of this process, shown by **step 1,** the data to be used during a field visit is selected from the central system and transferred to the client. The transfer of this data is done via a cradle in which the mobile device is placed and a USB cable connects to the desktop computer, connecting the two devices.

The mobile device consists of two aspects, a 'user interface' and an 'internal database'. Data transferred during **step 1** is stored locally. Upon request from the user (e.g. a query for a parcel), done via a custom built tool, map data is made available to the user **(step 2)**.

The next step involves the custom built 'QUERY and ENTRY' forms. The 'QUERY' forms primary purpose is to provide information about the farmer and the piece of land to the user whilst he/she is in the field. The 'ENTRY' forms on the other hand are used to enter the collected and observed information during the field control. Both these forms are directly linked to features in the map data and upon selection of a tool in the user interface these forms will automatically appear containing parcel specific information. Individual query and entry forms that are used for data entry are linked or geo referenced to individual parcels. This provides

the user with information about the farmer. This is shown in steps **5** and **7**. Any attribute data that is either viewed or entered via the forms is stored locally on the device where it can be accessed at any time. This is shown via the reversible arrows **6 & 8** indicating that data can be transferred in both directions. Furthermore, existing data can be edited at any time. Data is transferred upon request from the attribute data to the map data within the database, shown in **step 9**.
Arrow 3, which is an external component of the system, shows the possibility for integration of a GPS. Coordinates from the GPS will be viewed directly on the screen in real time, with the BRP map as a background. The GPS may then be used for a number of purposes including navigation as well as allowing the user to log the exact position of an offence or irregularity on the farm. Knowing this exact position makes it easier and time saving for future check–ups on the problem area.

On completion of the fieldwork, once the user is back in the office, they can connect to the desktop and via synchronization, as shown in **step 1,** data is transferred back to the desktop PC **(step 10)** where further analysis can be carried out on the results.

5.14 System Development

All development of the system was performed in the ArcPad Application Builder. The Application Builder is used to personalise and customise the program to meet the specified requirements. The development is carried out on the desktop and then deployed to ArcPad that is loaded on the mobile device. The ArcPad applet, a small module that runs inside a full application was used to provide a way of delivering the map-independent mini-application without having to alter the programs configuration.

During development the tools offered in the Application Builder were utilised to create the required query and input forms that would be used during the data collection process. Fortunately, this is relatively easy in ArcPad as it provides a method of dragging the required buttons, labels, drop down lists, etc from a toolbox onto the forms. Because the user interface displays information on the screen and accepts data from the user it was important to make the interface easy to understand as well as to operate. By doing this you minimise the risk of the user being daunted by the thought of using your program.

Once the interface was designed and the required tools were selected the next step involved writing code that informed the program what to do in certain situations. The required code for ArcPad is based on Microsofts Visual Basic.

On completion of the development, the application was deployed to ArcPad loaded onto the mobile device whereupon it worked exactly the same as on the desktop.

5.14.1 Graphical User Interface

The ultimate challenge of designing such a system is making it as user friendly as possible. It was important to keep in mind that not all users would be experts in Information Technologies (IT) and therefore the interface would need to be relatively simple to use. This becomes even more challenging when the ultimate result will be viewed and used on a small device such as a tablet PC (although larger than a PDA). It is therefore necessary to ensure that everything is able to fit onto a small screen whilst retaining high levels of functionality. Figure 5.7 shows the complete interface that was developed along with all the toolbars and buttons created. The map is an example of the plots of land, waterways and boundaries that can be viewed by the user. Many different data sets can be overlaid on top of these maps.

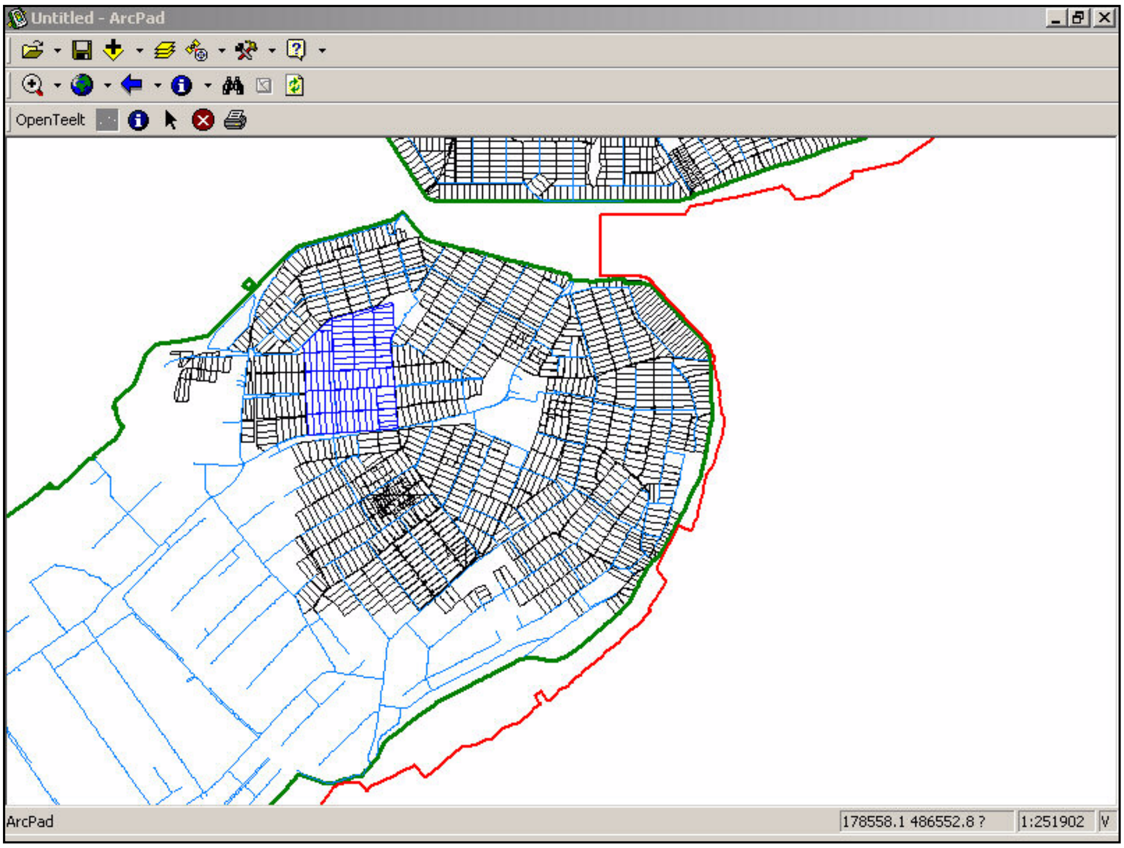


Figure 5.7 Shows the interface and toolbar buttons as well as the standard ArcPad toolbars created for the application. Displayed is a map of plots of land, waterways and boundaries.

If the applet is installed correctly, with the start up of ArcPad, one extra toolbar with 5 tool buttons should appear. This toolbar can be seen in figure 5.7 as the OpenTeelt toolbar. It must be noted that the first button (the GO button described below) becomes invisible once pressed.

Below is a description of these tools.

- The first button ensures that the. shapefile, "kadtest_arcpad" gets loaded and made 'editable'. Thereafter the second and third buttons can also be used.

- By activating the identify button and then selecting the required parcel of land, that parcels information can be called up enabling the user to view all recorded information relating to a parcel of land. This may be information collected on the day of inspection or it may be owner details that the water board already had stored.

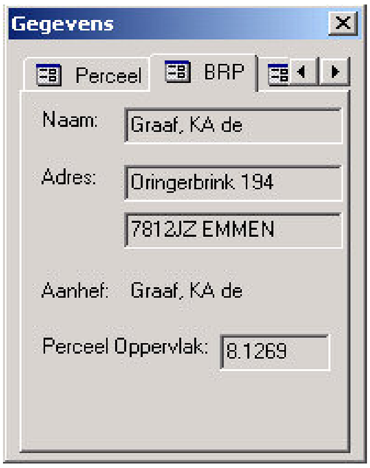
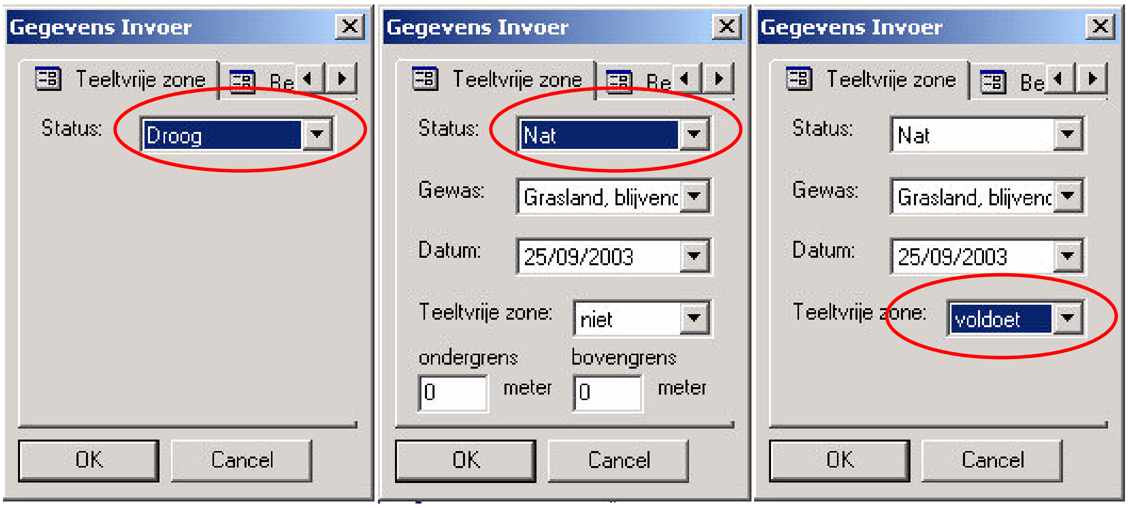


Figure 5.8 This figure shows one of the forms containing land user information.

- The third button allows the user to fill in data through custom designed entry forms. If the third button cannot be used and it registers a mistake it means that the data is not 'editable' and that the data is most likely 'read only'. The arrow button is used to call up the entry forms. These consist of 9 forms in total, each with their own fields for entry. Each form has options for yes/no or not applicable as well as a place for logging notes. The first of these forms related specifically to the registering of the teeltvrije zone, as shown below. Program logic is used so that particular input into one form will dictate the input required for subsequent forms. This is done to automate some of the data entry by using logic that has been programmed into the input forms. Depending on certain criteria this form would differ as to which fields need to be filled in and what values are applicable. For example, if the status of the canal/ditch is dry, further fields no longer apply and therefore are removed from the forms. However if the canal is wet all further fields remain to be filled in. The same applies to whether the zone meets regulations or not. This can be seen in figure 5.9 as well as in the demo provided in the attached CD. If the entered values are invalid then the user is notified of this and acceptable values are recommended. The remainder of the forms were based on the original hard copy checklists used. The original hard copy checklists can be seen in appendix A. These forms, as illustrated in figure 5.9 consist of entry fields and drop down lists.



1 2 3

Figure 5.9 Shows the three different scenarios that may apply to the registration of the teeltvrije zone. **(1)** – If the canal is dry then there is no need to monitor. **(2)** – If the canal contains water and the zone does not meet requirements then all fields are available for entry. **(3)** – If the canal contains water and the zone meets regulations then there is no need to fill in the values.

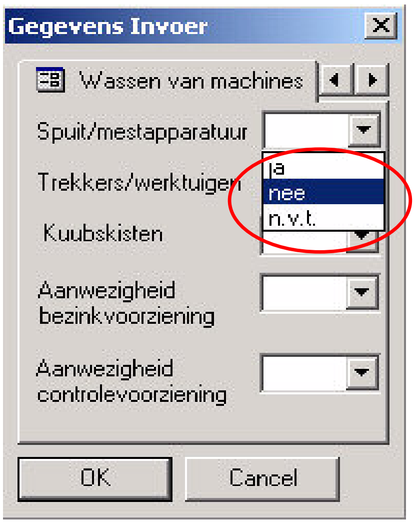


Figure 5.10 Shows an example of one of the general information forms designed for collecting specific information, this was based on the original hard copy checklists (appendix A).

- The third button is the standard exit ArcPad button that is used to exit the program.

- The fifth button, and one considered important in the context of this study, leads to an automatic generation of the fines as described in section 5.11. These fines are generated based on specific owner information as well as information that was collected during the field visit. The forms are stored as .html forms in a fines folder on the device. In the future these fines will be delivered via wireless internet connections to the farmer using e-mail.

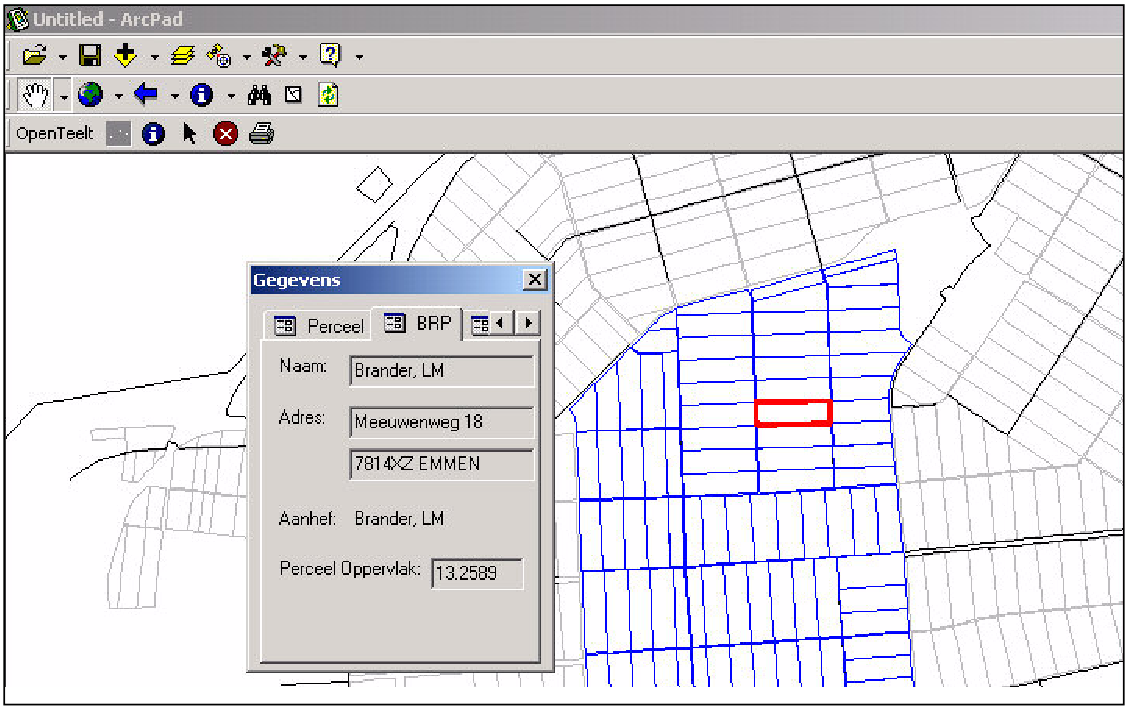


Figure 5.11 Gives an overall impression of the user interface and forms as the user would see it in the field. It can be seen how information is specific to a particular parcel of land.

5.15 Usability Testing and Evaluation

A very often overlooked aspect of prototyping is usability testing during which an evaluation of the prototype is made. Prototypes are produced to verify a function or to be demonstrated to the customer. Unfortunately during this project, time constraints were a limiting factor. As a result proper field-testing and evaluation of the prototype was not possible. However, numerous in house tests and demonstrations were performed, during which the system was demonstrated to the intended users throughout stages of its development. The usability experts evaluated the prototype according to general guidelines for how good user interfaces should be designed and whether or not all of the requirements were being met. The final results were pleasing to the intended users at the water board who have considered the system to be successful and see the potential such a system could bring to their fieldwork tasks. Due to the lack of time and opportunity to carry out such an evaluation properly, the necessary tests would be carried out at a later stage.

Based on previous fieldwork performed during other projects, where the same devices were used in a similar environment, it was possible to come to the following conclusions regarding how the hardware performed in the field:

- With minimal training and some GIS expertise it becomes easy for anyone to use the handheld device effectively.
- The devices were relatively easy to use although the larger screen size on the tablet PC was beneficial compared to that of a PDA.
- The onscreen keyboard is small but with practice it is easy to become comfortable using it.
- Provided used carefully the devices are relatively durable. Fortunately the nature of control meant that the devices were not exposed to extreme conditions, although it is recommended to have a protective cover in case of water damage.
- The connected GPS became awkward to handle, as it was quite large and only connected to the handheld device via a cable. This meant that the GPS had to be placed in the users pocket in order to use the device easily.
- Battery life was sufficient providing the devices were not left on when not being used. It is however recommended to take an extra battery pack into the field in case the battery does go flat.
- It was easy and fast to download the collected data through synchronisation to the desktop PC once back in the office. This saved the user the effort of having to sort and mange the collected information into their necessary locations.
- It was concluded that the developed system would be a valuable tool for the collection of field data during field control.
- Potential is seen for further development and interest in use within other departments.

5.16 Task-Oriented Application Modules

Customization and personalization are two primary reasons for implementation of ArcPad. There are many departments within the water board. Each of the departments has separate tasks that need to be performed in order to protect water resources. Very often task-oriented application modules are developed on a build-to-order basis in order to solve problems encountered at every department. It may however be more desirable that the application modules be developed to meet requirements at a individual level. With some manipulation of the databases, and redesign of input forms, development of application modules is possible. Therefore with training in one of the mobile software packages this would be possible in any organisation.

The same digital data capture used here could be applied to any of the departments in the water board with minimal effort and in a number of scenarios. Any task that involves the manual collection and use of information related to a spatially referenced map has the potential of benefiting from the use of some form of mobile GIS.

Other possible applications within the water board, include:

- General water control
- Strengthening of river dykes
- Water management
  - Water quantity management
  - Maintenance
  - Water quality management
- Pollution control
- Treatment of effluent
- Maintenance of the roads and waterways.

As long as there is a need for someone to collect and gather information in a mobile environment then such a tailor-made application has the potential to be used.

5.17 Conceptual Prototype – 'Wireless Scenario'

During the early development phase of this project, it was hoped that it would be possible to make use of the increasingly powerful 'server centric scenario'. The server centric scenario, also known as the 'thin client' centres on the server instead of the mobile client. In the server centric scenario all processing and data storage takes place on the server rather than the client and the mobile device acts as a means of viewing the data that is held on the server rather than data held internally. In order for data to be transferred between the mobile device and server some form of connection is necessary. Due to the mobile environment of this application, wireless connections, as described earlier in this thesis could be used.

An example of this is the GPRS card that is installed into the tablet PC. This would allow data transfer to take place through the use of wireless communication. The architecture behind such an idea is shown here in figure 5.12.

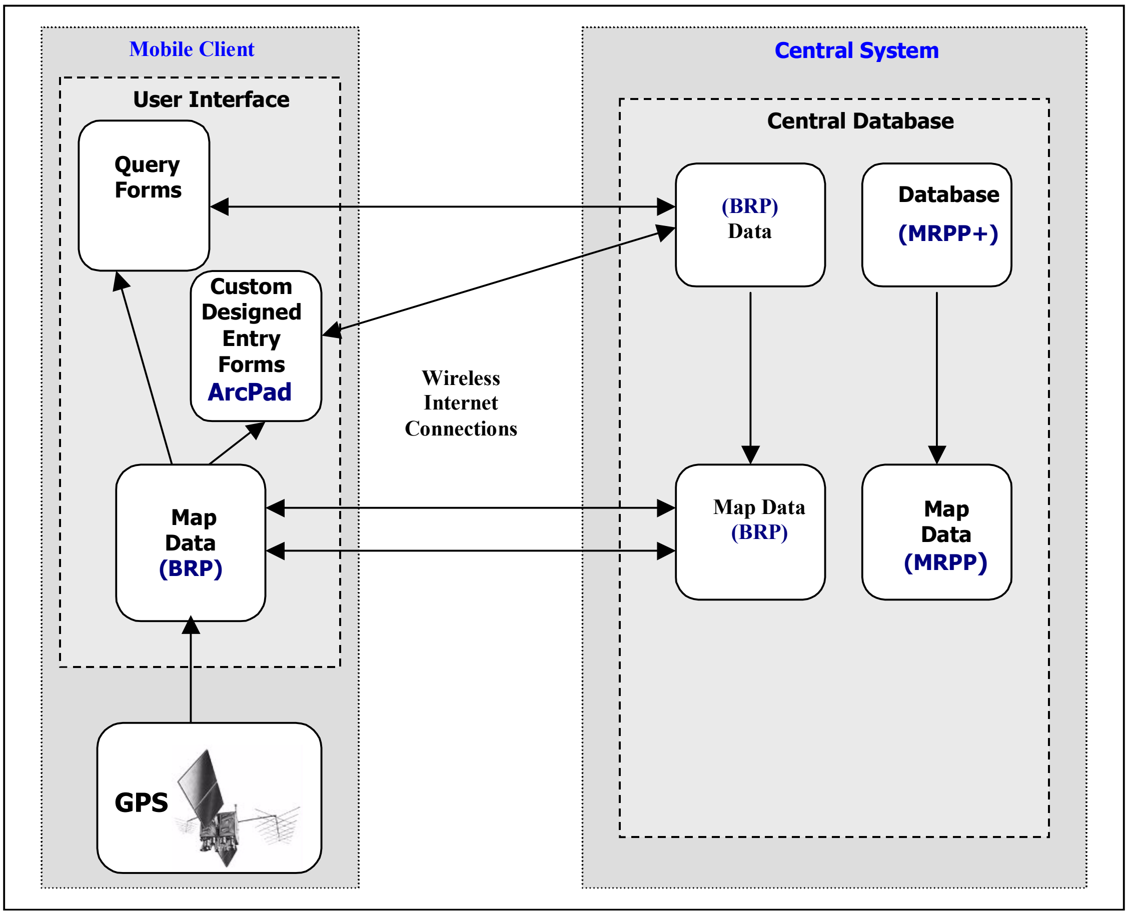


Figure 5.12 The architecture behind the conceptual prototype, in which a wireless component would be integrated in a thin client scenario.

It is obvious that the biggest difference between the two prototype scenarios is on which side (mobile device OR server) most of the processing and data storage takes place. A second difference is the method in which data is exchanged between the device and the central system. The scenario used within this project required no need for real time data exchange as data only needs to be loaded onto the device and thereafter all processing is performed locally on the mobile device. In the above case however, all processing would take place in the central system. There is a need for quick data exchange through a wireless internet connection.

Within this scenario a lot of focus is placed on the importance of having access to real time data as apposed to data that is old. At the same time though, due to the nature of the information required by the user in the field (owner and land information), this is not a vital necessity as this kind of information is not continually changing. The benefits are seen rather through the fact that the processing would occur in the central system as opposed to on the device, meaning less memory is required. More importantly though is the fact that collected data and mutations in data are changed in the central system all in real time. This means that if needed the controller would not need to return to the office for long periods of time as the water board would have access to the collected data as it is collected. Other benefits of the on-line

communication between personnel in the office and in the field, is that 'if newly collected data is rapidly mirrored to a remote server, it is possible to overcome the fear of losing data because a device may have failed in the field. Another advantage is that, messages and other data like maps can be transmitted to the user in the field in almost real time, as they are produced.
Fines can be sent immediately to the target groups via e-mail. This eliminates the risk of unwanted pollution and contamination from continually polluting the water ways while the fine is processed and then posted to the farmer, ultimately benefiting the environment.

The worry however is that the user in the field now relies heavily on the wireless communication working. Failure in the central system would also affect the field workers ability to perform his work effectively. A possible solution to this would be if the application were able to store locally, a copy of all the data that is sent. This at least would ensure that if there were a failure in the central system that there is a backup of the data stored locally on the device.

5.18 Conclusions

The objective of this case study was to develop a prototype based on PDA, GPS and GIS technologies for the mobile collection of water quality information during field control programs. This was successfully accomplished and the result was a system that showed the potential to be used in order to improve the speed and efficiency of field data management at the water board. Unfortunately due to time constraints the system could not be properly tested in the field. In house testing and demonstrations however, were successful and the intended users recognised the potential such a system could bring to their everyday work. The potential benefits that have been identified include:

- Maximising field worker productivity
- Driving down the costs of field operations
- Improving the accuracy of data
- Improving the service offered to the farmers
- Less post-processing of data necessary.

Proper testing would commence at a later stage.

The system's potential for easing navigation and the sharing of information via the use of wireless internet connections during control has not yet been fully explored. It is hoped however that further developments regarding functionality offered in the conceptual prototype could follow shortly.

6 Conclusion

6.1 Review of this Thesis

The purpose of this final chapter is to review the findings of this investigation into the world of mobile technologies and how these can improve monitoring programs. The findings of parts 1, part 2 and part 3 are discussed, ultimately evaluating the results in order to see whether this research answered the questions that were discussed in the introductory chapters.
In this thesis, the development of integrated data collection systems designed for acquiring, storing, displaying and transmitting the geo-positional data during field campaigns was addressed. The goal was to provide a more accurate, efficient and robust method for gathering data. This was accomplished by integrating new hardware and software components with new mobile communication technologies.

An effective method to assess whether or not an investigation has accomplished it's initial goal, is to see whether the objectives of the study have been met.

The objectives of this thesis were, to investigate:

- The current problems faced by fieldwork and monitoring programs with regard to access to information.
- The current state of mobile information and communication technologies, which make this fundamentally new information process possible.
- The added value of **location** within information services.
- The design of a system that is accepted by intended users as relevant and appropriate (case study).

6.2 Developments in Integrated Monitoring Systems

With the very complex nature associated with the monitoring of water systems, there has been an increasing need to integrate modern technologies for field data collection and management, with recent developments in water management as discussed in 'Exploratory Data Analysis in Water Quality Monitoring Systems'. Emphasis is placed on providing information for water management; however, often under considered is that, to provide high quality information, high quality data needs to be collected in the field. In order to provide information there has been a recent rise in the use of information technologies, including Geographical Information Systems (GIS) and mobile mapping, that are used to help manage, analyse and query spatial data sets in a mobile environment.

What is not always considered and is a problem that faces any GIS, is the process of data collection and data input. As discussed in chapter 4, costs of input often consume as much as 80% or more of project costs, and the whole data input process is labour intensive, tedious and error prone. As a result, focus in this thesis was placed on the need to improve the data collection stage of monitoring and fieldwork.

The developments and the technologies discussed in the preceding chapters have brought about a new revolution regarding field data management. These communication and simulation sectors offer new options to realise a fast and cost effective method for field data management and data collection. The surge of development regarding these technologies has meant that mobile mapping and computing has been incorporated into monitoring programs, thereby revolutionising the way in which fieldwork is carried out.

The 'Tailor-Made' scenario emphasised in this paper, comprised customising software and mobile ICT configurations to suite specific projects needs enabling fieldworkers to optimize the way in which they collect and use geographical data sets in a mobile context.

There are many different possible configurations that can be incorporated within these systems. Should the necessary protocols for wireless communication and data exchange not be available, the 'Tailor-Made' scenario can still be applicable through the customisation of programs, with tools and forms, for the improved collection of location-based field data. An example of this was illustrated in the case study.

Some of the mobile protocols discussed, such as wireless Internet connections (*described in chapter 3*), have enabled users to further share data by communicating between each other and/or a central system. In addition, the technologies discussed allow users to link real-time field data collection from various devices to a centralized data server located at a remote location.

The aim of this new paradigm to field data management is ultimately to streamline and optimize field programs. If the fieldworker has spatial data in the form of maps and notes available digitally, he/she is able to make more informed and better decisions in a mobile environment using GIS tools. The second element is that the data collection process is made more efficient through the use of tools and forms on which the data can be entered digitally and geo-referenced according to it's location. With this new format in which the initial, but vital data is collected, the intermediate steps of data input, where hard copy data had to be digitally captured and referenced, is now eliminated. This new method will both speed up the process, and provide more effective and efficient quality data for information generation.

These developments have opened the door for creating new applications that bring computing power to field scientists. For disciplines with an active fieldwork component, associating environmental parameters with a location is essential.

6.3 The Mobile-Digital Map

> 'Map making and geographic analysis are not new, but a GIS performs these tasks faster and with more sophistication than traditional manual methods do. While the most common product of a GIS is often presented in map form, the real power of GIS lies in it's ability to analyse' (Roy, 2002).

GIS could be described as the latest technology to pack up its data and take its capabilities on the road. The capabilities of mobile GIS as opposed to traditional techniques go a lot further than querying data for example. Today, mobile GIS bridges the gap between the office and the field with a direct physical link to the enterprise system. Mobile GIS offers:

- Use of existing data in the field
- Ability to add data from the Internet to your application
- Map Navigation using GPS
- Display and querying of data – Identifying and location of features
- Measure of distance, bearings and area
- Editing data amongst many more GIS functions.

The advantage is that there is no need to be at your desktop in order to perform these operations. It is possible to perform these functions whilst in the field or at the point of interest.

Technology has changed the role of a map from a static presentation medium to a dynamic and explorative medium (Maasdam, pg 79). This has meant that maps are no longer merely sheets of paper that graphically represent an area of land, they have now become an integrated component of the entire monitoring process, often within information systems like GIS's.
Maasdam notes that, 'Scientific Visualisation and Exploratory Data Analysis' creates a new tool-driven revolution that is likely to dominate research in those disciplines concerned with the spatial/temporal structure of our world. These tools both extend and amplify existing tasks as well as change the nature of the task itself.

Being able to take or access numerous maps in the field along with GIS software, allows the user to perform queries and analysis on this data whereas before, this was only possible in the office. Furthermore, using positioning technologies (GPS), a digital map can be used to aid in navigation to site specific problems.

6.4 The Future is Bright

The future of mobile and virtual GIS is bright and brimming with opportunities *(Diamond, 2004)*.

This statement has probably never before been as applicable as at present. Wireless Internet connections, have enabled internet GIS technology to open new paths for disseminating, sharing, displaying, and processing spatial information on the Internet. Currently, one of the biggest limiting factors is man's imagination itself. Although the technologies will keep on developing, we are now left with the challenge of trying to use these, in as many scenarios as possible.

Rapidly advancing trends are heading towards lower prices and faster speeds. This is going to facilitate new and widespread use of mapping technology and digital field tools. It will be possible to reduce the operating costs by implementing new payment methods through, inter alia, accessing and paying for GIS functionality on an as needed basis. This will make it possible for a wider range of people to make use of such technologies.

It can only be hoped that the development of mobile field tools will carry on advancing at it's current rate. This will undoubtedly increase the capacity to which digital data can be used to help with data management and the decision making process in a mobile context.

> *Thanks to the pioneering spirit of people like you, GIS is no longer confined to our offices. It is exploding into the hands of everyone (Diamond, 2004).*

7 References

- Anywhere You Go News.(December, 200). *UMTS Will Cover All of Europe by 2010*.
- Beinat, E. (2001). *Location-based Services: Market and Buisiness Drivers*.
- Bergner, K., Grosu, R., Rausch, A., Schnidt, A., Scholz, P., Broy, M. (1998). *Focusing on Mobility*. Institute for Information, Technical University of Munchen.
- Buschgens, A. J. B. (2001). *Gisinzet bij het Lozingenbesluit Open teelt en Veehouderij*. ESRI Nederlands.
- Castells, M. (1998). *Information Technology, Globalisation and Social Development.* Conference Paper. University of California, Berkely.
- Colofon. (2003). The Netherlands – A Natural Waterscape. Published by Unie van Waterschapen.
- De Jong, P. T. J. C. Van Rooy and S.H. Hosper. (1994). *Living with water: at the cross-roads of change*. Pages 477-493 in Proceedings of the international conference Living with water. Amsterdam, The Netherlands.
- Delta Method (2002): www.deltamethod.net
- Duffy, M. D., Assad, M. G. (1989). *Information Management: Strategy formulation and implementation*. Oxford University Press.
- Goodchild, M. F., Kemp, K. K. (1991). *Introduction to GIS. National Centre for Geographic Information and Analysis*. University of California, Santa Barbara. Third Printing.
  Harkey D., Appajodu S., Larkin M. (2003) *Wireless Java Programming for Enterprise Applications*. Canada: Ipsen R.
- Maasdam, R. (2000). *Exploratory Data Analysis in Water Quality Monitoring Systems*. Unpublished master's thesis. University of Salford, England.
- Mitchell, A. (2002). *Mobile Communications Technologies for Young Adult Learning and Skills Development*. ULTRALAB. P. 16-23.
- Ongely, D. E. (1993). *Global Water Pollution: Challenges and Opportunities*.
- Pascoe, J. Ryan, N., Morse, D. (1998). *Human Computer Giraffe Interaction: HCL issues in Fieldwork Environments*.
- Pascoe, J., Ryan, N., Morse, D. (2000). *Using While Moving: HCL Issues in Fieldwork Environments*. University of Cantebury. P. 417-437.
- Schetselaar, E. M. (2002). *Capturing digital data in the field – Geological field data capture using palm-based RDBMS and PC-based GIS*. Workshop on capturing digital data in the field, British Geological Survey (BGS).
- Simonis, I. (2002). *Optimisation of field data management using mobile GIS, wireless technologies and distributed simulation and visualisation systems*. Institute for Geoinformatics, University of Muenster, Germany. Also see WB
- Sommerville, I. (2000). *Software Engineering*, 6th edition. Chapter 8.
- Sommerville, I. (1995). *Software Engineering. 5th edition, Chapter 6*.
- The Pocket Oxford Dictionary of Current English. (1978). (Sixth edition). Oxford University Press.

- Thompson, E. (2003). *Integrating PDA, GPS and GIS Technologies for Mobile Traffic Data Acquisition and Traffic Data Analysis*. Unpublished masters thesis. IT University of Goteborg, Sweden.
- Timmerman, J. G (1)., Schobben, H. M (2). (1997). *Information Needs for Dutch National Policy Evaluation*. (1) Institute for Inland Water Management and Waste Water Treatment, RIZA, (2) Institute for Coastal Zone Management, RIKZ. The Netherlands.
- Timmerman, J. G., Adriaanse, M., Breukel, R. M. A. (2000). *Making Monitoring Tailor-Made in Europe*. Institute for Inland Water Management and Waste Water Treatment, RIZA. The Netherlands.
- Timmerman, J.G. , Hendriksma, (1997). Informatie op maat: een raamwerk voor waterbehher. H2O (30), 1997: 17, p. 528-530. (In Dutch, English abstract). Referenced from: Maasdam, R. (2000). *Exploratory Data Analysis in Water Quality Monitoring Systems*. Unpublished master's thesis. University of Salford, England.
- Timmerman, J.G. and W. H. Mulder, (1999). *Information needs as the basis for monitoring*. European Water Management 2 (2): 41-45. Referenced from: Timmerman, J. G (1)., Schobben, H. M (2). (1997). *Information Needs for Dutch National Policy Evaluation*.
- Toussant, N. A. (1998). *Using Mobile Data Management Systems for Increased Efficiency*. P.279-283. San Antonio.
- Townsend, M. A. (2001). *Mobile Computing and Communications: New Interactions Between Information Architecture and Infrastructure Use*. Taub Urban Research Centre, New York University.
- UN/ECE Task Force on Monitoring and Assessment, 1996. Working programme 1994/1995. *Guidelines on Water – Quality Monitoring and assessment of Transboundary Rivers* (volumes 1 to 5) Working programme 1994/1995 Institute for Inland Water Management and Waste Water Treatment (RIZA), Lelystad. Referenced from : Maasdam, R. (2000). *Exploratory Data Analysis in Water Quality Monitoring Systems*. Unpublished master's thesis. University of Salford, England.
- van Leusen, M., Ryan, N.(30-05-2002). Masters Thesis. Rijks Universiteit, Groningen, The Netherlands. *Methodological Investigation into the formation and Interpretation of Spatial Patterns in Archeological Landscapes*. Chapter 7: Educating the Digital Fieldwork Assistant.
- Vellinga, P., van Drunen, M. (eds.).(2001). *The Environment: a multidisciplinary concern*. Fourth edition, Amsterdam, Institute for Environmental Studies . pp, 289.
- Vivoni, E. R., Camilli, R., Rodriguez, M. A., Sheehan, D. D., Entekhabi, D. (1998). *Development of mobile computing applications for hydraulics and water quality field measurements*. Department of Civil and Environmental Engineering, Massachusetts Institute of Technology, USA.
- Wagtendonk, A. (2004) An analysis of computer assisted fieldwork through case studies; Development and use of digital fieldwork tools in an academic environment. Spatial Information Laboratory, Vrije Universiteit Amsterdam, The Netherlands.
- Ward, R. C., J. C Loftis and G. B. McBride, 1986. *The "data-rich but information-poor" syndrome in water quality monitoring*. Environmental Management, 10(3), p.291-297.
- Westlake, T. (2203). *Mobile Mapping*. MapInfo Asia-Pacific.
- Worboys, M. F. (2001). GIS: *A Computing Perspective*. University of Keele.

Electronic References

- Anderson, C. (2001). *Mobile Positioning-Where You want to be!*. Available from Internet: URL http://www.wirelessdevnet.com/channels/lbs/features/mobilepositioning.html [last accessed: 2-26-2003]
- Chivers, M. (May 23, 2003). *Boulder County Sees Benefits of Mobile GIS*. Articles. Available from URL: www.directionsmag.com/article.php?article_id=368
- DCS Technologies. *Data Capture*. Available from Internet: URL: www.dcs-va.com/page30.html Available from URL: www.ub.rug.nl/eldoc/dis/arts/p.m.van.leusen/ch7.pdf
- Diamond, L. (No Date). *Mobile Mapping and Virtual GIS*. GIS Solutions. Available from Internet URL: http://www.gisdevelopment.net/technology/mobilemapping/techmp002a.htm [Last accessed March, 2004]
- European Environmental Agency. (November, 1996). *Surface Water Quality Monitoring*. Available from Internet: URL http://reports.eea.eu.int/92-9167-001-4/en/page003.html
- Harada, R. (No Date). *Thin Client Versus Thick Client Computing for Mobile Data Collection*. Psion Teklogix. Available from Internet: URL www.psionteklogix.com/assets/downloadable/Thin_Client_Computing.pdf [last accessed 02-0202003].
- Harrington, A. (02-05-2002). *Mobile GIS Depends on Location*. Available from Internet: URL www.geoplace.com/gw/2002/0205/0205mgis.asp [last accessed 23-10-2003].
- Howell-Jones, J. (15-12-2000). UMTS will cover all of Europe by 2010. Article in 'Computing'. Available at URL: www.vnunet.com/News/1115545 [Last accessed 18th Nov, 2003].
- Leusen, M. van, N. Ryan (2002), *Educating the digital fieldwork assistant.* PhD Thesis, ch 7.
- Magon, S., Shukla, R. (2002). *Location-based Services, the ingredients and the Alternatives*. Available from Internet: URL http://www.gisdevelopment.net/technology/lbs/techlbs006.htm
- Maguire, D. (2003). *Mobile Geographic Services*. Available from Internet: URL www.gisdevelopment.net/technology/mobilemapping/techmp003.htm [last accessed 05-04-2003].
- Microsoft. *Mobile Device Wireless Connectivity*. Available from Internet: URL www.microsoft.com/library/shared/deeptree/asp/deeptree/asp?stcfg=/technet [last accessed: 2-11-2003]
- Mennecke, B., Pick, J. (March, 2003). *Geographic and Location-based Technologies for Decision Support*. Available from Internet: URL http://galletta.business.pitt.edu/amcis2003/08DSS4_Geographic.htm
- Norman, S. (1996). *Water Quality Monitoring: Notes from the field*. Lake Tahoe Basin Mangement. Available from Internet: URL www.watershed.org/news/sum_96/monitor.html [last accessed: 3-24-2003]
- Reid, H., Francica, J. (No Date). *"Thin" Is "In".* Geoworld. Available from Internet: URL www.geoplace.com/gw/2000/0600/0600tt.asp
- Dr. Roy, A. (January 28th, 2002). *Web Mapping Solutions*. Available from Internet: URL http://www.directionsmag.com/press.releases/index.php?duty=Show&id=4298

- Sengupta, s., Sen, S. (2002). *Open Standards in Location based Services*. Applied Technology Group. Mumbai. Available from Internet: URL www.gisdevelopment.net/technology/lbs/techlbs002.htm
- Smith, J., Kealy, A., Williamson, I. (2001). *Spatial Data Infrastrucure- An Integrated Architecture for Location Based Services?*. University of Melbourne. Also see: http://www.sli.unimelb.edu.au/research/publications/IPW/JSmith_2.doc
- Spencer, B. (2002). *Mobile GIS*. GeoSolutions. Available from Internet: URL www.geoplace.com/asiapac/2000/0700/0700sol.asp
- Spiney, J. (2003). *A Brief History of LBS and How OpenLS Fits into the New Value Chain*. ESRI. Available from Internet: URL http://www.esri.com/industries/locationservices/publications.html
- Srinivas, U., Chagla, S. M. C., Dr. Sharma, V. N. (No Date). *Mobile Mapping: Challenges and Limitations*. InfoTech Enterprises. Available from Internet: URL www.gisdevelopment.net/technology/mobilemapping/techmp004.htm
- Technology Crafters. (2002). *A Comparison Of Thin and Thick Client Applications for Wireless and Mobile Applications*. Technology Crafters, Inc. Available from Internet: URL www.technologycrafters.com/technologycrafters/documents/Thick%20Vs%20Thin%20Client.pdf
- U.S. Army Corps of Engineers. (No Date). Collection of Spatial Data Sources. Available at URL: http://corpsgeo1.usace.army.mil/geo/metadata/sec7input/datacoll.html [2004, February 28].
- U.S. Army. (1994). Engineering and Design - Flood-Runoff Analysis. *Data Collection and Management*. Chapter 15. p. 15.1-15.3. See also: http://www.usace.army.mil/inet/usace-docs/eng-manuals/em1110-2-1417. Publication Number: EM 1110-2-1417.
- U.S. Environmental Agency. (last updated September, 2003),*Monitoring and Assessing Water Quality*. Available from Internet: URL www.epa.gov/owow/monitoring/monintr.html
- Wadhwani, A. (2001). *Recent Advances in Mobile GPS/GIS Mapping Technology*. Available from Internet: URL www.gisdevelopment.net/technology/mobilemapping/techmp005.htm

Appendix A – A copy of the original paper checklists used by the water board during field controls.

Zuiderzeeland WATERSCHAP

Bezoekrapport Lozingenbesluit open teelt en veehouderij

Naam bedrijf : ______________________________ Datum bezoek : ______________________________

Contactpersoon : ______________________________ Controleur : ______________________________

Adres : ______________________________

Postcode + plaats : ______________________________

Bedrijfstype : 0 akkerbouw
0 vollegrondsgroenteteelt
0 vollegrondsbloementeelt
0 melkveehouderij
0 pluimveehouderij
0 varkenshouderij
0 fruitteelt
0 bloembollenteelt
0 spoelbedrijf landbouwgewassen
0 boomkwekerij
0 vaste planten teelt
0 overig, namelijk: ____________________________

Vergunningplichtige activiteit(en) o.g.v. LBOT aanwezig? 0 ja, namelijk: ________________________________
0 nee

Gelegen in kwetsbaar gebied? 0 ja
0 nee

Onderwerp/bepalingen	Akkoord		
	ja	nee	n.v.t.
1. **Huishoudelijk afvalwater** afkomstig vanuit bedrijfsgebouwen (artikel 6)			
• inhoud septictank: _______ m^3			
• andere zuivering, namelijk:			
• *toelichting:*			
2. **Wassen** en **uitwendig reinigen** van voertuigen, werktuigen en/of apparatuur (artikel 7)			
• uitwendig reinigingswater spuit- en/of mestapparatuur			
• uitwendig reinigingswater trekkers, werktuigen e.d.			
• reinigingswater kuubskisten			
• aanwezigheid bezinkvoorziening			
• aanwezigheid controlevoorziening			
• *toelichting:*			
3. **Spoelen** van landbouwgewassen (o.a. bollen, groenten en fruit) (artikel 8)			
• *toelichting:*			
4. **Ontijzeren** van grondwater (artikel 9)			
• aanwezigheid bezinkvoorziening			
• aanwezigheid controlevoorziening			
• *toelichting:*			

Onderwerp/bepalingen	Akkoord		
	ja	nee	n.v.t.
5. **Reinigen** van gebouwen, stallen en/of bedrijfsruimten (artikel 10)			
• reinigingswater melkput, melkleidingen, melktank en tanklokaal			
• reinigingswater pluimveestallen			
• reinigingswater hygiënesluis en/of ontsmetlocatie			
• *toelichting:*			
6. **Koel-** en **condenswater** (artikel 11)			
• koelwater			
• condenswater			
• aanwezigheid controlevoorziening			
• *toelichting:*			
7. **Afstromen/afspoelen** van hemelwater en **afspuiten** van erfverharding (artikel 12)			
• opslag ruwvoer, "nat" voer, bijproducten e.d.			
• opslag mest, compost e.d. op *verhard* oppervlak			
• opslag mest, compost e.d. op *onverhard* oppervlak			
• stalling voertuigen, werktuigen en/of apparatuur op *verhard* en/of *onverhard* oppervlak			
• *toelichting:*			
8. **Teeltvrije zone** (artikel 13)			
• kavelnummer :			
• gewas :			
• gemeten afstand :			
• *toelichting:*			
9. Toepassen **bestrijdingsmiddelen** (artikel 15)			
• driftarme doppen			
• kantdoppen			
• toepassen herbiciden in talud			
• toepassen herbiciden op droge slootbodem			
• *toelichting:*			
10. **Vullen** spuitapparatuur (artikel 17)			
• *toelichting:*			
11. Toepassen **(kunst)meststoffen** (artikel 16)			
• kantstrooivoorziening			
• driftarme doppen			
• kantdoppen			
• *toelichting:*			
12. Overige **lozingen, bemonsteringen** en/of **constateringen**			
13. **Vervolgactie(s)**: ja/nee; zie controleverslag Wvo			