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Spatio-temporal visualisation and analysis

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MSc Thesis

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Abstract

Local water boards are responsible for the maintenance of the water system in a certain area. Water boards are more and more confronted with new targets concerning ecological and financial targets in addition to their traditional tasks of water quality management and water quantity management.

GIS are strong at visualising and analysing a given state of the development of an area. The integral approach to water management poses two important additional demands to information, being historic information and the possibility to assess long-term effects of measures taken.

These demands cannot be fulfilled by regular GIS, but are within the field of spatio-temporal GIS. Research into spatio-temporal GIS has resulted in different concepts and software systems. However, these systems often use proprietary storage formats, or lack functionality of regular GIS.

This thesis investigates whether or not today's level of technology allows for the realisation of combined spatio-temporal visualisation and analysis functionality, including thematic information as an extension to regular GIS instead of using stand-alone software and/or hardware.

For this purpose, a prototype spatio-temporal GIS is developed, that adds animation and 3-dimensional dynamic maps to a desktop GIS.

The prototype is applied in a spatio-temporal analysis of phosphate in part of the Province Friesland in the Netherlands. The prototype is evaluated through a SWOT analysis.

The main conclusion of this evaluation and thereby of the entire study is that the current state of technology, combined with the availability of extendable GIS indeed makes it possible to develop spatio-temporal GIS as an integral part of existing GIS applications.

Although the prototype is limited to visualisation and analysis of measured data, the experience gathered in the application of the prototype revealed that spatio-temporal GIS can be a valuable addition to the existing set of instruments at hand of decision makers. It is therefore advised to further develop the prototype resulting from this study.

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Disclaimer

The results presented in this thesis are based on my own research in the

Department of Geography at the University of Salford, Great Britain. All

assistance received from other individuals and organisations has been

acknowledged and full reference is made to all published and unpublished

sources used.

This dissertation has not been submitted previously for a degree at any

Institution.

Signed: Marten Hogeweg

Acknowledgements

'*The views of space and time which I wish to lay before you have sprung from the soil of experimental physics, and therein lies their strength. They are radical. Henceforth space by itself, and time by itself, are doomed to fade away into mere shadows, and only a kind of union of the two will preserve an independent reality*', Hermann Minkowski, physicist, 1908 (Capra, 1984, p. 154).

1 Introduction

Over the past years waterboards have faced many developments both in the process of water management and in the technologies that support this process. Demands from the water management process have lead to the development of certain technologies, and vice versa, new technology has had a counter effect on the management process as well.

Current issues are putting available instruments to the test. Questions cannot solely be answered using a geographic information system (GIS) or a statistical application. The combined spatio-temporal analysis of information becomes necessary.

This document contains a study into the possibilities of extending available GIS applications with spatio-temporal visualisation and analysis functionality.

The next section illustrates one of the many complex problems that waterboards have to solve nowadays. The example is followed by a description of the effect that these new issues have had on the water management process and on the supporting technology. Based on the increasing demand for spatio-temporal analysis and visualisation, combined with the technological conditions posed on such an instrument, a study aim is formulated. Finally, this chapter outlines the approach followed in the study.

1.1 Contemporary decision making by waterboards

The waterboards in the Dutch province Friesland face a number of developments regarding their water management process:

- In the autumn of 1998 the province experienced the consequences of heavy rainfall, which resulted in significant damage.

- Wetterskip Fryslân will introduce an Operational Management System to support daily water management decisions.

- The provincial authority of Friesland released their 2rd Water Management Plan.

- The water boards in Friesland jointly launched an Integral Water Management Plan.

Figure 1   Water boards in Friesland

In addition there are a number of technological developments:

- The corporate GIS application INTWIS is operational and its database is being filled with information on the entire water system in Friesland.

- Several databases are available that contain measurements on water levels and fluxes in the water system, measurements of rainfall in the province and measurements of the concentration of a large number of substances (so called water quality information, examples of which are Nitrogen, Oxygen, PCB, Cadmium, Chloride and Phosphate).

One of the actions that resulted from these developments concerns a study into the efficient and fast drainage of water in situations of high water and the minimisation of damage due to high water or intense rainfall.

To answer the questions raised in the study, geographic information is used of diverse nature and originating from various governmental or commercial sources. The information varies from detailed insight into the hydrology of the area (including hydraulic works, waterways, historical measurements on water levels and rainfall) to land use information, demographic information, cadastral maps, and many more.

A question that has to be answered is: 'Given a specific rainfall scenario, what will be the damage in the province, where is damage likely to occur, what measures can be taken and when will they have to be taken, in order to minimise the overall damage?'.

To answer the above and other questions, insight is necessary into *both the spatial and temporal behaviour* of the water system and the effects of this behaviour on issues as regional planning, nature development and such. The combined spatio-temporal behaviour cannot be answered using available technologies since these technologies focus on either the spatial context or the temporal context.

1.2   Evolving waterboards

Several technologies now find their way to waterboards. Among these are remote sensing, the use of Internet and such. Also from point of view of the policymaking process, new developments occur. Some examples are accountability of the policymaking process and public participation in the planning process.

Key issue in each of these developments is *information management*. Information management deals with collecting, storing and making available of information that is used to support the water management process.

Below both the process oriented and the technology oriented developments relating to information management for local water boards are described.

1.2.1   Changing policymaking processes

Waterboards are responsible for the maintenance of the water system in a certain area. This includes not only the care for the (good) quality of the water, but also providing the required amount of water: enough to meet the demands for agricultural purposes and not too much from the point of view of safety.

Hydraulic structures such as sluices and pumping stations are used to transport and store water in a controlled manner to ensure a proper quantity of water. To improve the water quality waterboards use treatment plants.

Apart from the technical targets (quality and quantity) there is a growing pressure on waterboards to meet ecological and financial targets. Meeting these different targets by applying the appropriate means at the right moment and the right location is called *integral water management*. Integral water management requires the availability of information on the historic, current and predicted future hydraulic situations in the controlled area (see also the study mentioned in the example given above).

Up-to-date information of the current situation is essential when deciding whether to grant a request from an inhabitant to do something that affects the water system. Information on the past situation of the water system is used to determine trends (for example a slow decrease of water quality) that might

require an adjusted water management. In those cases it must be decided
what measures to take, where to take them and when to take them.
Predictions of future situations are used to assess the expected effects of
measures taken and to evaluate alternative measures.

In answering these questions, water managers currently are supported by
various applications. GIS are used to visualise and analyse the effect of
measures to the environment (spatial context). Other applications (from
spreadsheets to statistical packages) are used to visualise and analyse the
long-term effects of measures (temporal context).

1.2.2   From island automation to integrated information systems

In addition to geographic information the water management process uses
large amounts measurements collected from the field in the form of
parameters that described the quality and quantity of water (Chloride
concentrations, water levels, ecological parameters and so forth). The
measurements are stored in databases that are well suited to answer either
spatial questions (where is the PCB concentration higher than some value,
can the sources of this contamination be identified) or temporal questions
(when did the PCB concentration start to rise). However, until recently this
meant converting data from one database to another. This situation is called
'island automation' (Hainje, 1999, p 8).
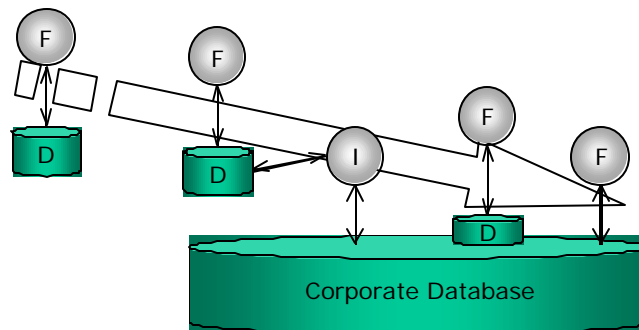
Figure 2   From island automation to integral information management

In the above figure 'F' stands for functionality, 'D' stands for Data and 'I' stands for interface.

Island applications (on the left) cannot share information. This is partly solved by building interfaces. Data is duplicated and reliability of information cannot be guaranteed. The interface can also connect the application to a corporate database that serves as common reference for data. Gradually, applications will connect directly to the corporate database and only little application specific information is stored separately (on the right).

Over the last five years, the Dutch local waterboards have initiated the integration of various databases. A new data model (URL: Adventus) and new GIS applications (URL: INTWIS and GIS-ZES) have been developed. These GIS applications serve as the interface to the corporate databases in which different types of information are stored.

Today GIS serves both as an instrument for integration of different sources of information, and as an instrument that supports decision-making in general.

Apart from these developments, the advances in computer technology cannot be ignored either. The increasing speed, storage capacity and graphic capabilities of desktop computers will not come to a standstill soon.

PC hardware catches up with high-end equipment and visualisation software is ported to desktop platforms. Some examples are:

- AVS from Advanced Visual Systems Inc. (URL: AVS).
- C Tech's Environmental Visualization System and Mining Visualization System (URL: CTech).

It is now physically possible and financially feasible to create databases that store many gigabytes of geographic information as well as long-term records of measurements and to make all this information accessible to many users.

1.3 Aim of this study

Given the current set of instruments to support management decisions, spatial and temporal questions can only be answered separately. There are no integrated tools available for the combined spatio-temporal analysis.

Both the developments in the field of water management and the technological developments lead to the notion that one of the next steps in the evolution process of waterboards is to introduce spatio-temporal analysis and visualisation as an extension to currently available GIS.

Since this new functionality should fit in the concept of integrated information management, specialised software (such as those mentioned above) is not preferred.

This leads to the formulation of the following statement and study aim:

> *Today's level of technology allows for the realisation of combined spatio-temporal visualisation and analysis, including thematic information as an extension to currently used GIS instead of using stand-alone software and/or hardware. The aim of this study is to investigate the validity of the statement.*

1.4 Study approach

To investigate the validity of the statement, a prototype spatio-temporal extension to GIS is developed. Prototyping is a process that enables the developer to create a model of an application (Pressman, 1987, p 22). This

model is then compared to user requirements and refined until user requirements are fulfilled. In a regular prototyping approach, several iterations of requirements gathering, design (more or other alternatives), application and evaluation occur until the prototype meets the requirements. In this study a single iteration will be applied.

This prototype implements methods and techniques that are collected from a review of earlier research. The prototype is put to the test in a practical application. Finally, a SWOT analysis of the results of the practical tests is used to assess the validity of the statement.
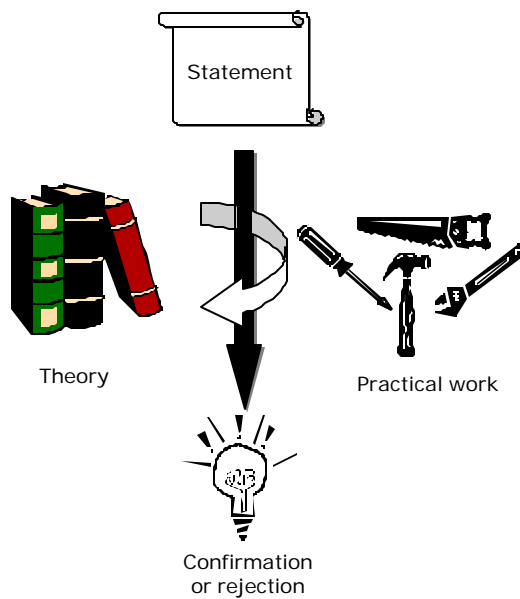
Figure 3   Study approach

The study approach set out above translates into the following activities:

- Limit the definition of spatio-temporal visualisation and analysis to the scope of this study.
- Identify components in a spatio-temporal GIS.
- Gain knowledge of the alternatives that exist for these components.

- Apply selected techniques for the components in a spatio-temporal prototype.

- Evaluate the spatio-temporal prototype by applying it to a specific problem.

- Conclude with an assessment of the statement based on the experience gathered from applying the prototype.

1.5   Outline of this document

Chapter two of this document gives a definition of spatio-temporal GIS within the context of this study. Spatio-temporal GIS is put next to other forms of visualisation and analysis. In Chapter 3 a spatio-temporal GIS is decomposed into a number of essential components. For each of the components, an overview of research is given. The theoretical part of this thesis is concluded by selecting methods to implement each of the components in a prototype spatio-temporal GIS. This prototype is described in Chapter 4, while chapter 5 presents a practical application of the prototype. Finally, chapters 6 and 7 contain the evaluation of the practical work and the overall conclusions with respect to the statement (see 1.3).

2   Spatio-temporal GIS

This chapter describes the position of spatio-temporal analysis in relation to other methods of visualisation and analysis. It also limits the scope of spatio-temporal visualisation and analysis within this study.

2.1   What is special about spatio-temporal?

The real world is not static. Both spatial and non-spatial components of the real world evolve over time. As mentioned in the introduction, water managers visualise, query and analyse the information collected from the real world to help make decisions on measures to be taken. This information exists in the spatial domain (it is measured or located somewhere in the real world), the temporal domain (it occurs sometime, or it exists for some period) and the thematic domain (it has some characteristic properties). The axes in the cube below represent the three domains:
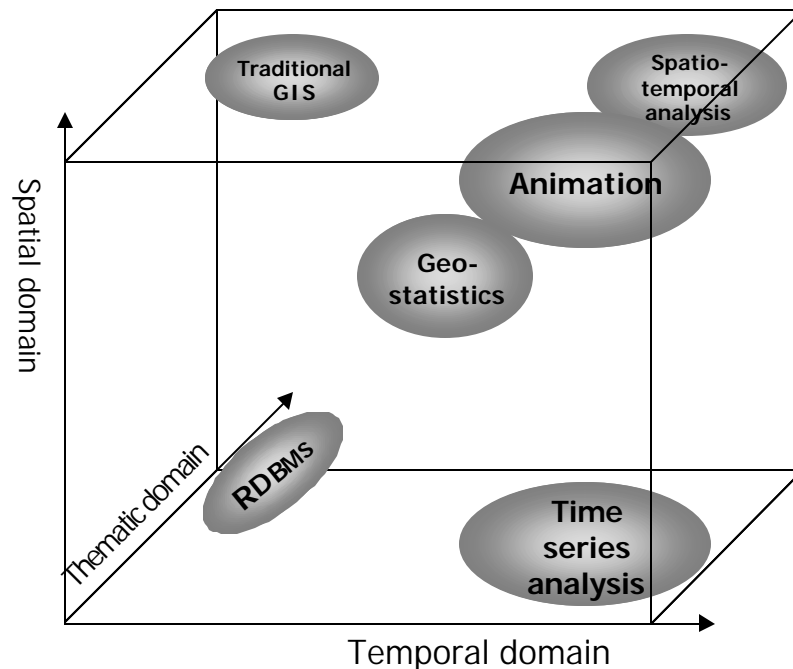
Figure 4   Methods applied in the spatial, thematic and temporal domain

The ellipsoids inside the cube locate a (not complete) number of methods

applied when querying, visualising, and analysing the information at hand.

The arrows indicate higher integration of the specific domain in the methods

mentioned. Th e table below contains a brief description of the other methods

of analysis.

Ellipsoid	Strengths
Traditional GIS	Important in thematic and spatial domain. Topological relations can be analysed (for example, determine watershed analysis by combining the river stream network with elevation information). Various sources of information can be combined into new information.
RDBMS	Strong in answering thematic questions. Supports temporal and spatial domains only when co-ordinates and date stamps are modelled as attributes of tables in the database. In this case, regular SQL can be used to answer most questions (Veldwijk, 1997, pp. 44- 49).
Time series analysis	Strong in analysing individual time series or pairs of time series. By shifting one of the time series, the lag between events can be determined (for example rainfall in relation to water level rise). Another strong point is to eliminate seasonal trends from the data before determining trends. Frequency analysis reveals information on how often events occur and can be used to predict or simulate future data.
Geo-statistics	Geo-statistics can be defined as the recognition and analysis of spatial correlations and the statistical approach of attribute values at unsampled locations (Miller, 1999, p. 376). The most well known method of geostatistical interpolation is named Kriging. Jaagus applied this and other methods such as asymmetry and excess analysis to study the variability of meteorological fields (Jaagus, 1994, pp. 946 - 947).
Animation	Animation can be used to reveal changes to objects, being in their location (movement), shape (growth, change), or attributes (sluice gates that are opened and closed). Animations can be played back without reloading or re-querying and provide a useful means of communication.

Table 1   Comparing spatio-temporal analysis to other methods

Looking at these analysis methods lead to the following 'definition' of a spatio-temporal GIS.

The ideal Spatio-Temporal GIS combines the strengths of traditional GIS, RDBMS, time series analysis, geo-statistics, and animation.

2.2   Are spatio-temporal GIS applications or functionality?

Over the past years many researchers have focused on spatio-temporal GIS. Most of the research took conventional GIS as a starting point and looked for ways to represent spatio-temporal data within conventional GIS. These studies take spatial information as a starting point and extend this with time. This has lead to different models for storing spatio-temporal data, which are based on data models existing in current GIS with temporal extensions (Kemp and Kowalczyk, 1994).

Nowadays, the GIS vendors and users acknowledge that data last longer than software programs. The work of the OpenGIS Consortium (URL: OpenGIS) and developments of GIS vendors are consistent with this idea. Geographic data are separated from functionality (ESRI, 1999) and stored in corporate databases together with non-spatial data (URL: Adventus). This allows organisations to have a single data management and backup/recovery strategy. It indeed frees GIS vendors from developing and maintaining proprietary database code and makes it possible to take advantage of the innovations in DBMS technology (such as Oracle 8i Spatial). GIS vendors need only to focus on functionality related to their field of expertise, being GIS!

This study focuses on analysing a data set that has both a spatial and temporal extent. Hence, the data model is 'fixed', and the temporal GIS

consist only of functionality and not as a separate software program. This notion is consistent with the trend seen at local water authorities to migrate from island applications to integrated information systems as described in 1.2.2.

In the current study, spatio-temporal GIS is considered a set of additional functions with respect to normal GIS, that operate on an existing data model and that allow spatio-temporal visualisation, query and analysis.

2.3   Spatio-temporal features

When considering the temporal component of spatial features one can think of the following aspects:

- The feature's geometry may change over time (expanding urban areas).
- The feature's location may change over time (moving cars or tornados).
- The feature's attributes may change over time (ownership of land parcels).
- Any combination of the above changes may occur.

Within this study changes to the geometry of features (such as cadastral boundaries, see van Oosterom, 1997) are not considered. Also, change to the location of features is not considered here. Instead, focus is on a specific form of change in attribute values, namely the analysis of long-term variation (both spatial and temporal) of water quality measurements.

Change in attribute can apply to different types of spatial features. For instance, air temperature varies continuously in three spatial dimensions as well as over time, while water levels vary in two dimensions and over time. However, it is physically not possible to measure these attributes at every possible location (since this would fill up space entirely!). Normally this results in a set of discrete measurement locations, spread across an area. At these

locations the target attributes (water level, air temperature, phosphate
concentration) are measured regularly.

Another aspect of change in attribute is the distinction between instantaneous
values (such as water level) and values that hold for a period of time (such as
land ownership). The former changes are recorded as measurements at
certain location, while the latter are considered being properties of an object
at a specific location.

*This study looks into the spatio-temporal variation of certain types of
instantaneous measurements collected at discrete locations.*

2.4   Developments in related fields

This section describes developments in two fields that are strongly related to
GIS: scientific visualisation and statistics.

Research and development in the field of scientific visualisation have focused
on issues pertaining to three-dimensional computer graphics rendering, time
series animations, and interactive (in real time) displays on computers.

Scientific visualisation and GIS have evolved more or less parallel to each
other. One of the reasons for this can be found in the demands on processing
power that interactive visualisation of 3-dimensional graphics puts on the
supporting hardware platform.

As PC hardware catches up with high-end equipment visualisation tools are
being ported to desktop-platforms. Visualisation tools are increasingly being
integrated with GIS software (URL: EVS). The current level of integration
(conversion of data from a GIS to a visualisation environment) is a first step.

Rhyne (1997) predicts that GIS and scientific visualisation will converge within the next five years. Already some GIS support 3-dimensional dynamic map display (even in VRML) combined with geographic analysis capabilities. A next step could be to extend traditional visualisation functions of GIS with the advanced techniques developed in scientific visualisation software.

A similar development can be seen in the field of (spatial) statistics. Developers such as SPSS and MathSoft (URL: SPSS, URL: MathSoft) are connecting their statistical software to desktop GIS. The level of integration between GIS and the statistical software may vary from data transfer through import/export to access to all functionality of the statistical software from GIS without any conversion activity.

2.5   Component-based Development

Component-based development (CBD) allows applications to be constructed from pre-built software components, rather than having to develop the entire application from scratch. The benefits of this approach include increased productivity and improved quality, both of which lead directly to reduced development costs.

Within this context, components can be defined as pre-built software 'parts' with well-defined interfaces and behaviour that can be used and re-used across a number of different applications.

The relevance of CBD for GIS is in fact already given in the previous paragraph. Developers of statistical and visualisation software are linking these systems to commercial GIS platforms.

Components also play an important role in the OpenGIS™ Services Architecture (Kottman, 1999, pp. 1-7). This Services Architecture 'provides a

definition of essential parts of a computational view of an information system for geospatial processing. In other words, it provides a framework of services required for the development and execution of geospatially oriented applications. This framework consists of the definition of interfaces and a description of the behaviours expected via these interfaces.'

A subset of the elements in the OpenGIS™ Services Architecture is called 'Geospatial Domain Services'. This subset consists of a number of services, of which the following are relevant to this study:

- Geospatial Domain Access Services – defines a set of interfaces for locating, retrieving and disseminating selected geospatial information from a geospatial information system (GIS), or geospatial library, and for updating the contents of a library (by storing, deleting, or modifying geospatial information).

- Geospatial Analysis Services – exploits information available in a Feature or Feature Collection to derive application-oriented quantitative results that are not available from the raw data itself.

- Geospatial Display Services **-** prepare and render Feature Collections or Coverages to an output device, such as a screen or a printer.

The statistical software systems discussed in the previous paragraph can be regarded as Geospatial Analysis Services, while the scientific visualisation systems can be positioned as Geospatial Display Services.

In the next chapter the above Geospatial Domain Services will be elaborated as components of a spatio-temporal GIS.

2.6   Applications of spatio-temporal GIS

This study focuses on the application of spatio-temporal GIS in the field of water management. Of course the possible applications of spatio-temporal

analysis extend beyond the field of water management. It can be used to analyse traffic congestion, railroad/bus-transportation plans, crime analysis, geomorphology and many more. The problems under study in these fields of application have both a spatial and a temporal component. Integrating these components leads to developing more fundamental understanding of the processes involved and thereby helps developing actual solutions instead of reacting on symptoms.

3 Components of a spatio-temporal GIS

3.1 Introduction

To assess the statement formulated in 1.3 a prototype will be developed that allows visualising and analysing the temporal variation of measured parameters over time in combination with spatial information using GIS. As part of that development the current chapter will answer the following questions:

- How can spatio-temporal information be stored?

- What options exist for visualising spatio-temporal data?

- How can spatio-temporal data be queried?

- What types of spatio-temporal analyses exist?
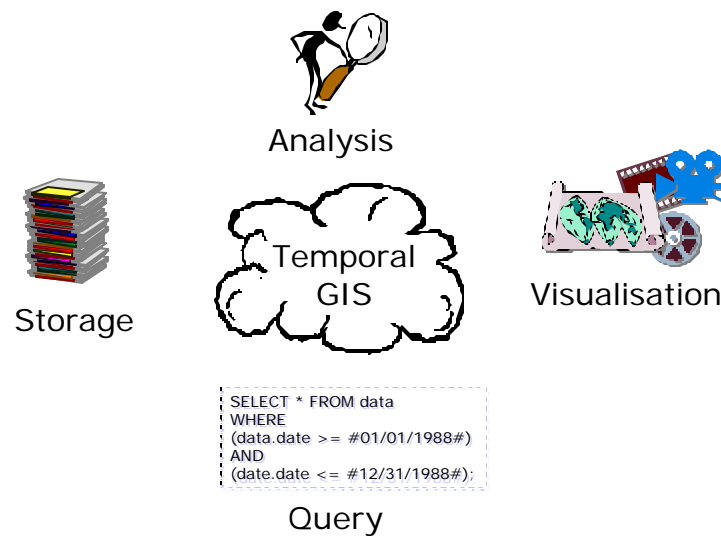
Figure 5   Aspect of Spatio-temporal GIS

In this chapter, each of these aspects is elaborated in more detail. For each aspect, the link to the practical part of this study is made, by explicitly indicating how it will be implemented in the prototype.

3.2   How can spatio-temporal data be stored?

3.2.1   Spatio-temporal data models

Time is a continuous dimension (although quantum mechanics may conclude otherwise). Information systems (irrespective of there storage format) are not capable of storing continuous information. Therefore some form of discretisation is necessary. This lead to different data models for spatio-temporal data. Langran (1992, pp. 37 - 44) and Candy (1995, pp. 15 - 34) distinguish several different methods to model spatio-temporal data:

Snapshot: The snapshot model stores time as an attribute of each complete geographic data set. Each feature update (or at regular intervals) creates a complete new version of the dataset. Each data set exists independently of each other. Normally the time is assigned to the name of the dataset or can be found in the name of attribute columns and such.

Update: The update model stores one complete version of the dataset. New information is stored as additional datasets only when and where change has occurred. The dataset at some moment must be constructed from the base dataset and the stored updates. The advantage of the update model over the snapshot model is the reduction of required storage space.

Composite: The composite model is similar to the update model. However, the base state and all updates are stored within one dataset. The advantage of the composite model over the update model is the preservation of spatial topology.

4D: The 4D model stores time as an additional attribute of each

                vertex in the (vector) data model. Each vertex thus is defined

                by (x,y,z,t). This model allows spatio-temporal join operations

                and topological queries while avoiding data redundancy.

Various researchers applied these models in spatio-temporal applications. For

example Van Oosterom and Maessen (1997) have applied a modified 4D

approach in a cadastral application. Temporal attributes extend cadastral

objects and indicate when the objects exist. Selecting objects from the

database on both spatial and temporal attributes creates maps. Peuquet and

Wentz (1994) have applied the update model in the design of TEMPEST.

Hoinkes and Mitchell (1993) have applied the snapshot model in an

application that displays the development of the built environment of Montreal

in the 18th century. Jaagus (1994) applied the snapshot model in the analysis

of meteorological processes.

3.2.2   Basic data model: Adventus

This thesis focuses on water quality information that is measured at point

locations spread over an area of interest and during a period of several years.

In the Netherlands, local waterboards carry out this activity as part of their

responsibility for maintaining a basic level of water quality. Over the past five

years a growing understanding of the need for standardisation of the

description of such information within the water management society lead to

Adventus (Hogeweg, 1999, pp. 86 - 91). Adventus aims to be a data model

that defines and relates all information that is essential for local waterboards.

Part of Adventus is dedicated to storing measured data that is collected at

point locations.

During the design of the data model two opposing parties appeared, each of

which had a particular view on the measured data. On the one hand, some

types of data are gathered at regular intervals as part of a time series.

Examples of this type of information are water levels and discharges, often

called water quantity data. On the other hand, water *quality* data are gathered

quite differently. A sample of water, or mud or soil is taken from the field. A

laboratory analyses the sample and finds that the sample contains different

chemical substances.
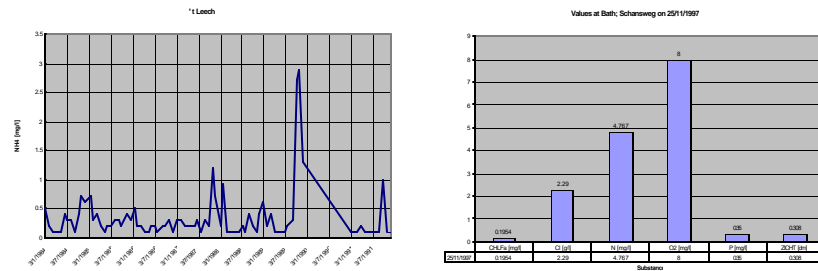
Figure 6   Water quantity data versus water quality data

One of the problems that Adventus solved is the possibility to integrate water

quality and water quantity data. Separating the way in which the data were

collected from the way in which the data are stored did this. Essential item in

the Adventus model is the measured value itself. The location (*where*), the

moment in time (*when*) and the type (*what*) are all considered attributes of the

value. Adventus stores also attributes that describe *why* and *how* the value

was determined, but this research does not consider such attributes.

3.2.3   Different forms of time

Langran (1992, p 34), Easterfield et al. (1991) and others, distinguish different

forms of time associated with:

- The moment for which a value has been determined (world time).

- The moment th e value is stored (database time).

- The moment the value was retrieved from the database ().

When all these different forms of time are considered, it is possible to answer

questions such as: On 22 June 1998, what did my database think the value of

parameter X was at location Y on 10 August 1994? The figure below

illustrates the influence on the outcome of question such as those mentioned

before (Maasdam, 1997, p. 2).
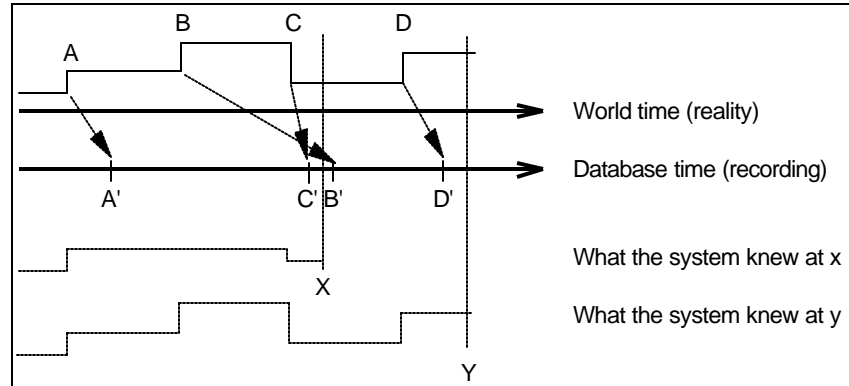
Figure 7   Difference between world time and database time

According to Hermosilla (1994, pp. 89 - 90), the notion of the different forms

of time is one of the essential requirements of a Temporal GIS. The example

above illustrates the importance of the difference between world time and

database time. In addition the temporal domain should have a varying

granularity. This means that events may be stored at irregular intervals,

depending on their occurrence. Having a fixed temporal granularity could

mean that events are not recorded (when changes in the real world time

occur more frequent than changes are stored in database time) or vice versa,

the same state is recorded multiple times (when the database time has a

higher granularity than the events occur in real world time).

However, the purpose of this MSc is not to design a complete Temporal GIS,

but to show that it is possible to visualise and analyse spatio-temporal data

using available technology. Therefore it is assumed that the database is up-

to-date and that the time stored as an attribute of the measured data

corresponds with the real world time.

> *Adventus is the basis for the data model used in this research. This*
>
> *research only considers real world time as an attribute of the measured*
>
> *values. For animation the snapshot model is used.*

3.3   What options exist for visualising spatio-temporal data?

3.3.1   The representation of spatio-temporal data

UNIGIS graduate Caroline Pennekamp (1999, pp. 62 - 64) suggests a

selection scheme that helps to determine how to present spatio-temporal

data. This scheme is an extension to the classical visualisation theory of

Bertin. Pennekamp introduced a 'guideline for mapmakers who want to

represent time, using conventional static map techniques or with help of more

sophisticated new animation software'. The guideline consists of a selection

process and a decision table. Putting the answers of the selection process

against the table results in a presentation method, that best meets suites the

question asked.

The following table contains the five steps in the selection process, and the

answers related to the information used in this study.

Step 0: The purpose.	The purpose of visualisation in the context of this study is to support the user in discovering spatio-temporal relations in water quality information.
Step 1: Change in place or in attribute?	This study focuses on change in attribute.
Step 2: Selection of time classification.	This study considers the following dynamic variables: Duration, Moment, and Rate of change.
Step 3: Select level of measurement of object to represent.	Water quality information is considered ratio data. Apart from the actual values, also derived information (such as the fact that the value exceeds some threshold value) can act as objects to represent.

Step 4: Select possible static visual variables based on measurement level of data and kind of time question.	The data used in this study is collected at point locations. Relating either colour or size of the points to the value seems sensible. Classes such as orientation and shape are less appropriate. The combination of size and colour might be used to visualise two different parameters simultaneously.
Step 5: Animation facilities possible?	This study will use ESRI ArcView with a number of extensions. Animation is possible.

Table 2   Questions and answers in the selection of a visual representation.

According to Buziek (1997, p. 2), animation falls into the category of kinematic maps. Other categories are static maps and dynamic maps. Static maps are not modifiable in their graphic design. 'Traditional' analogue maps are static maps. Kinematic maps show animations of spatio-temporal data as a video. The user cannot change the data displayed and the way of display. Dynamic maps allow the user to include different themes or take different points of view (in three dimensions).

3.3.2   Animation

Animation is an obvious means for the visualisation of the spatio-temporal domain (see Oosterom (1997), Brown (1997), Scholten (1997), Unwin (1998) and others). Most of this research uses animation to visualise the variation of some attribute value over time and space by displaying a series of classified maps in sequence.

Blok and Köbben (1998, pp. 4 - 6) have gone a step further and explored the use of animation as a method for the analysis and discovery of *spatio-temporal patterns* (see 3.4.2).

3.3.3   Three-dimensional visualisation

Most of the research on visualisation mentioned above assumes that two-dimensional maps are used as a means of visualisation. The dataset used in this study contains values of water quality parameters, collected at irregular and different intervals at various point locations in the study area. One alternative to regular maps and animation that is included in this study is to represent time as the third dimension (that is, points in three-dimensional space have co-ordinates (x, y, t)). Three-dimensional visualisation is already common practice in the scientific world (see 2.4 and URL: CTech), were meteorological, hydraulic and geological models are applied. One of the problems with 3-dimensional visualisation so far has been the amount of computing power necessary to construct solid bodies from a collection of points due to increased complexity.

One alternative to create solid bodies from a set of points in 3-dimensional space is to use voxels. Voxels are the three-dimensional equivalents of pixels. A two-dimensional object can be represented by squares of different size (quad-trees). In a similar fashion, cubes, stored in an octree, can be put together to create three-dimensional objects.
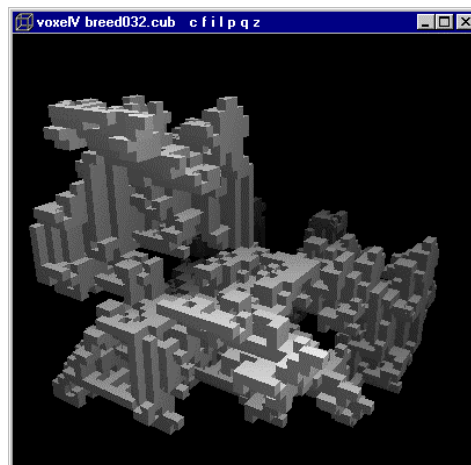
Figure 8   A three-dimensional object consisting of voxels

The software package VoxelV (URL: NotNot) creates images such as the

above. A drawback of these packages is that there is no means of querying

the data. Following the trends outlined in sections 2.4 and 2.5 it can be

expected that functionality such as that of software systems of VoxelV (and

others) will become available as visualisation tools for GIS.

> *With respect to visualisation of spatio-temporal data, the practical part of*
>
> *this study focuses on a combination of animation and dynamic maps,*
>
> *containing a three-dimensional representation of the data.*

3.4   How can spatio-temporal data be queried?

3.4.1   Selecting data from the database

Being able to select a subset of a spatio-temporal dataset to visualise or

analyse is an important component of a spatio-temporal GIS. In fact, selection

and visualisation are both essential activities in the analysis process.

In the spatial domain, several operators have been identified, that relate two

sets of geographic features. Researchers have defined equivalent operators

in the spatio-temporal domain (Erwig and Schneider (1999, p. 6)). The

following table contains several of these operators. The table also mentions

the spatial equivalent of each operator as well:

Temporal operator	Corresponding spatial operator
Early/late	Disjoint
Meets	Meets
Equals	Equals
During	Contains
Starts/finishes	Covers
Overlaps	Overlaps
Intersects	Intersects

Table 3   Temporal operators and spatial equivalents

According to Peuquet and Wentz (1994) these operators describe topological relations. Peuquet and Wentz additionally see Boolean and generalisation operators. Boolean operators (such as AND, and OR) are used to combine topological operators into more complex expressions. Generalisation operators relate patterns of two different types of phenomena, recorded at different temporal resolutions (such as rainfall due to seasonal changes and due to climatic changes).

In this study, the spatio-temporal data are stored in a relational database (Microsoft[®] Access 2000). Therefore SQL is the first candidate to use as means to query the dataset. SQL is well suitable for asking most questions to a database (Van Oosterom and Maessen, 1997 used SQL to select cadastral objects including the history of ownership and changing boundaries). However, the queries involved might become very complex (sub-queries, and sub-sub-queries). As an example, the following query selects the Chloride concentrations (Cl^-) that occur during a period where the water levels (h) were higher than some level h_0.

```
SELECT Cl⁻ FROM Dataset WHERE date ≥ (SELECT Min(date)
FROM Dataset WHERE h > h₀) AND date ≤ (SELECT Min(date)
FROM Dataset WHERE h > h₀)
```

Note that this query does not yet account for the possibility that water levels occasionally drop below h_0 and then starts to rise again (something which is not uncommon in a tidal area!). This would lead to a number of distinct periods for which the Chloride concentration should be selected instead of only one period as in the above query.

This complexity resulted in the fact that several researchers have proposed extensions to SQL that implement the temporal operators as additional

selection criteria *(*Güting et al, 1998, pp. 14 - 32). Modern databases facilitate

this by allowing a user to program functions (also known as stored

procedures), that work on data in the database and that can be used in SQL.

```
SELECT Cl¯ FROM Dataset WHERE PeriodContainsDate(date, h
> h₀) = TRUE
```

In this second example the function PeriodContainsDate returns True when

the given date (first argument) is within any period for which $h > h_0$ (second

argument) and returns False otherwise.

Erwig and Schneider (1997, pp. 9 - 11) introduced the concept of *spatio-*

temporal data types. Using these new data types, the authors are able to

represent *continuous changes* of spatial objects over time. Clearly, this is not

possible in a relational data model where the use of records implies that only

discontinuous changes are possible. Erwig and Schneider acknowledged the

power of SQL and therefore designed an extension to account for spatio-

temporal querying.

> *With respect to querying spatio temporal data, this thesis focuses on the*
>
> *use of regular SQL. The Adventus data model contains various criteria that*
>
> *are used to select data, including type of value, date, and location.*

3.4.2   Selection by classification

GIS maps that contain the spatial distribution of some attribute normally use

some form of classification. The range of values is divided into a number of

classes and each class is represented by some colour or texture pattern. On

of the possibilities is to apply a classification that only displays those values

exceeding some threshold value. The resulting map immediately shows those

locations where high concentrations of materials can be found, or where high

water levels occur, etc.

Here the available functionality for classification are used as an additional

means of selecting data.

3.5   What types of spatio-temporal analyses exist?

Blok and Köbben (1998, pp. 3 - 5) have explored methods that support the

analysis and discovery of spatio-temporal patterns using animation. Three

patterns are distinguished: convergence, similarity and stability.

Convergence means that events occur close to each other in time and space.

An example of convergence is the arrival and departure of trains and busses

at railroad stations. If the two parameter show convergence then this means

that passengers are assured of smooth links between train and bus

transportation.

Similarity means that different parameters show similar patterns in the spatio-

temporal domain. An example of this could be a relationship between the

phosphate concentration in the effluent of a treatment plant (that is

discharged into the surface water), and the phosphate concentration in the

surface water at a nearby location. Similarity can thus be used to determine

the spatial extent of a contamination with high concentrations of phosphate in

the effluent (the locations away from the treatment plant, will show low

similarity and vice versa).

Stability seeks for trends in the spatio-temporal patterns. An example of this is

found in the discussion on climate change. Is the temperature actually

increasing globally, or is it just a 'temporary' phenomenon.

Animation is the proposed means of investigation of spatio-temporal patterns
of the three mentioned types. The combination of animation and selection by
classification (see 3.4.2) makes it possible to put the focus on extreme values
only.

Another possibility is to display the frames in the animation 'on top' of each
other, instead of sequentially. This alternative form of animation, combined
with selection by classification can support the discovery of areas that meet
some criterion in the temporal domain.

With respect to analysing spatial temporal data, this thesis focuses on the
exploration of patterns (convergence, similarity, and stability) through
animation.

3.6   Putting it all together

The above paragraphs have outlined the principal aspects of a temporal GIS:
data storage, visualisation, query and analysis. When performing a spatio-
temporal analysis, each of these aspects will be used in combination as
illustrated below.
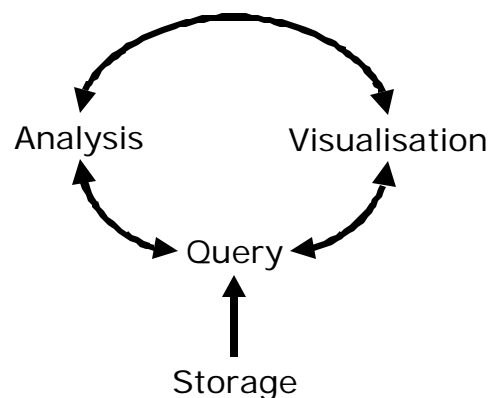
Figure 9   Integrated use of different aspects of spatio-temporal GIS

One selects (Query) data from the database (Storage) and visualises these data (visualisation). On the other hand, the result of the query is a way to analyse the stored data (Analysis). Visualisation is an important aspect of analysing data. This can be through animation or three-dimensional dynamic maps. The generation of new queries on the database as a result of the analysis and visualisation activities completes the cycle.

In this view Visualisation is however not limited to animation and 3-d dynamic maps. 'Regular' GIS visualisation techniques are part of spatio-temporal visualisation as well. This also is the case for Query and Analysis. Functions that are used in regular GIS analysis might also be used in spatio-temporal analyses (see also 2.2).

3.7   Relation to component based development

The selected alternatives for each of the aspects are only related to each other through the information that is considered. When creating a visualisation explicit knowledge of the way the information is stored is not required, since visualisation uses the result of a query to the database (see Figure 9). Similarly, when a query to the database is issued, the result of that single query can be used in animation, 3-dimensional dynamic maps, a time series graph or a tabular report. On the other hand, it must be known how to perform a particular query and how the result of that query will become available in order to be able to visualise that result.

The spatio-temporal prototype thus consists of a number of distinct *components* (or *services* in OpenGIS™ vocabulary) each of which fulfils a particular task and each of which is linked to other components through a well-defined *interface*.

When compared to the OpenGIS™ Geospatial Domain Services (Kottman, 1999, p. 6), the spatio-temporal prototype developed in this study appears to contain Geospatial Domain Access Services (storage and query component), and Geospatial Display Services (visualization component).

What lacks are Geospatial Analysis Services that implement the 'automated' discovery of spatio-temporal patterns (similarity, convergence, stability, see section 3.5). In addition, the Geospatial Domain Access Services of the prototype do not implement spatio-temporal relations (disjoint, overlaps, intersects, contains, see section 3.4.1) as part of a query language. In the prototype developed in this study the user himself provides these services by combining available query and visualisation functionality! Note that also the OpenGIS™ Services Architecture does not yet contain any service that is related to spatio-temporal information.

4   A spatio-temporal extension to a GIS

The previous chapter identified the different components of a spatio-temporal GIS. With respect to each of the components (storage, visualisation, query and analysis) alternatives were mentioned. From these a subset has been selected for implementation in a prototype spatio-temporal GIS.

This chapter explains into detail what the spatio-temporal prototype can do. First, the architecture of the prototype is described, followed by the implemented functionality for each of the components.

4.1   Target environment

4.1.1   User requirements

Although a detailed requirements analysis is not a part of this study, some remarks can be made from the review of earlier work on spatio-temporal GIS.

Transparency: the user should not have to worry about how or where to store spatio-temporal data, or how to transform data from the measurement database into output.

Ease of use: Any of the special purpose functions should be self-explaining. A user who is familiar to the ArcView user interface should be able to access and apply the functionality of the spatio-temporal prototype.

Flexibility: The functionality should not restrain the user in its normal use of the ArcView GIS.

Seamless integration: The prototype temporal GIS should be an integral part of regular ArcView and all functionality of ArcView should be available as well.

4.1.2   System architecture

The above requirements for the spatio-temporal prototype led to the

straightforward system architecture, which is presented below:
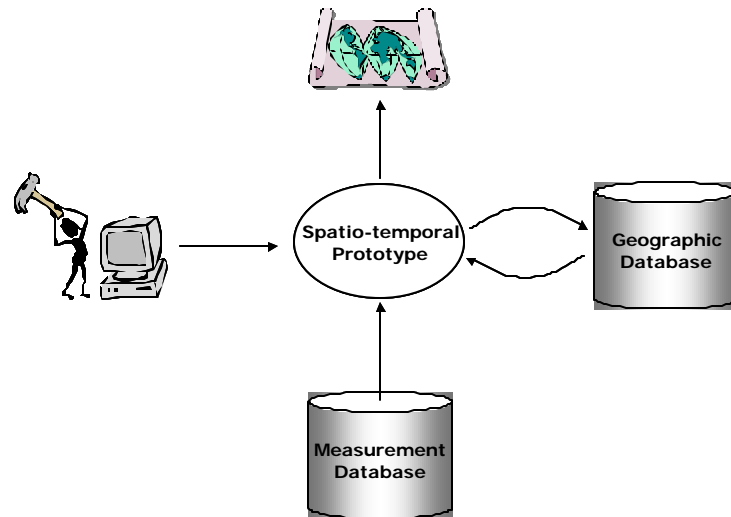
Figure 10   Architecture of spatio-temporal prototype

The architecture consists of a user, output in the form of maps, a geographic

database and a measurement database. The spatio-temporal prototype is

developed as an extension to ESRI's ArcView GIS, using the Avenue

programming language.

The user is presented with a number of additional menu items and dialogs

within ArcView.

The output of the spatio-temporal prototype mainly consists of animations and

3-dimensional dynamic maps (see 4.2.3 for more details).

The geographic database consists of a number of themes that can be used in

ArcView. Some of these themes are used for reference only, while others are

generated by the spatio-temporal prototype itself.

The measurement database contains the water quality data that is used in the application of the prototype (see 4.2.2 for more details). This database is implemented in Microsoft Access and is accessed through ODBC (open database connectivity).

4.2   Target functionality

4.2.1   Additional GUI elements

The functionality of the prototype is accessed through a number of menu items. These items are part of the normal Graphical User Interface (GUI) for Views and 3D Scenes.
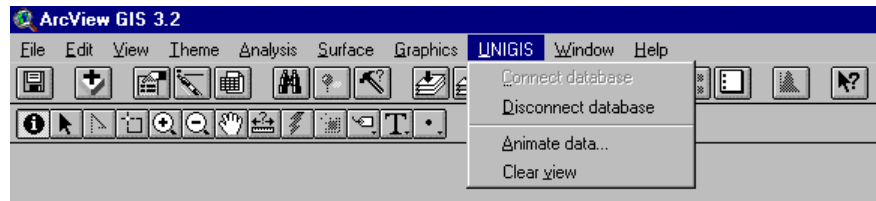
Figure 11   Spatio-temporal prototype additions to the View GUI

The first two menu items (Connect database and Disconnect database) are used to establish a live link to the database (see 4.2.2). The menu item Animate data gives access to the animation functions described in 4.2.3. The menu item Clear view can be used to free a view from all graphics that are created by animations.
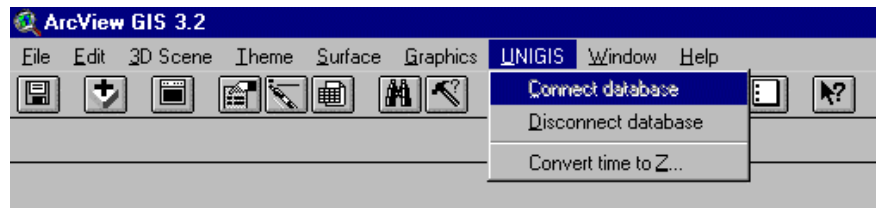

Figure 12   Spatio-temporal prototype additions to the 3D Scene GUI.

The first two menu items are identical to the corresponding items in the View GUI. The space-time data can be viewed as a 3-dimensional data cube through the menu item Convert time to Z (also described in 4.2.3).

The following paragraphs contain a detailed description of the functionality of the spatio-temporal prototype. The description follows the subdivision of the prototype into the four main components of spatio-temporal GIS as outlined in the previous chapter. When appropriate, reference is made to the system architecture and the user requirements.

4.2.2   How the prototype stores spatio-temporal data

The storage component of the spatio-temporal prototype is formed by the database that contains the measurements that will be visualised and analysed. With respect to the storage component of a spatio-temporal GIS the following decisions were made in paragraph 3.2: 'Adventus is the basis for the data model used in this research. This research only considers real world time as an attribute of the measured values.'

Whenever a database is designed, a number of steps are taken:

- Design a logical data model.

- Design a physical data model.

- Create the database elements (such as tables and indexes).

- Fill the database.

Design a logical data model

A logical data model is an abstract representation of part of the real world that is to be captured in a database. The core of a data model is a number of entities that represent some part from reality. Example entities are: Country, Person, or License. Note that entities can both represent physical objects (a Car) or virtual objects (such as Province). The properties of the objects to be

represented in the database are also part of the logical data model. They form

the attributes of the entities. The relations between the entities form the third

part of the logical data model. An efficient means of representing a logical

data model is by using entity relationship diagrams (ERD).

One of the problems faced when putting together a logical data model lies in

answering the questions what entities and attributes to include. One of the

decisions made with respect to the storage component of the spatio-temporal

GIS is that the data model will be based upon Adventus. Adventus consists of

more than 300 entities and over 2000 attributes. The following ERD shows

that part of Adventus that is considered relevant to this study:
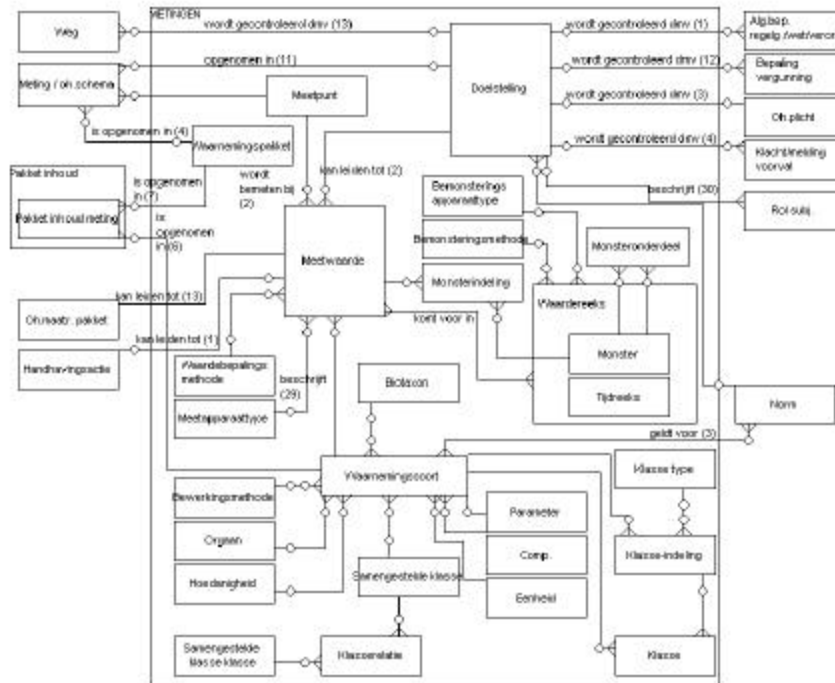
Figure 13   ERD from Adventus used in the spatio-temporal prototype

The above ERD is one of almost 30 diagrams and focuses on the description

of measurements. Below is a simplified version that narrows the number of

entities down to only those entities that are considered here:
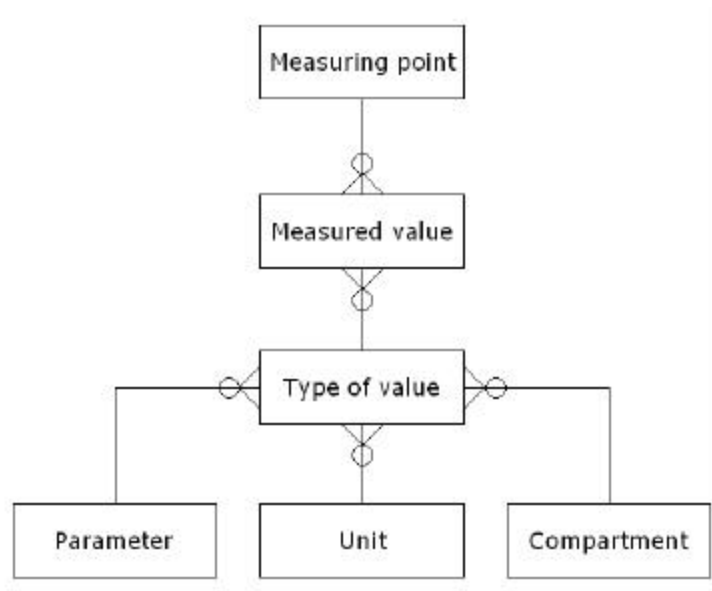
Figure 14   Simplified logical data model

The simplified model is restricted to describing values that were measured at
some location and are of some type.

Design a physical data model

The physical data model is a translation of the logical data model. In the
translation process aspects such as performance, fit-for-purpose and data
volume play a role. The data used in this study will consist of large time series
of water quality information. The use of the database is focused on retrieving
the values of some particular type at all locations for some moment in time (a
time slice). Only a few different types of values will be considered (see
paragraph 5.3 for a detailed description of the dataset used in this study).

The above considerations lead to a further simplification of the entity 'Type of
value' and to the introduction of entities that hold the values of only one type
for all the locations.
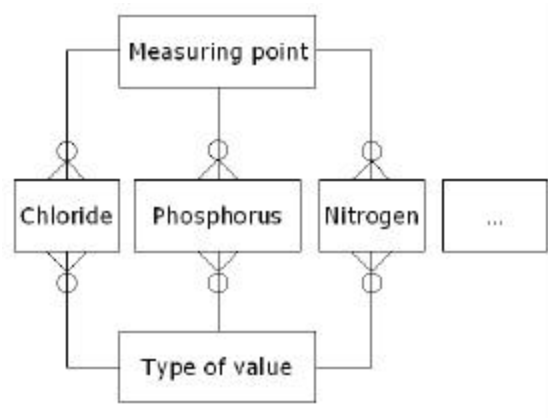
Figure 15   Physical data model

Create the database elements

The measurement database is created in Microsoft Access 2000. The entities

from the physical data model are translated into tables. The tables that hold

the actual value of a specific type are given a name that reflects the code of

type of value that was given to it as part of Adventus. The names of the

attributes of the tables are taken directly from Adventus, except for the

coordinates of the measuring points[1].

Fill the database

The data used in this study was supplied in various formats, among which are

dBase, Excel and plain ASCII files. Using the possibilities of Microsoft Access,

Microsoft Word and ODBC, the data was loaded into the database.

---

[1] The coordinates of a location in Adventus are named MRFXCOOR, MRFYCOOR

and MRFZCOOR. GIS such as ArcView can detect coordinate attributes, as long as

they have more natural names, such as X, Y and Z.

Connecting the database to the GIS

Once the database was filled, standard ArcView functionality was used to connect the GIS and the database. Through the SqlConnect object in Avenue, a direct link to the database is possible. This link allows for queries to be formulated and posted to the database. The result of such a query can directly be used in Avenue as a VTab object.

A second option is to use the dialog on the right. This dialog is part of the Database Access Extension that is available as a free extension to ArcView. Through the dialog, a simple query can be defined that results in a representation of a selection from the database in an ArcView table.

Figure 16   Add Database Table dialog

In the spatio-temporal prototype the SqlConnect object is used to retrieve data for a specific type and date from the database. The Database Access Extension is available for use whenever appropriate (thus contributing to the user requirements transparency and flexibility).

4.2.3   How the prototype visualises spatio-temporal data

As decided in paragraph 3.3 two alternative forms of visualising spatio-temporal data are explored: 2-d animated maps and 3-d dynamic maps.

2-Dimensional animated maps

Researchers have acknowledged the value of animation to visualise and analyse spatio-temporal data. Blok and Köbben (1998, pp. 3 - 5) have

identified three types of spatio-temporal patterns that can be discovered using animation and that are supported by the spatio-temporal prototype (see 3.5).

From this it follows that the animation functionality should support the simultaneous animation of two variables. On the other hand there might be cases where only one variable is animated. The animation functionality of the prototype should support this (user requirement flexibility). These design criteria lead to the following dialog.
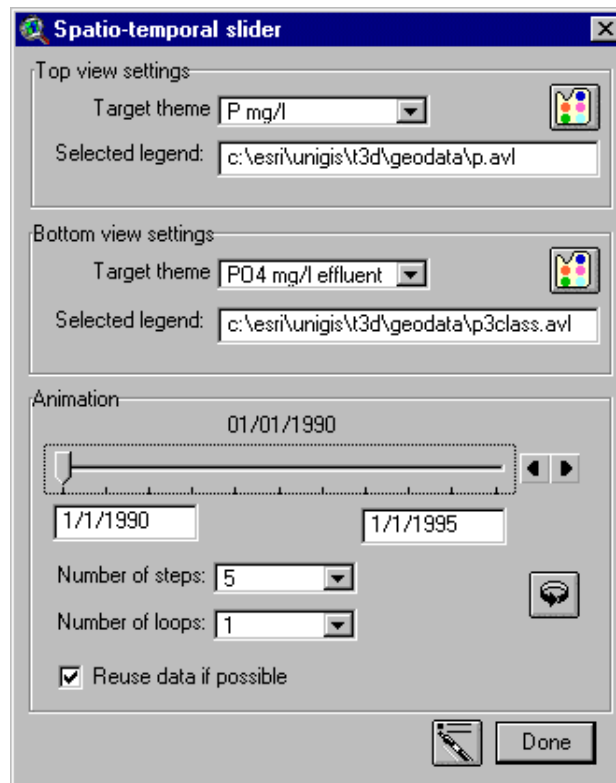

Figure 17   Dialog to support animation

The upper part of the dialog is meant to select what types of values are animated. The lower part actually controls the animation itself.

The animation function makes use of two View documents that exist in the ArcView project file of prototype, named 'Top' and 'Bottom'. These views can

contain any number of thematic maps in any order. The themes that can be
animated in the prototype are point themes with names equal to a specific
type of value (for example: P mg/l as in the example above for the Top view).
In the dialog the user selects a type of value that will be animated in the Top
view and a type of value that will be animated in the Bottom view. In addition
the user selects a legend that is applied to the animated theme. The legends
itself are ordinary ArcView legends that are created using the Legend Editor
(thus contributing to the user requirements seamless integration and
flexibility). The Legend Editor can be accessed directly from the dialog
through the button .

The principal means of controlling the actual animation is through the slider.
One can drag the slider to some point in time between the start and end dates
and the time slice for that moment will be displayed in the Top and Bottom
views (note that if there is no legend selected for the Bottom view, only the
Top view will be animated). This allows for fast browsing through the dataset.
Selecting the button will start an automatic sequence of time slices
(actual animation) up to the end date.

The user has further control over the animation through two drop-down lists.
The first list sets the number of steps that will lead from the start date to the
end date of the animation. The second list sets the number of times the
animation will repeat itself.

The prototype supports temporal focussing and brushing. The user can focus
on a specific period by entering the start and end date for that period and
increase or decrease the number of time slices in the animation. Brushing is
supported by allowing the user to position the slider at a relative position
between the start and end date and then showing the time slice for that
moment.

Normally, the data for a time slice is selected from the measurement database. For large datasets this may take up some time thus disturbing the notion of animation. To speed up animation, the check box on the dialog can be used to indicate that data retrieved earlier should be reused if possible.

The following sequence of images is taken from the animation of Kjehldahl Nitrogen at measurement locations in the southwest part of the Province Friesland in the Netherlands (data courtesy of Wetterskip Fryslân).
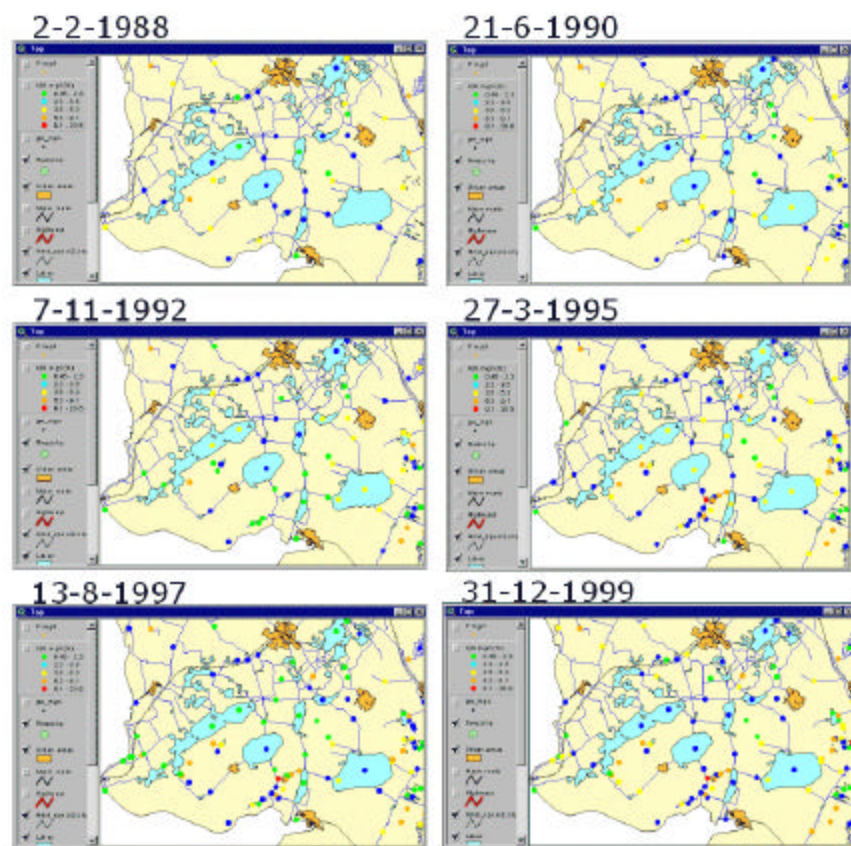
Figure 18   Animation of Kjehldahl Nitrogen in Southwest Friesland.

In the actual animation, the prototype creates a graphic object (point) using the selected legend to determine colour, shape and size for each of the measurements in a time slice. The graphic objects of subsequent time slices are presented on top of each other, thus creating the effect of animation. To

clear a view of graphic objects that were created by an animation, one can

select the menu item Clear view, available from the UNIGIS menu in the View

GUI.

3-Dimensional dynamic maps

In the 3-dimensional dynamic maps that can be generated with the prototype,

time is considered the third spatial co-ordinate of a measurement in addition

to the existing two co-ordinates of the measurement location. To support this,

the dates of the measurements are converted to a spatial dimension. This is

done through the so-called time-space transformer dialog:
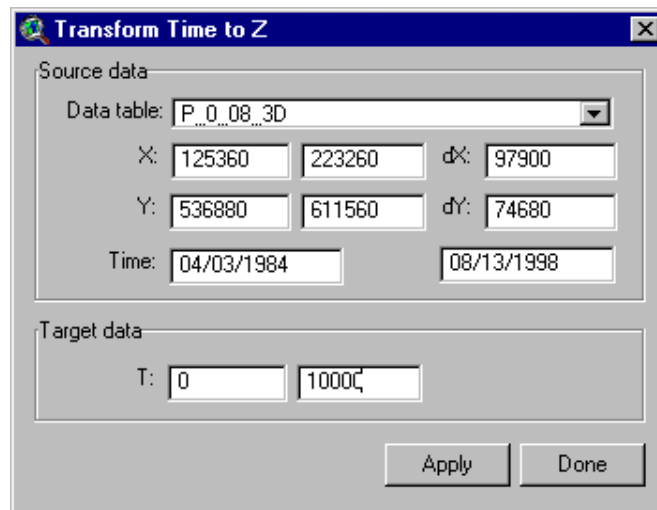
Figure 19   Dialog to support the transformation of time to a co-ordinate

The user selects a data table in the upper list box. The spatial and temporal

extent of the dataset is displayed in the remaining fields of the upper half of

the dialog.

Next the target spatial extent of the time co-ordinate is entered. The values

are in the same map units as are the X and Y co-ordinates. When the user

clicks the Apply button, the dates of the measurements are transformed to co-

ordinates. For this purpose, the dates are converted to their numeric Julian

representation[2].

The Julian representations of the start and end date of the data table and the

entered target extent result in the following linear relationship.

$$Z = M * t_{Julian} + N,$$

Where:

$t_{Julian} =$ Julian representation of a date,

$M =$ $(d-c)/(b-a)$

$N =$ $(b*c - d*a)/(b-a)$

$a =$ Julian representation of the start date of the data table

$b =$ Julian representation of the end date of the data table

$c =$ Value entered as target for the minimum Z co-ordinate.

$d =$ Value entered as target for the maximum Z co-ordinate.

The coefficients M and N are used to update the data table, according to the

following SQL-statement:

```
UPDATE   TABLE_NAME_3D
SET    Z = M * DateSerial(MWADATUM) + N;
```

---

[2] The Julian day is the number of days since January 1, 4713 BC. Each Julian day

starts at noon. For example, the Julian representation of 9:43 PM on March 31, 2000

is 2451635.405.

The 3D Point theme has to be created manually from the data table and

added to a 3D Scene. For this, available ArcView functionality can be used.

The data table has now become a data cube.

Once the data cube is in the 3D scene, it can be rotated, zoomed and panned

using available functionality of the 3D Analyst. Below is an example data

cube.
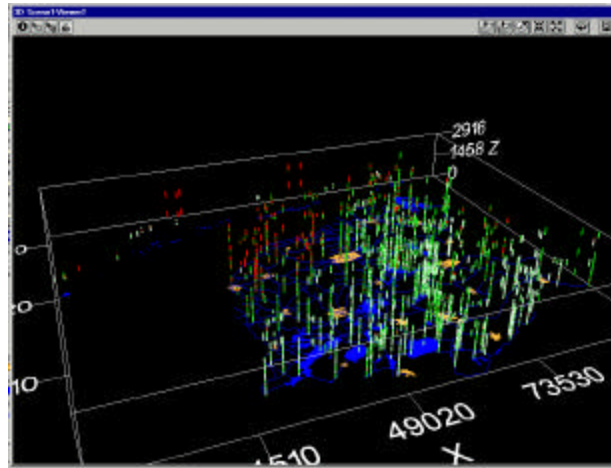
Figure 20   Visualisation of a spatio-temporal dataset in 3-dimensions

4.2.4   How the prototype queries spatio-temporal data

The prototype support the following kinds of querying spatio-temporal data:

- Using legends.

- Using SQL to create a dataset to be used in a 3 -dimension dynamic map.

- Using SQL to create statistical figures and reports.

Using legends to query spatio-temporal data

Both the animations and the 3-dimensional dynamic maps make use of

normal ArcView legends to classify the measurements. Normally the range of

values in the data set is divided into a number of intervals of equal size, or the

intervals are selected such that the number of values in each of the classes is equal.

A more advanced use is to define a legend only for those values larger than some threshold value. This will result in a map that only shows those values that meet the criteria of the classification. An example of such a classification is shown on the right.
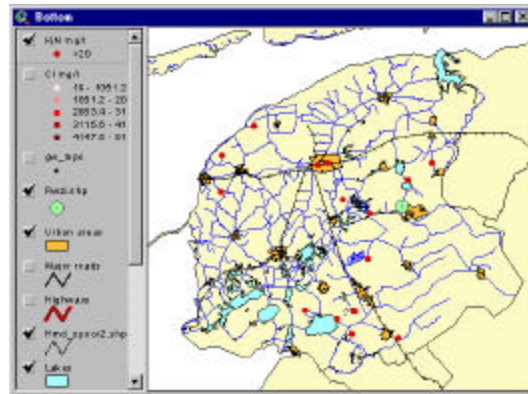
Figure 21   Query by legend: select extreme values

This type of legend can be used to scan for those locations that do not conform to target values.

Another alternative is to define a legend that relates classes to the mean value in the data range and the standard deviation. The example on the right shows the same dataset as in the previous picture, using the standard deviation legend.
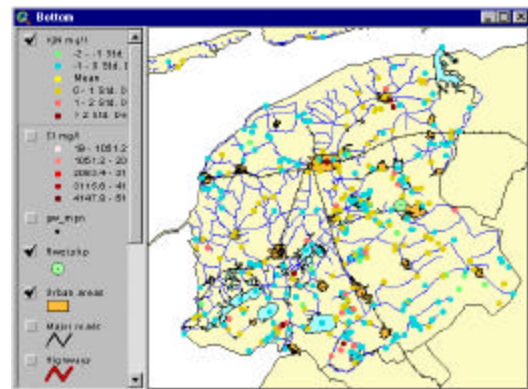
Figure 22   Query by legend: display deviation from mean

The creation of legends is supported by available ArcView functionality.

Using SQL to create a dataset for 3-dimensional dynamic maps

The display of the spatio-temporal dataset in a 3-dimensional data cube
requires the user of the prototype to create a table that contains the dataset.
This table can be created using the available options of the ArcView
Database Access Extension in combination with the options for creating and
storing queries in the measurement database (Microsoft Access).

An example is to select only those Phosphate measurements > 0.08 (this is
the target for Wetterskip Fryslân for the average Phosphate concentrate
during the summer period, see Grontmij, 1997, p. 75). The query for this
dataset is:

```
SELECT    First(WNS363.MPNIDENT) AS MPNIDENT,
          First(GW_MPN.X) AS X, First(GW_MPN.Y) AS Y,
          First(GW_MPN.Z) AS Z, First(WNS363.MWADATUM) AS
          MWADATUM, Avg(WNS363.MWAWRDEN) AS MWAWRDEN


FROM      GW_MPN RIGHT JOIN WNS363 ON GW_MPN.MPNIDENT =
          WNS363.MPNIDENT


WHERE     (((Month([WNS363].[MWADATUM]))>=4 And
          (Month([WNS363].[MWADATUM]))<10))


GROUP BY  WNS363.MPNIDENT, Year(WNS363.MWADATUM);
```

The result of the query is a set of values that represent the average of
Phosphate per measurement location over the months April to September
(this is considered to be the summer period) for each year in the original
dataset.

Note that the query is defined and stored in the measurement database. The

prototype spatio-temporal GIS can make use of these saved queries, just as

of the original data tables.

For one location the result is presented below:

MPNIDENT	X	Y	Z	MWADATUM	MWAWRDEN
045	200100	574860		19/4/1984	1.03166666666667
045	200100	574860		17/4/1985	0.851666666666667
045	200100	574860		12/5/1986	0.57
045	200100	574860		13/4/1987	0.713333333333333
045	200100	574860		20/4/1988	0.621666666666667
045	200100	574860		19/4/1989	0.946
045	200100	574860		9/4/1990	0.48
045	200100	574860		9/4/1991	0.61
045	200100	574860		13/4/1992	0.438333333333333
045	200100	574860		13/4/1993	0.321666666666667
045	200100	574860		19/4/1994	0.326666666666667
045	200100	574860		12/4/1995	0.363333333333333
045	200100	574860		15/4/1998	0.426666666666667

Record: 1 of 13 (Filtered)

Figure 23   Resulting summer average for one location

As outlined above, the resulting table can be viewed as a 3-dimensional

dynamic map, as shown in the next example:
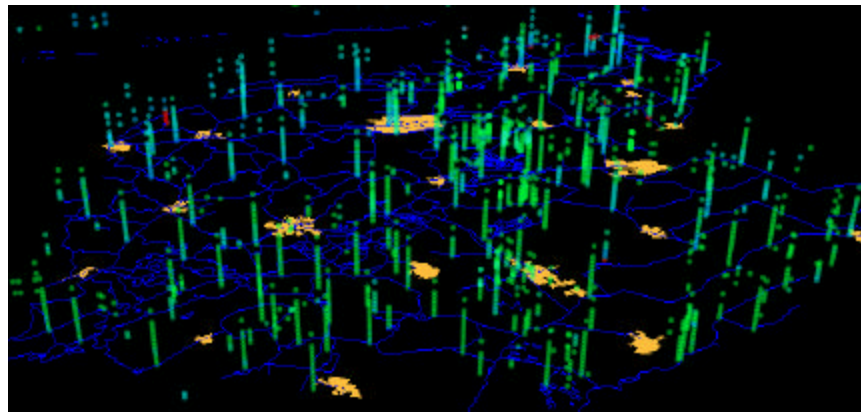
Figure 24   3-Dimensional dynamic map of summer average of Phosphate

Using SQL to create statistical figures and reports

Apart from visualising and analysing (see the next paragraph) spatio-temporal

data through animation and dynamic maps, the data can also be visualised

and analysed through regular queries on the database.

SQL can be used to retrieve periods within the temporal extent of the dataset

that share some particular property (such as high values). Here the spatio-

temporal prototype touches the field of 'regular' time series or data analysis

(see 2.1).
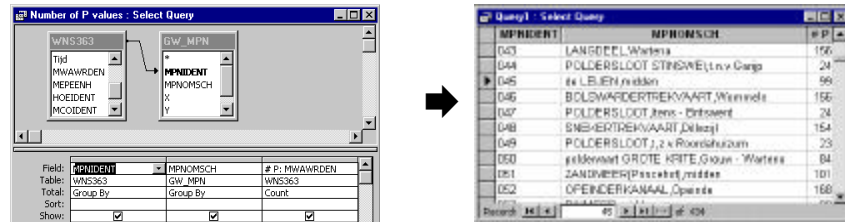
Figure 25   Visual design of a query in Microsoft Access

The prototype allows for this type of querying since the measurement

database is implemented in Microsoft Access.

4.2.5   How the prototype analyses spatio-temporal data

The prototype provides the user with a number of flexible functions to store,

query and visualise spatio-temporal data. These functions form the building

blocks of spatio-temporal analyses, just as normal spatial operations form the

basis for cartographic analysis. Defining an area that stretches out 30 m from

a linear feature makes no sense until the distance appears to be the minimum

distance between (for example) a railroad and houses. Then the buffer

operation can be used to determine how many people would have to be

moved if the government planned a new railroad through urban areas.

The functions defined in the previous paragraphs are similar. Alone they may seem to be of little value, but put together sensibly they become a useful instrument for spatio-temporal analysis using regular GIS. That fact is the core of this study.

The next chapter shows how the tools developed as part of the prototype can be put to use, solving a real case.

5   Application of the prototype

The prototype has been applied in a spatio-temporal analysis in the area of

Lake De Leijen in the Province Friesland in the Netherlands. This chapter

contains a description of the case, the questions asked, the method applied to

answer these questions and the answers. The case study is used to evaluate

the potentials of the spatio-temporal prototype. Results of that evaluation can

be found in chapter 6.

5.1   Lake De Leijen

Lake De Leijen is located in the Province Friesland in the Netherlands, about

8 km North of the city Drachten.
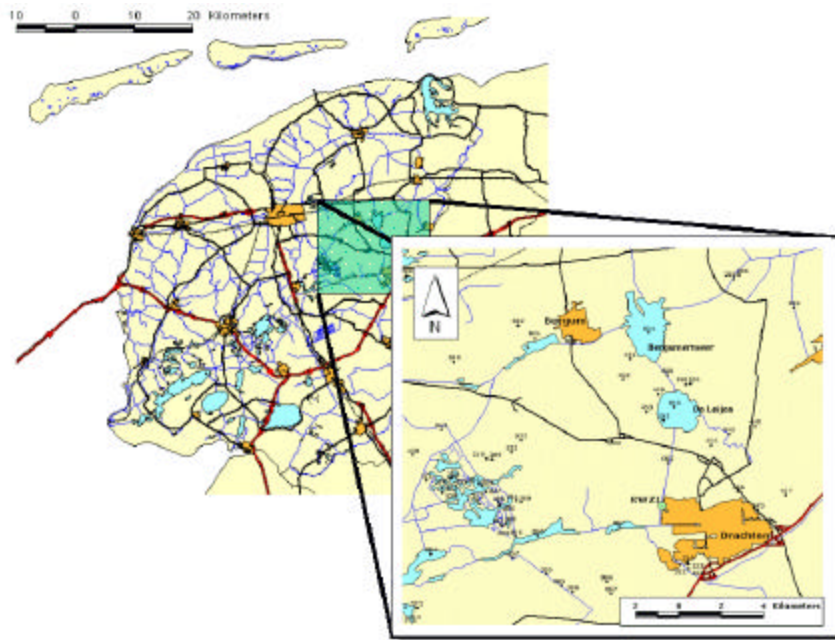
Figure 26   Location of lake De Leijen in Friesland

De Leijen forms the transition from the peat bog in central Friesland to the

higher sandy soils in the east of the province. The lake is part of the Friesian

main water infrastructure. The lake is part of the nature reserve De Marren.

Several functions are assigned to the lake, among which are use for
swimming, ecology and drinking water. Apart from these the lake is important
for recreation, fishery and water level management.

Each of the functions poses specific demands on the quality of the water in
the lake, formulated at either national or provincial level or formulated by the
local water board in Friesland: Wetterskip Fryslân.

A comparison of the measure values of several water quality parameters and
the target values (based on the specific demands) indicates that the targets
are not met in the lake.

A complicating factor is the presence of a water treatment plant in Drachten.
The effluent of the plant is released in the surface water system that is directly
in connection to Lake De Leijen. An analysis has proven a direct relation
between the effluent of the treatment plant and the concentration of
phosphate in the lake.

In the period from April 1996 to December 1998, a special installation has
been used in the treatment plant aimed at removing as much phosphate from
the effluent as possible.

5.2   The questions asked

From the fact that water quality targets are not met and the fact that measures
are taken by the local water board (one of which is the dephosphatisation
installation) the following questions arise:

- The dephosphatisation installation at the treatment plant Drachten has a
  noticeable positive effect on the phosphate concentration in the effluent
  from the plant to the surface water. Is the phosphate concentration in
  Lake De Leijen also affected positively?

- How is the development of the water quality of Lake De Leijen over the past years?

- How can the spatio-temporal prototype be used to answer the above questions?

The answer to the third question is given as part of addressing the other questions. The different functions of the prototype are put to the test in different combinations.

5.3   What data are available?

For the entire province 435 measurement locations are available. At these locations, the measurement database contains the types of values for the period 1984 to 1998 as listed in the table below. For each location on average one value per month is available.

Id	Description
433	Cl mg/l
332	KjN mg/l (N)
346	N mg/l
352	NH4 mg/l (N)
357	NO2 mg/l (N)
492	NO2 mg/l (N, filtrated)
358	NO3 mg/l (N)
363	P mg/l

Table 4   Types of values available in the measurement database

For the treatment plant Drachten, the Phosphate concentration in the effluent and the discharge of the effluent are available for the period 1990 - 1998.

5.4   The answers given

5.4.1   What is the influence of the dephosphatisation installation?

This section gives a qualitative analysis of the influence of the

dephosphatisation installation on the phosphate concentration in the area

near Drachten.

The effect of the dephosphatisation installation at the treatment plant of

Drachten on the water quality can be found from the concentration of

phosphate in the effluent of the installation. The effluent is the direct

connection of water (after treatment) to the surface water system.
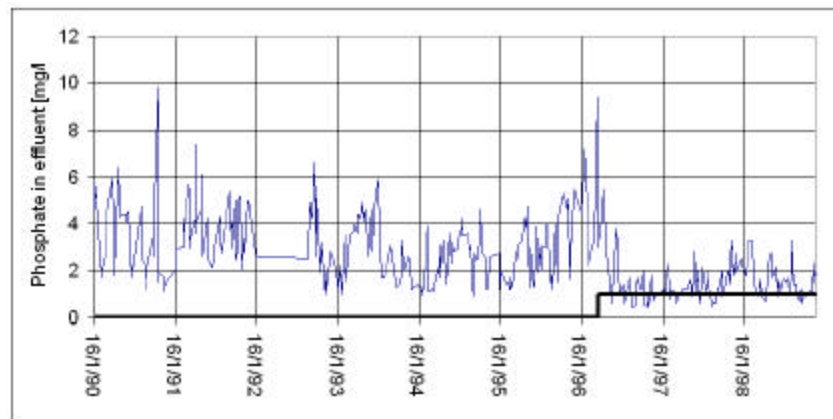
Figure 27   Phosphate concentrations in the effluent at Drachten

The graph shows the phosphate concentration in the effluent of the treatment

plant Drachten in combination with the operation status of the

dephosphatisation installation. Visual inspection shows the positive effect of

the installation on the concentration of phosphate in the effluent.

Of particular interest are the measurement locations 052, 045, 057and 056

(see Figure 26). The following graph shows the long-term development of the

phosphate concentration at these four locations, combined with and indication

of the operational status of the dephosphatisation installation at Drachten.
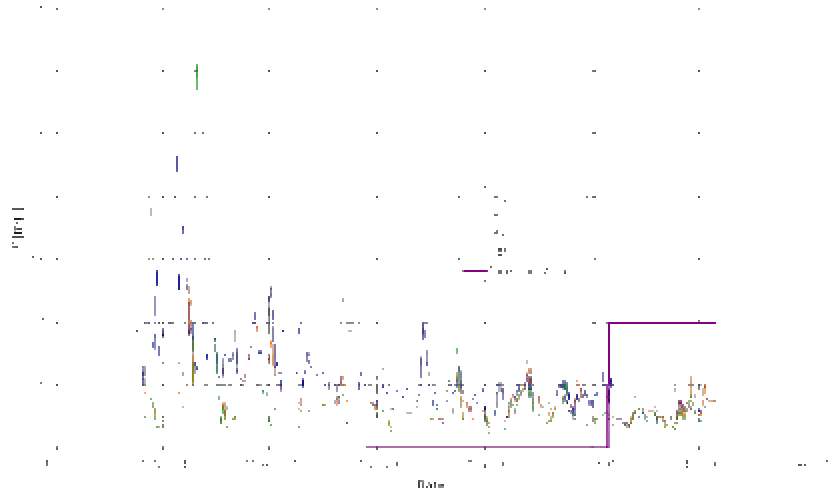
Figure 28   Phosphate concentrations near RWZI Drachten

The measurement database was queried to find the percentage of phosphate

values at these locations below and above the threshold set at 0.5 mg/l in the

period before the dephosphatisation installation became operational and in

the period during its operation. For the locations shown in the figure above

this results in the following:

	Before dephosphatisation			During dephosphatisation		
Location	#	# > 0.5	%	#	# > 0.5	%
052	162	75	46.3	42	3	7.1
045	88	42	47.7	32	1	3.1
057	87	10	11.5	32	2	6.3
056	88	4	4.5	32	0	0.0

Table 5   Percentage of phosphate values near Drachten above 0.5 mg/l

For these points the figures suggest a real improvement of the phosphate

concentration during the operational period of the installation. Recalling the

map of the area, a second observation may be that locations located to the

North of the installation (052 and 045) benefit more than those to the West of

the installation (057 and 056). This may be due to the fact that the direction of

flow near the installation is from South to North (see Grontmij, 1997 p. 20).

The spatial extent of the influence of the dephosphatisation installation could

be determined using the above procedure for all locations in the area.

However, a much faster way is to create an animation of the phosphate

concentration at the measurement points near the treatment plant.
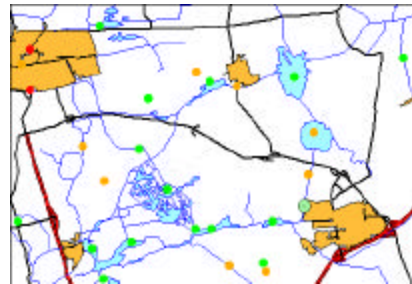
31-12-1984   6-8-1990
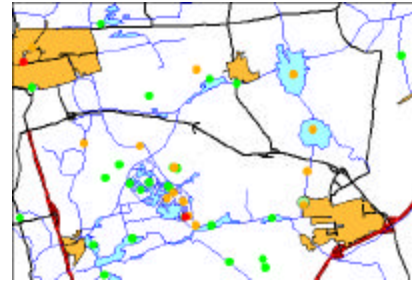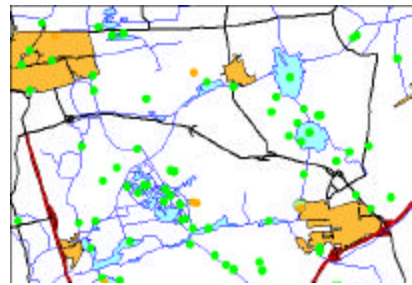
11-3-1996   8-4-1997
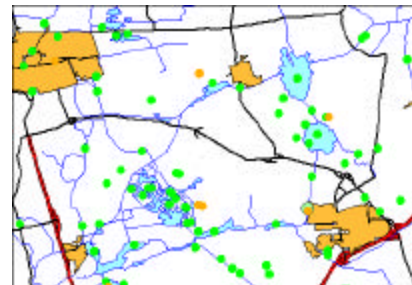
Figure 29   Effect of dephosphatisation on local phosphate concentrations

For this purpose a legend has been applied to the animated theme,

containing three classes for phosphate concentrations: ≤ 0.4 (green), 0.4 - 1

(orange), >1 (red). Figure 29 shows four images taken from the animation.

Starting from April 1996 the values near the treatment plant at Drachten are

noticeably more in the first class (locations change from orange to green).

This means that phosphate concentrations have indeed decreased after

applying the dephosphatisation installation.

Two types of temporal patterns can be recognised from the animation: convergence and stability (see 3.5). The fact that the phosphate concentrations indeed are noticeably better after starting to use the installation is a form of convergence. The stability pattern is discussed in the following section.

5.4.2 How is the development of water quality in De Leijen?

The development of water quality in De Leijen area can be answered by seeking stability patterns in the spatio-temporal domain of water quality parameters. Looking at two important statistical quantities, mean and variance does this.

For the water quality parameter phosphate, the mean and standard deviation were calculated by applying the follow SQL statement to the measurement database:

```
SELECT    First(WNS363.MPNIDENT) AS MPNIDENT,
          First(WNS363.MWADATUM) AS MWADATUM,
          Avg(WNS363.MWAWRDEN) AS MU,
          StDev(MWAWRDEN) AS SIGMA

FROM      GW_MPN RIGHT JOIN WNS363 ON GW_MPN.MPNIDENT =
          WNS363.MPNIDENT

GROUP BY  WNS363.MPNIDENT, Year(WNS363.MWADATUM);
```

The results are stored in two new tables in the measurement database. These tables respectively hold the yearly mean and standard deviation values of the phosphate concentration. An animation of the standard deviation of the phosphate concentration was made. This animation, of which some snapshots are given below, indicates that the variation in the phosphate

concentration in a region near Drachten is less after the dephosphatisation

installation was put to use.

31-12-1984   18-12-1998
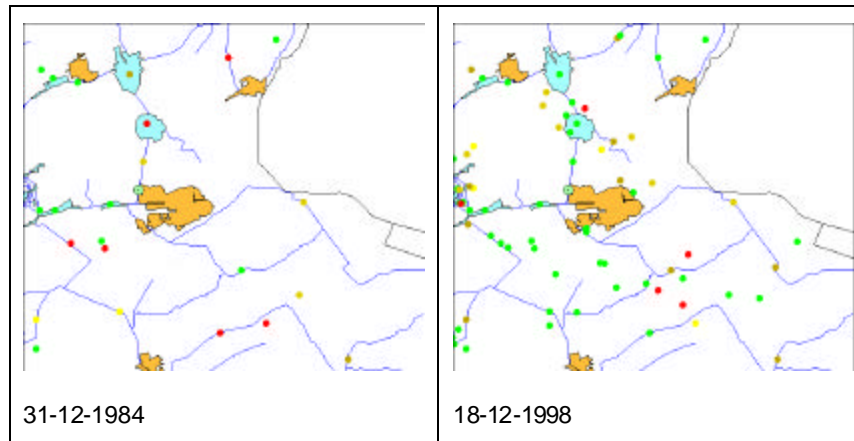
*Figure 30   Start and end situation of yearly standard deviation in phosphate
                  concentration*

This conclusion is confirmed by examining the time series of the standard

deviation at some locations near Drachten. The graphs are presented below.
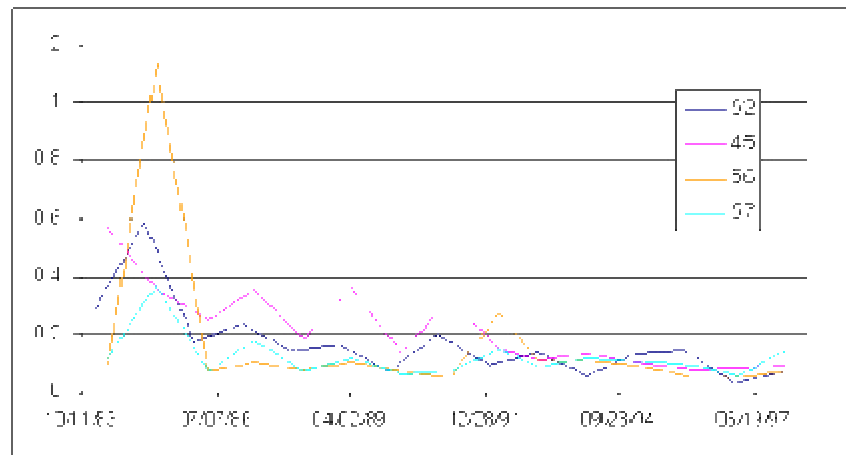
*Figure 31   Standard deviation of phosphate per year at four locations near
                  Drachten*

The decreasing trend in variance is evident. The graph also confirms that the

variation in the standard deviation itself is decreasing over time. The decrease

in standard deviation itself means that the values are *stabilising in space*,

while the decrease in the variation of the standard deviation means that the

values are *stabilising in time*!

5.5   Taking a different perspective

5.5.1   The data cube

In the previous paragraph the water quality near De Leijen was analysed through animation. A second part of the developed prototype allows visualising an entire dataset in a single 3-d dynamic map.

This paragraph considers the phosphate concentration in the entire province of Fryslân. A 3-d dynamic map consists of a number of thematic maps combined with a cloud of points. Each point in the cloud of data represents a value on a specific date ranging from the transformed coordinates of the start and end date of the dataset. The points therefore fill a cube of space (hence the term data cube).

The 3-d dynamic map below contains the summer average of the phosphate concentrations in the province over the period 1984 to 1998. The summer average in a year is defined as the average of the values from April to (and including) September in that year.
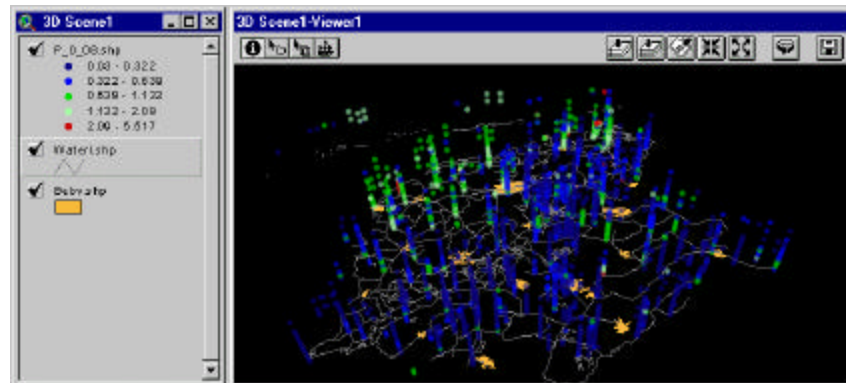
Figure 32   3-d Dynamic Map of phosphate concentration in Fryslân

In the northwest part of the province (upper left part) it is immediately apparent that phosphate concentrations are high compared to other parts of the province. This lasts over the entire period of the dataset. On the other

hand, in the southeast part of the province, the phosphate concentration is
high at first, but improves over time.

The difference can be explained by examining the soil type (Ormeling, 1976,
p. 10) in the province. The northwest part of the province consists of various
types of clay while the southeast contains sand and moor types of soil. Clay is
known to contain higher phosphate by nature than sand or moor, which
explains the observations made by viewing the dataset in a 3-d dynamic map.

5.5.2   Availability of data

Apart from inspecting the values, information on the availability can also be
revealed from these dynamic maps. This is illustrated by the following figure:
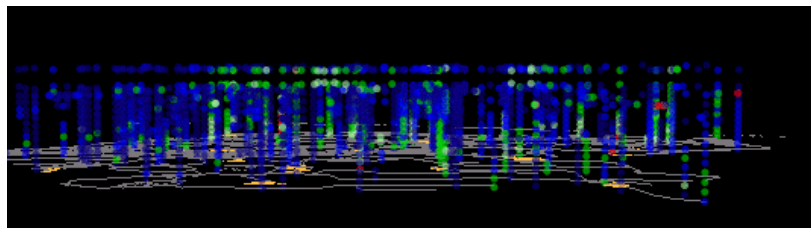
Figure 33   Availability of data visualised through a 3-d dynamic map

In this map, the temporal axis is pointing straight up. Near the most recent
data (the top of the cloud of points) there is a gap in the dataset. For the years
1996 and 1997 there are no values available in this dataset. This can be
checked using the identify tool available in the 3-d view, and selecting some
points near the gap, or query the measurement database.

5.5.3   A closer look at the animations

The animation functionality available in the prototype selects data for a
specific time slice from the measurement database. For this purpose, the
most recent available measurement is selected in the time slice (see A3 for
more details). Classifying the measurements in a time slice on the date of the

values instead of on the values themselves can show how that may vary per
location.

This can be done using a traditional map as in the following figure
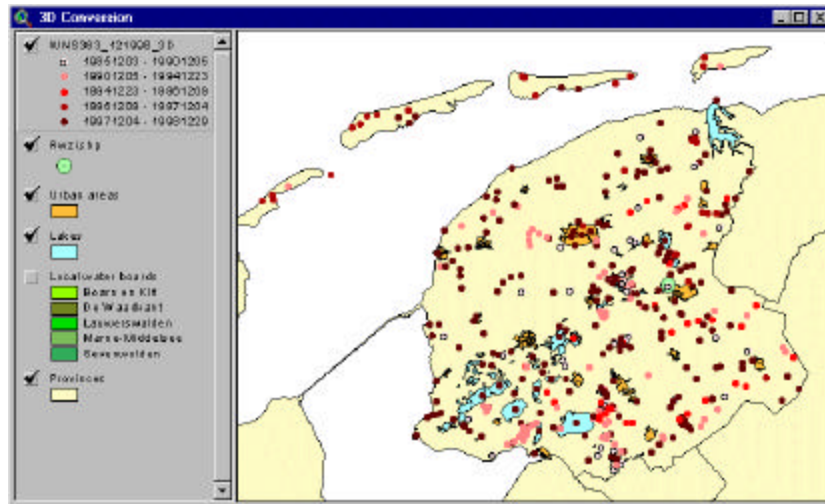
Figure 34   Classification of dates of data points in a time slice (2-d)

Although the classification clearly distinguishes recent and old data, there is
no means to judge the time slice, other than using the 5 classes. This is
entirely different from the 3-d dynamic maps below:
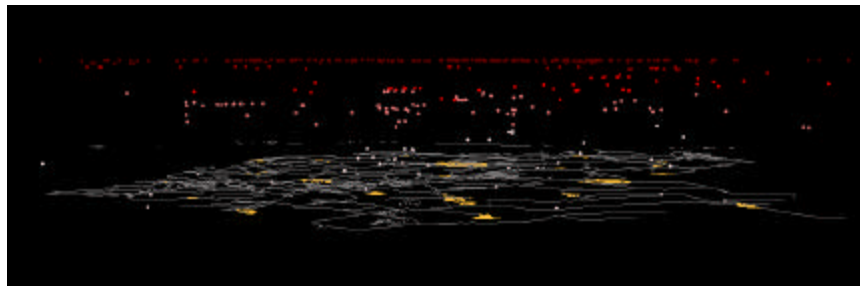
Figure 35   Classification of dates of data points in a time slice (3-d)

In this case the height of a data point is directly related to the date of the
measurement at that point. Higher points represent recent measurements.
The colours used here are based on the same classification of the dates as in
the 2-dimensional representation, but now as additional information.

6   Evaluation of the spatio-temporal prototype

6.1   Introduction

This chapter contains an evaluation of the spatio-temporal extension. Experiences that were collected from the experiments described in the previous chapter are collected here.

A SWOT analysis is used to evaluate different aspects of the spatio-temporal prototype. The aspects reflect the main components of the spatio-temporal GIS (see Chapter 3).

SWOT stands for **S**trengths, **W**eaknesses, **O**pportunities and **Th**reats Analysis. Strengths and weaknesses relate primarily to internal issues of the prototype. What is the prototype good at? What are its weaknesses? On the other hand opportunities and threats are primarily to do with external and future issues. Does animation indeed contribute to an increased knowledge in spatio-temporal analysis? What will be the influence of developing technology on spatio-temporal analysis?

6.2   Storage

The table below contains the results of the SWOT analysis with respect to the storage component of the prototype.

Strengths	The database is implemented in an open environment that can be accessed using ODBC or using office automation products.
	Using SQL the data can be aggregated (for example calculate summer averages as was done in 5.5).
Weaknesses	The database is in a specific format. The prototype does not contain functionality to import data from other sources into the database.

		Due to performance considerations, the database does not fully comply the Adventus model.
		There is no functionality to validate the measurements.
		The prototype makes use of temporary storage of data when used in animation or 3-d dynamic maps. There is no functionality to manage these temporary files properly.
		To function properly, the current prototype requires the data tables to be sorted on the date of the measurements.
	Opportunities	The data model is simple and straightforward and can contain many different kinds of measurements. Water quantity information and information on the operating status of hydraulic works could be entered in the database. Analyses similar to those presented here can be carried out to support the evaluation of water management strategies. The prototype could even be filled with for example crime related data and counter actions taken by law enforcement agencies.
	Threats	When large amounts of data are stored, performance might decrease rapidly.
		Water boards have in use a wide variety of databases to store measurements on water quality and quantity. The Adventus data model is not supported yet in all of these databases.
		The database used here was based on the generally accepted Adventus data model. However, a single logical data model can still result in several actual implementations of databases. This can originate from the fact that different database platforms use different data format (for example Single versus Real versus Floating point numbers) or use different indexing names.

Table 6   SWOT analysis of storage component of the extension

6.3   Visualisation

The SWOT analysis for visualisation is split up into two parts, one for

animations and one for the 3-dimensional dynamic maps.

6.3.1   **Animation**

The results of the SWOT analysis for the animation component are presented

below.

Strengths	Temporal brushing and focussing is supported, by entering both start and end date of the animation as well as the number of time steps to be used.
	Apart from animation, the user can browse through the dataset to visualise specific moments in time or start an animation from some point in time.
	When viewing a specific time slice, normal GIS functions are available and the data of the animation can be viewed directly.
Weaknesses	There are no options to control the speed of the animations.
	During application of the prototype it appeared that the query used to select a time slice was not functioning well. This became clear since there was too little variation in the type of value being animated, when compared to the time series at some locations. A solution appeared to be to make sure that the data in the database was stored in ascending order by date.
	The animations create graphic objects for the time slices. In order to know the actual value at some point in time, the user must identify the location and then look for the proper column (corresponding to the desired date).
	The data in a time slice represents the most recent available measurements at each location. This can create confusion when searching for temporal patterns but assures a high point density in the slice.
Opportunities	The procedure for animation developed here makes use of available classification functionality to assign a colour to a point feature based on the value at that point at some specific moment. This can easily be extended to line and area features, as well as to fields (grids) of data.
	In addition to colour, the animation could rotate or resize shapes according to some values. The animation of two parameters in one shape using different shape modifiers could be an alternative to using two different views.
Threats	Performance could be a threat when large numbers of measurement locations are animated. The current algorithm is performing at top speed. The fact that a general purpose GIS was used and common data formats, means that no software optimisations could be applied.

	Animation itself provides no quantitative information on temporal processes. In both cases of the application, there was no hard evidence that the suggested trend really took place. Spatio-temporal patterns are therefore hard to find.

Table 7   SWOT analysis of animation component of the prototype

6.3.2   3-d dynamic maps

The results of the SWOT analysis for the 3-d dynamic maps are presented

below.

Strengths	The 3-d dynamic visualisation gives provides a means to view an entire dataset at once. Gaps in the dataset or extreme values can be determined easily. The 3-d dynamic maps can be used to analyse the data on actuality.
Weaknesses	When compared to the 2-dimensional maps used in the animation component, the analysis functionality of 3-d dynamic maps is limited. The use of the 3-d dynamic maps is not automated in the prototype as much as should be according to the requirements ease-of-use and seamless integration.
Opportunities	The 3-d view in ArcView can be exported to VRML, allowing disseminating the presentation of data and analysis results over the Internet easily.
Threats	Navigating through the 3-dimensional data cube (rotate, zoom, pan, fly-over) requires considerable skill. Because of the flexibility in position to view the data cube, it is easy to loose the proper geographic reference, resulting in incorrect conclusions.

Table 8   SWOT analysis of 3-d dynamic maps component of the prototype

6.4   Query

The table below contains the results of the SWOT analysis for the query

component of the prototype.

Strengths	As long as the result of the query fits the structure required for animation or 3-dimensional visualisation, there are no limitations on the query used.
Weaknesses	The query functionality of the ArcView Database Access extension is limited.
Opportunities	Several researchers have developed extensions to query languages that implement spatial and temporal concepts. These concepts would greatly enhance the analysis capabilities of the prototype.
Threats	This prototype relies on the established technique of Relational Database Management Systems and the associated query language SQL. With the advent of object-relational databases and the introduction of Internet technologies (specifically search engines) in software applications, it can be questioned whether their will be a place for SQL in the future.

Table 9   SWOT analysis of the query component of the extension

6.5   Analysis

The table below contains the results of the SWOT analysis for the analysis

component of the prototype.

Strengths	The prototype makes it possible to combine different types of analysis: ? Standard GIS analyses (including spatial statistics through ArcView extensions). ? Time series analysis (by copy/paste to a spreadsheet). ? Spatio-temporal analysis through animation and 3-d dynamic maps.
Weaknesses	The prototype only provides a framework within which analyses can be carried out. Doing the actual analyses relies heavily on the available functionality of ArcView (such as Spatial Analyst) or Microsoft Access. In this study the evolution over a period of 15 years of water quality in Fryslân was used as a test-bed for the prototype. During this period considerable change to human activity and infrastructure has taken place. These

	should be taken into account as well in a true spatio-temporal analysis.
Opportunities	The prototype can be used to browse through a dataset, look for relationships or patterns and formulate hypotheses. These can then be verified using the same instrument. Different types of analyses (thematic, time-series, statistical) can be carried out in combination with the prototype.
Threats	Spatio-temporal relations (convergence, similarity and stability) are hard to quantify.

Table 10   SWOT analysis of the analysis component of the extension

6.6   Analysis of the user requirements

Apart from the four main components of a spatio-temporal GIS, four main

requirements were formulated (section 4.1.1). The functions of the prototype

(animation and 3-d dynamic maps) are put against these requirements below.

Seamless integration	The function to create 3-d dynamic maps only consists of the transformation of time to a spatial coordinate. Visualising and analysing the data cube is done using available ArcView 3D Analyst functionality. The animation function does not even require availability of the 3D Analyst extension to ArcView. Whenever an animation is paused, all of ArcView's analysis functions can be used.
Ease of use	Both functions are as easy to use as is ArcView itself. The animation function requires no special knowledge. The 3-d dynamic maps require the ability to use the movement controls of the 3-dimensional views that come with 3D Analyst, but not more than that. For both functions the prototype provides the user with short help messages when editing some field on the dialogs.
Flexibility	Both animations and 3-d dynamic maps were developed as additional functions to existing functionality. The user is free to add thematic information for visualisation or analysis. The use of the functions is not restricted to some specific scenario. The user can select to animate one or two themes over a specific period for a selected number of times and using a selected number of slices.

	In addition the user can select to use different geographic areas and zooming scales. The database can contain any type of data as long as these data can be stored in the prescribed structure (section 4.2.2).
Transparency	The function developed to support animation (Figure 17) fulfils this requirement. Selecting a type of value to animate and a legend to use is enough. The animation function retrieves data from the database when necessary. However, this assumes that the measurement database contains all possible types of values, which is not often the case. The 3-d dynamic map function (Figure 19) requires some user activity before a dataset from the measurement database can be visualised. The actions are performed using available ArcView menu items that can be automated.

Table 11   Analysis of the user requirements

7   Conclusions and recommendations

This final chapter of this thesis contains an overall evaluation of the

experiments. Conclusions with respect to the validity of the statement are

drawn and recommendations are made

7.1   Conclusions

The aim of this thesis (section 1.3) was to assess the possibility to perform

spatio-temporal visualisation and analysis as an addition to available GIS

functionality. For this purpose a prototype has been developed that

implements two types of spatio-temporal visualisation, namely animation and

3-d dynamic maps.

These functions were used in the analysis of water quality parameters in the

province of Fryslân in the Netherlands. From the application of the prototype it

can be stated that there is no technological barrier to extending regular GIS

with spatio-temporal functionality.

The prototype allows for animation and 3-d dynamic maps to visualise spatio-

temporal data. Both types have particular strengths and weaknesses for

visualisation and analysis (sections 6.3.1 and 6.3.2). It can be stated that the

two are complementary instruments to visualise or analyse a dataset. The

animation function implemented in the prototype is strong at comparing

different parameters in relation to each other (spatio-temporal patterns such

as convergence, similarity and stability, section 3.5). The 3-d dynamic maps

make it possible to view an entire dataset at once and to assess data

availability.

The prototype allows for two types of querying a dataset. First the data

selected for visualisation is selected by SQL queries and second the use of

tailor-made legends provides a means of classifying and filtering before presentation.

The fact that the prototype consisted of a number of distinct components indeed resulted in the possibility to extend the functionality of one component without having to modify any of the other components. This experience supports the claims of the component-based development methodology.

The prototype by no means represents a full spatio-temporal GIS. There are various additional functions that could be included in the prototype, among which are the spatio-temporal relations that were identified in section 3.5. For now these relations have to be translated to queries that can be executed on the database or can be visualised using custom legends. Of course this will be difficult for more complex (or combined) spatio-temporal relations. Developing functionality to support these types of analyses is beyond the scope of this study.

7.2   Recommendations

As stated above one cannot speak of a spatio-temporal GIS yet given the functions of the developed prototype alone. As stated in the study approach (section 1.4) prototyping is a software development methodology that starts with a rudimentary version of the desired application that is refined in a number of design, build and evaluation cycles until user requirements are met. The prototype developed as part of this study can be seen as the result of the first cycle and requires further cycles to become a true spatio-temporal GIS.

This study focused on the technological part of spatio-temporal analysis. It was assumed that spatio-temporal functionality such as animation is indeed effective in the analysis of data over a long period to discover trends and

such. The prototype developed during the study can be compared to regular analysis functions (such as time series analysis) to assess its effectiveness.

During application of the prototype, it became clear that although powerful, animation alone is not enough to recognise spatio-temporal patterns. For this purpose research in the objective quantification of spatio-temporal patterns should be carried out.

This study has focused on the spatio-temporal variation of certain types of instantaneous measurements collected at discrete locations. Other temporal aspects of spatial features (such as change to geometry or location, section 2.3) were not included. As mentioned in the SWOT analysis (section 6.5) it is essential to include changes to the environment as well as changes to the parameter under investigation. The prototype could be extended to include these temporal aspects as well.

The spatio-temporal prototype consists of a number of distinct components. As mentioned in section 2.5 the concept of component based development plays an important role in geographic software development nowadays. The impact this concept has on existing GIS and the new options that emerge for analysis deserve further study.

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Internet resources

Adventus, http://www.adventus.nl

AVS Inc., http://www.avs.com

Ctech, http://www.ctech.com

ESRI Inc., http://www.esri.com

GIS-ZES, http://www.gis-zes.nl

GOCAD, http://www.ensg.u-nancy.fr/GOCAD

INTWIS, http://www.intwis.nl

Mathsoft, http://www.mathsoft.com

NotNot, http://www.xs4all.nl/~notnot

OpenGIS, http://www.opengis.org

RSINC, http://www.rsinc.com

SPSS, http://www.spss.com

A   Technical issues

This appendix contains a more technical description of some aspects of the spatio-temporal GIS prototype.

A.1   The connection to the database

On Microsoft Windows (all tastes), ArcView uses ODBC (Open Database Connectivity) to connect to databases. The object model of ArcView 3.2 contains two classes that can be used to connect to a database: SQLCon and ODBCConnection. The prototype uses the SQLCon option.

A SQLCon establishes a connection to an SQL database. ArcView users can choose the SQL Connect choice on the Project menu to open the SQL Connection Manager window and connect to and query SQL databases.

The results of a query against an SQL database are stored as an ArcView virtual table that can be joined, linked, and summarised like any other ArcView virtual table.

Note that apart from the connection from ArcView to the database, simultaneous access can be gained by opening the database directly from Microsoft Access. Modifications to the dataset performed from within Microsoft Access become visible to ArcView (for example, new types of values being added, or new data for existing types). In this sense both Microsoft Access and ArcView can be considered clients to the database server as is depicted below:
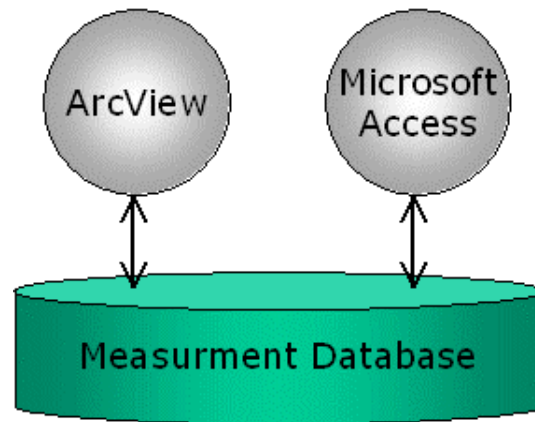
Figure 36   ArcView and Microsoft Access clients to the measurement database

A.2   **Animating a dataset**

One of the main problems faced when creating an animation is performance.
In the developed prototype performance is influenced by the time to recover
the data to display and the time to redraw the map.

The data to display is the result of a query to the database. Given the amount
of data and the complexity of the queries, this limits the performance. This
was experienced in early versions of the prototype. To avoid unnecessary
queries the results of the queries in an animation are 'cached' in the theme to
animate (see Figure 17).

The time to redraw the map depends on the number and the complexity of the
map. A map in ArcView is displayed in a View. Apart from the various themes,
a set of graphic objects can be associated to the View organised in GraphicList
objects. ArcView can redraw an entire view, a theme, including those themes
that are 'on top' of this theme and the GraphiList associated with the view. The
prototype uses the last option, since it is fast and gives the least amount of
flickering between time slices.

Using this option meant that for every legend applied in an animation, the

background colours have to be set. The colours of the graphic are created

using the BasicMarker object of ArcView. This object only has a background

colour! BasicMarkers are combined as layers into CompositeMarker objects that

therefore do have foreground and outline colours in addition to the

background colour.

A.3   Selecting data for a time slice

The prototype selects the data for a specific time slice in an animation using a

query similar to the following:

```
SELECT    Last(MPNIDENT), Last(MWADATUM), Last(MWAWRDEN)
FROM      DataTable
WHERE     (MWADATUM <= #mm/dd/yyyy#)
GROUP BY  MPNIDENT;
```

A consequence of this is that if at some location there are a few 'ancient'

measurements available, these will show up in every time slice. On the other

hand, since the data considered in this study is measured on average every

month, limiting the data used in a time slice to only those values measured

exactly on the date of the time slice, normally would result in very few data

points. This could lead to loss of geographic pattern recognition possibilities

that requires a high data point density.

A.4   Accompanying CD-ROM

The CD-ROM that is supplied with this document contains an HTML-based

presentation of the prototype developed during the study, including the source

code of the prototype. The ArcView prototype itself is included as well with the

necessary data. To use the prototype, ArcView 3-D Analyst is required.