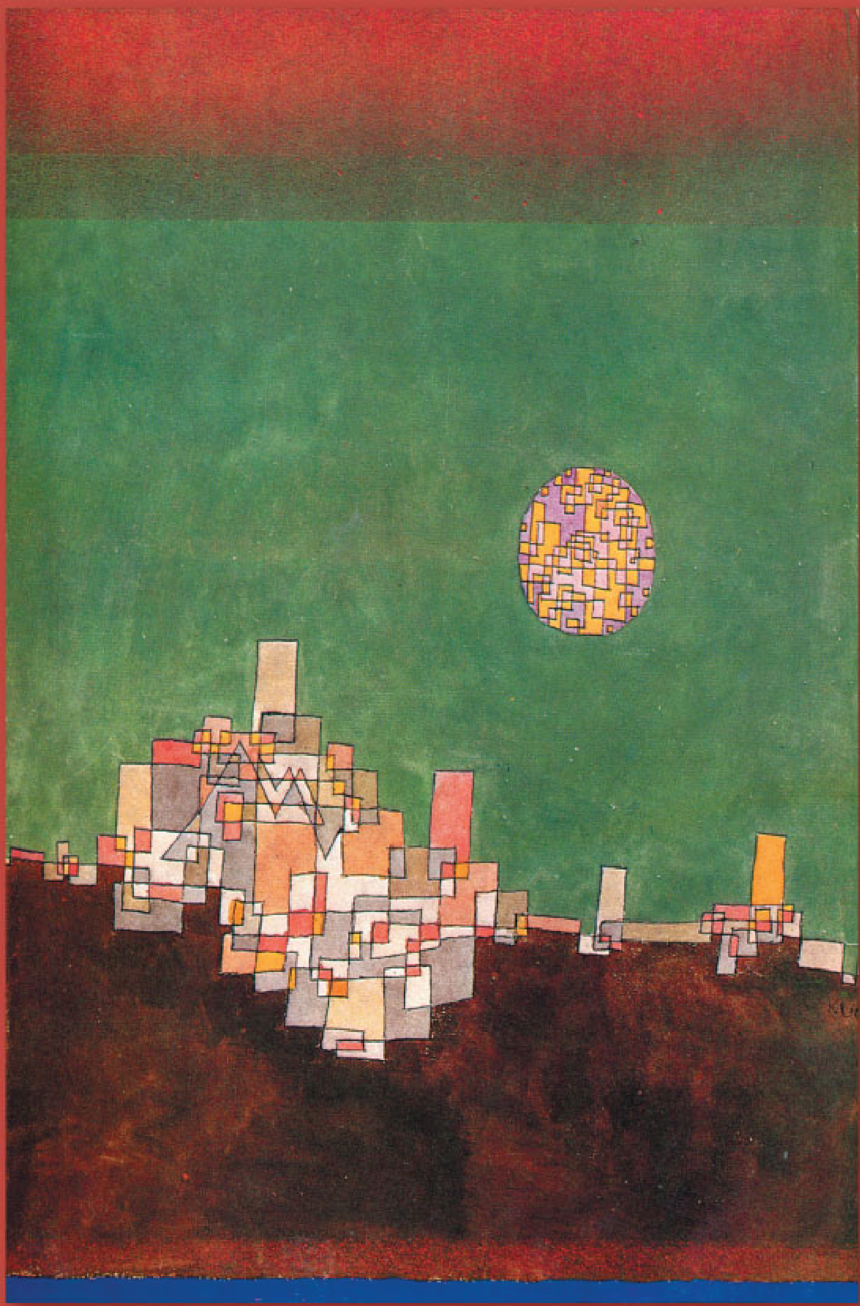
The core of GIScience

a process-based approach



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ITC

Chapter 12

Use and Users

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Introduction

Geoinformation systems and information products need to be adjusted to their uses and users. This can be considered as a design process to which we can apply a systematic approach (see Figure 12.1). Who exactly are *users* of spatial information? One view could be that users are those who use a system without the complete technical expertise required to fully understand that system. As most GIS and EO applications are complex, and since almost all maps today are produced by some combination of GISs and EO methods, by this definition virtually anyone who has ever looked at a map is a user: there will be components of the hardware, software, and management or data systems that even an expert is unlikely to fully understand.

At the same time, it would be wrong to think of a user as somebody who sits at the end of the research chain and is only fed information from various flows of observed or derived data. After all, as a recipient of spatial information, the user could have an important role in defining what information should be generated, as well as in what form it should be presented. Moreover, it is often difficult to distinguish the producer of information from the consumer of that information. Perhaps the term stakeholder, which has also been used in the discussion on governance in Chapter 1, is more appropriate, as it connects the use of spatial data and information to an identified issue for which access to and use of spatial data and information are considered to be relevant and important.

It is clear that enormous volumes of data are being generated. This phenomena was identified by the editors of a special 125th anniversary issue of the prestigious science journal *Science* entitled "What we don't know" as a significant scientific challenge.

Among other things, the editors posed 25 key scientific questions, one of which was "How will big pictures emerge from a sea of biological data?" [90]. Such a question can be easily broadened to "How will big pictures emerge from a sea of data"!

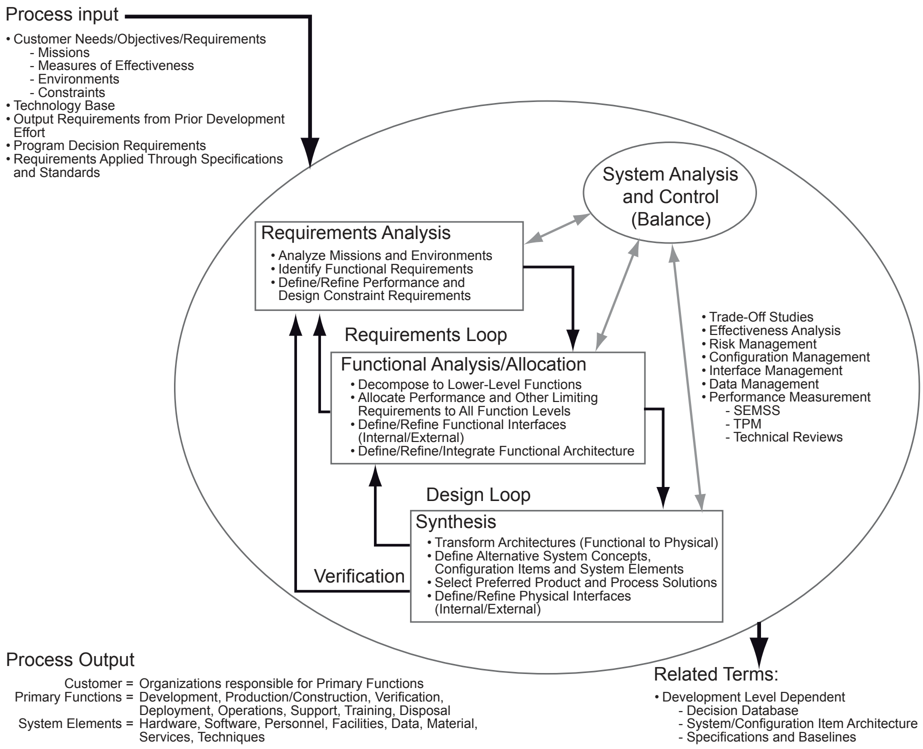

Figure 12.1 Systematic approach to the design of a new product for the consumer market

The objective of this chapter is to illustrate the enormous variety in applications of spatial information in daily life. Each application is of course derived from people perceiving a lack of spatial information related to a specific problem. After reading this chapter you will be able to explain a number of problems for which the solutions require spatial information. You also will be able to identify the stakeholders involved and their information needs. Each section in this chapter on *Uses and users* will, therefore, define the problem, describe characteristics of stakeholders involved and discuss responses or, where applicable, possible solutions. It is important to note that the usability of any system's products is determined by how practical and convenient the capability of that system is for users. In other words, a specific geoscience application becomes truly useful only when it provides a solution to a broad societal problem (such as a navigational aid, as described in one of the following sections, helps us optimizing our travel between locations given constraints such as road and traffic conditions.

There is a great deal of geographically referenced data available that is generated by Earth Observation, as well as other sources such as censuses and field observations. These data need, firstly, to be grouped, analysed and processed in order to generate useful information. In other words, to provide answers to *how*, *what*, *where* and *when* questions. The application of data and information allows us to answer *how* questions—for example, we can show *how* a remotely measured indicator such as the NDVI (Chapter 9) is related to green vegetation biomass (i.e. a linear relationship that saturates with an asymptote at higher levels of green vegetation biomass). The next level is an understanding of *why* a phenomenon occurs—for example, *why* NDVI is linearly related to green vegetation biomass. *Where* and *when* questions are of course the obvious ones in a GI Science context. Finally, we can use this understanding to come to a “wise” conclusion, such as predicting food production in an area and, if a food shortage threatens, to carefully consider options for short-term and long-term alleviation of that shortage. Such information products are therefore important inputs for the governance of famine relief efforts.

Applications may vary in their level of complexity. Multiple users may access geoinformation generated for applications as diverse as the assessment of flooding hazards, monitoring the condition of coastal defences, or managing nature conservation areas. Sometimes access is structured via GIS interfaces, specifically designed for multiple users. These issues are discussed in some detail in Sections 12.2-12.4. In Section 12.5 a further level of complexity is illustrated with the description of a flexible geoinformation application designed to allow multiple users in the Netherlands who are interested in spatial planning to exchange digital spatial plans at a national level.

12.1 The users of route planning and navigation systems

12.1.1 Introduction to route planning and navigation

For a number of years, computerized GISs were expensive and operators had to possess a high level of skill to be able to carry out even basic tasks. These systems were, therefore, inaccessible to all but a limited few. It was through one particular application, however, that the public at large also became familiar with GISs: route-planning systems. These systems, which were originally distributed on CD-ROMs, but are now widely available on the World Wide Web, help users to find the best answer to a fundamental question: "How to get from A to B?". These users may be individuals who want to move in geographic space for all kinds of reasons and by various means of transportation (e.g. car, bicycle or on foot), but they may also be professional transporters for whom time and distance have economic consequences.

Road networks are physical geographical structures and network analysis is the GIS operation applied for route planning. But route planning is only one aspect of answering the question "How to get from A to B?". Once the route has been determined, users will actually have to follow it. In the past this was usually done by consulting printed road maps and checking road signs, but modern navigation systems such as in Figure 12.2 assist users while moving from A to B by giving visual and/or verbal instructions such as "turn right after 300 m".

Figure 12.2
An example of a car navigation system.

This section presents the use and user requirements related to route planning and navigation. These requirements are the starting point for a discussion of the main components of this particular kind of GIS. The discussion will not be a technical one (for that, we refer readers to other chapters in this book). It will rather be approached from the perspective of system's use and users. The section concludes by giving us a glimpse of the future in relation to personal navigation systems.

12.1.2 Use and user requirements of navigation systems

Throughout the course of civilization, the need for travel and transport information has increased enormously. Fresh flowers are grown in Africa and transported to and sold in the Netherlands. People no longer necessarily live in the same town as where they work or go to university. And we take holidays in increasingly remote places. This has been made possible by improved means of transport, means that can move goods and people through space relatively fast and cheaply. In answering the question

"How to get from A to B?" a user aims at effective, efficient and satisfactory relocation in space, whereby she or he will normally make use of existing physical structures on (or above or below) the surface of the Earth. These physical structures consist of roads and paths. In this context, the *how* in the question means "along which route?" and not by which means of transportation, although the latter is, of course, a very relevant question as well. In view of the solution to be provided, it really matters whether the transport takes place by car, truck, airplane, bicycle, subway, train, boat or on horseback or foot.

There may be great differences in the purpose of relocation: transportation companies want to move goods or people from A to B in the fastest and cheapest way, with the lowest fuel costs. If a user wants to travel from A to B by truck or car, this may not necessarily be done by the shortest path. On the other hand, people on holiday, or those touring on a free Sunday afternoon, may not be interested so much in speed or even distance. They may be interested more in scenic and attractive routes with not too much traffic. In many respects, therefore, user demands and characteristics differ greatly. What they all have in common is that they do not want to get lost.

In their turn, governments also have an interest in optimal route planning and navigation, because they want to facilitate efficient travel and transportation. The latter, in particular, may lead to traffic congestion, the need for more roads, and unnecessary air pollution. In special cases, governments will want to prevent risks by not allowing the transport of hazardous substances in the vicinity of centres of high population concentration.

All in all, there is a need for tools or systems that help people to answer the question "How to get from A to B?". This question has two aspects, both of which can be related to the specific use and user requirements: (a) optimal route planning and (b) its navigation, i.e. actually following the planned route. In the past, it was very much up to the individual to find answers for these two aspects. People used their own experience, or the geographical knowledge of others, or they used traditional road maps. It is not hard to imagine that this often led to unwanted detours and unnecessary waste of time, money and fuel, not to mention marital disputes in the car! Thanks to the route-planning and navigation systems available today, the situation has clearly improved.

12.1.3 Navigation systems from past to present

In the early days of route-planning applications, a user had to buy a CD-ROM containing the application and the data in a shop and insert them into a personal computer. The resulting route description in words (containing distances, directions, locations and, possibly, time indications) and/or route maps could be printed on paper for navigating in the car. So, users would need a PC and printer. Nowadays, route-planning applications are freely available on the World Wide Web. Routes may well be planned with, for instance, Google Maps, one of the many route-planning applications now available on the Web.

In the past, navigation focused on answering the question "where am I?" and on taking subsequent decisions on directions to follow, turns to take, etc. The answers and decisions were based on linking map displays and route descriptions with what people saw in reality (including road signs). In the development of navigation systems, the biggest problem to be solved was that of assisting users to determine their (or their vehicle's) geographical position. In this respect, the availability to the public of GPS (Global Positioning System) after 2000 gave an enormous boost to non-military navigation systems. These systems now come as standard features in mobile phones and cars as well as stand-alone navigation devices.

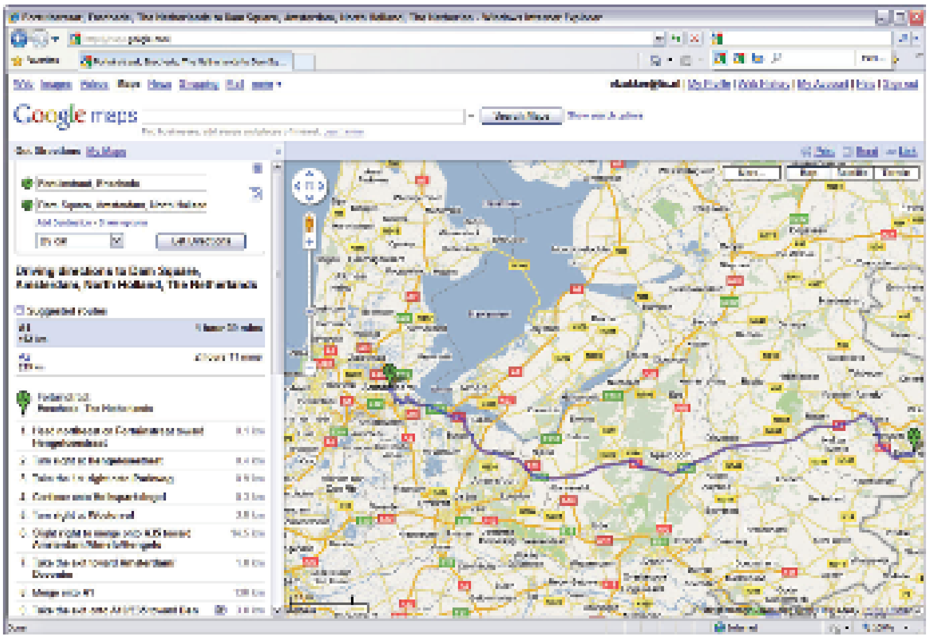

Figure 12.3
A route planned for a motor vehicle with the help of Google Maps going from ITC, starting at the Fortuinstraat (exit of parking lot) and ending on the dam square in Amsterdam. Source: [40]

The systems are not large (typically smaller than the palm of one's hand), primarily consisting of a display—a (touch) screen—on which the route map and further instructions are shown. With navigation devices such as those manufactured by TomTom or Garmin, users can also plan routes by typing in a destination; a point of origin can also be typed in, unless you are starting from your current position, which the system already knows via the GPS receiver or other means of positioning that is part of the navigation device. After the user accepts the proposed route, the device will help him or her to follow the route by giving verbal instructions or indicating directions to be taken by graphic symbols such as arrows. Of course, the system must also have sufficient capacity to store all the geographic (digital map) data of the area in which the user is moving. The required geographical data may be stored on, for instance, micro SD cards, or may be obtained through mobile Internet.

Geographic data are an essential part of systems for route planning and navigation. There are companies that specialize in collecting these data (e.g. TeleAtlas and NavTech), which they then sell to other companies that build and market navigation systems. The data that are collected are essentially data about physical structures, consisting of nodes and lines (edges) that connect these nodes. The lines may be road segments or, for instance, bicycle tracks or footpaths. These physical structures do not only have geometric properties: all kinds of attributes can also be attached to the line segments. Examples of such attributes would be the average driving speed on a particular road segment (calculated on the basis of speed limits, nature of the road, the presence of traffic lights and even data about the amount of traffic), its scenic attractiveness, the surface of the road and whether cycling is allowed on a particular road stretches. The more attributes there are, the better the various uses and user requirements can be met.

In addition to the road (line) segments, the geographic database will also contain many nodes and their (x, y) locations. These nodes are potential destinations of users, e.g. Points of Interest (POIs) such as a railway station or a soccer stadium, which may also be useful as navigational features ("after passing the church on your right-hand side,

Figure 12.4
Personal geo-identification through the interaction of three different information sources: reality, cartographic representations of reality, and individual cognitive maps in the user's mind. Source: [26].

turn left"). Potential destinations in an address database may also be stored as points on a line segment.

Clearly, the size of a geographical database required for a route-planning or navigation system is enormous. After all, such a database would have to contain a comprehensive collection of geographic names (e.g. street, town and city names). Some databases may even contain several versions of the same toponym, to cater for differences in spelling.

The quality of the physical-structure data is crucial for determining whether users will trust and appreciate a route-planning and navigation system. In this context, the accuracy and currency of the data is also important. In 2009, a navigation system for inland waterways had to be taken off the market because of mistakes in the depths stored in the database!

Knowledge of the geographical position of a user and his or her system is an essential requirement for the navigation functionality of any particular system. The earliest in-car navigation systems determined the position of the car by means of transmitters and receivers mounted in the vehicle and on lamp posts along the streets, in combination with mathematical calculations related to the steering movements of the vehicle and distances covered from the starting point. Obviously this kind of positioning was rather cumbersome and prone to error. A real break-through occurred in the year 2000, when a dedicated military satellite-based positioning system became available for civilian use: the accuracy of the system was no longer reduced for military reasons. In the course of the last decade, the quality of GPS receivers in navigation systems has increased enormously, so the movements of the users can be followed dynamically with sufficient accuracy.

The software of route-planning and navigation systems usually displays the geographic data from the database in map form. The user may determine which area is retrieved by means of entering addresses or geographic names. Users may also interact with the map display and pan to the area they are interested in. Zooming in and out of the map display is also a very common feature of interacting with the system. When the system contains a GPS receiver, the location is usually represented on the map display and the surrounding geographic data are automatically shown. During navigation, the GPS location symbol moves smoothly over the road symbols because the software *snaps* the incoming GPS coordinates with those of the road networks in the database.

When users want to plan a route between a particular point of origin and a desired (indicated) destination, they will start executing a real GIS operation on the geographic database. This operation is called network analysis (see Section 9.5) and the typical function called upon is optimal path finding. What is optimal depends on the user as well as being related to the attributes that are attached to the line segments in the database. Users may opt, for instance, for the shortest path, or the quickest or most scenic path. They may also indicate whether they will travel by car, bicycle or on foot. As, for instance, the direction of travel is also important (particularly in the case of one-way streets), you may imagine that the routing is a far from simple mathematical exercise.

Once planned, a route is stored in the system and the user is guided along it. Navigation instructions are automatically provided when needed, i.e. when certain locations have been reached (determined from the incoming GPS data). If users deviate from the planned route (consciously or otherwise), the system will first give a warning and suggest that the user returns to the planned route or will later automatically re-calculate an alternative route to the destination.

Compared to the traditional printed maps, however, the roles of map displays in these systems have changed. These maps can no longer be regarded as databases that show all geographic information that may be relevant for route planning and navigation. They now provide a dynamic and interactive interface to the system and the geographic information it contains, and they present an overview of the planned route (for cognitive confirmation) and supporting navigation, particularly in complex geographical situations. Map displays are thus specifically designed to meet different user requirements. A clear example of this is, for instance, the use of an oblique map view during navigation and the rotation of the map view in relation to the direction of travel. System/map designers also deal with cartographic generalization (e.g. leaving things out, or representing them in a simplified way), brought about by the limited size of display screens and the frequent zooming out (and in) by users. Such generalization is steered by the characteristics and requirements of the users.

Route planning and navigation in practice

René Boensma works for Velda, a company in Enschede, the Netherlands. Velda assembles and manufactures various products, such as water filters and pumps, for the maintenance and care of garden ponds. These products have to be shipped to retail sellers such as garden centres throughout the Netherlands and other countries in Europe. René used to work for the company as lorry driver, but nowadays he is more involved in distribution planning. René was interviewed together with the company's Assistant Director, Alexander Dalenoort.

The distribution of Velda's products to its customers has two aspects: route planning and the actual transport (including lorry navigation) of the goods. Both are subject to the economic maxim "time is money". In this commercial setting it is not just a matter of finding an answer to the question "How to get from the company to the customer in the cheapest/fastest way?" After all, the company has more than one customer and it is inefficient to travel to a customer with a half-empty lorry. In the planning of a lorry's trip several factors have to be taken into account: the orders, which are placed in sequence of date of delivery/urgency; the geographic location of customers; the volumes of the orders and the carrying capacity of the lorry; the height of the lorry (in view of the height limits of viaducts and fly-overs); and much more. In the past, René did this planning mainly on the basis of his experience with travel times, as well as with the help of printed wall maps provided by office suppliers. As a lorry driver, René trusted his experience, road signs and detailed printed maps such as town plans to navigate his route.

René Boensma, a route planner and former lorry driver of the company Velda (photo courtesy Velda BV).

Since the year 2000, transport companies use computerized route-planning and navigation systems. At the same time, traffic has become much more congested and route-planning and distribution problem much more complicated. For instance, customers demand specific delivery times (e.g. before 10:00 a.m.), and garden centres, which have united into big purchasing organizations with a network of distribution centres, have contracted specific transportation companies for the collection and delivery of goods. A relatively small company like Velda, with only five lorries, could not make deals with its customers anymore without accepting the condition that the goods had to be transported by a specific trucking company. These big companies also transport the products of other suppliers to garden centres and this may simplify the route-planning problem if the complete carrying-capacity of the lorry is taken up by goods for just one customer. On the other hand, the factors mentioned above and the increasing importance of the "time is money" motto have led to the development of more sophisticated route-planning software and even "fleet management" systems that only big transportation companies can afford. In fleet management systems, the actual real-time position of lorries is always known, allowing the central office to take measures in the case of problems (e.g. call the customer if there is a delay or re-direct a driver).

For these reasons, despite the overall growth of the company, Velda disposed of four of its lorries and put out to contract the transportation of its products to third parties. There is now only one lorry left and its driver definitely profits from the possibilities offered by modern traffic navigation systems. However, both René and Alexander say that they would never go anywhere without a traditional, printed map. Such a map gives a better overview (before and during the trip) and can be used in cases of emergency (loss of GPS signal or a power problem with the navigation system). Also, because of their experience and knowledge of local situations, they sometimes do not trust the route indicated by the system. René Boensma concluded by saying that for an experienced person like him, the map display on the screen of a navigation device plays a very important role in his decision-making on the road, as well as confirming his local knowledge.

Another example of a situation in which careful routing is required is when transporting hazardous materials such as explosives, flammable liquids, oxidizing substances, poisonous gases and radioactive materials.

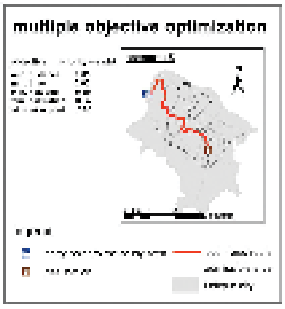

Figure 12.5
Optimal routing for transportation of petrol derivates in Lalitpur, Nepal, based on sample weighting scenario for the objectives involved [5].

Many factors play a role in the process of route optimization for the transport of hazardous materials, such as the number of people exposed to the risk (e.g. schools along transport routes), the accident rate on certain route segments, and travel times and distances. In many countries, most weight is given to economic factors and the accompanying risks are somewhat neglected. This can in part be explained by difficulties in finding suitable solutions for the route optimization problem. In response to this challenge, Avendano Castillo [5] developed a route-optimization model that can be used as a decision-support tool to take into account economic and risk factors when assessing routes for the transport of hazardous materials. As a case study, he selected the transport of petrol derivates in the city of Lalitpur, Nepal. A technique called "multiple-objective mathematical programming" was applied to calculate optimal routes that were dependant on five objective functions that were to be optimized (minimized): travel time, travel distance, risk for the population, risk for the urban environment, and risk related to natural hazards. Figure 12.5 shows an example of optimal route obtained with that model.

12.1.4 Future developments

The usability of the systems is still far from optimal and many improvements can be made. The attention of users is often diverted by the information on the display screen and by the verbal instructions. User research is required, for instance, on the relationship between geographic reality, the representation of reality by the system (through map displays, but also through verbal and graphic navigation instructions) and the mental maps in the minds of the users. Questions like "where am I?" and "which direction should I take next?" should and can be answered better with the help of route-planning and navigation systems. In this context, landmarks play an important role. In addition, the spatial awareness of people should increase, if only to prevent that they become totally lost if there is no longer any GPS signal, or when the device's battery is exhausted. Some spatial awareness is thus required in order to prevent that users blindly follow the navigation instructions of the system. Such behaviour has resulted in car drivers ending up in canals at night and truck drivers getting stuck in narrow village streets. In other words, systems should not only be based on use and user requirements, but should also foster and develop people's spatial abilities.

A problem that still awaits a solution is that of positioning indoors (where satellites are not "visible" for the receivers). Such indoor positioning is relevant for navigation in, for instance, commercial shopping malls, museums and subway systems. At the moment, there are simply no accurate, low cost, small-sized and infrastructure-free positioning solutions available, but much research is being done in this field. Avenues being explored include dead-reckoning systems (inertial systems with, for example, accelerometers, gyroscopes and magnetometers) and reference-based systems (such as cellular mobile-phone networks, WLAN/Wi-Fi, WPAN/Bluetooth, RFID, laser, ultrasound, Ultra-Wide band).

One interesting development is the collection and use of temporal geographic data for route planning and navigation. In fact, it would be useful if the amount of traffic on various road segments (which influences traffic speed) at different hours of the day and under different weather conditions could be used for dynamic route planning (e.g. calculate alternative routes to avoid traffic jams). Such data are already available, either as *live* data or as averages from the past, and their implementation is already operational. The data are collected by sensors in the surface of the road, or through other means. TeleAtlas, for instance, has an agreement with telecom provider Vodafone to get data about the lines of cell phones standing still on a particular road segment. This is an example of users themselves generating data that may be used by other users.

Other developments in this field, known as neo-geography, also affect systems for route planning and navigation. In the OpenStreet Map initiative, for instance, it is road users themselves who collect data about the road network, not only data about the geometry of these roads (simply stored by recording GPS traces), but also about their attributes. In a similar initiative in the Netherlands, cyclists (volunteers) collect all kinds of attributes of cycle paths (such as safety at night and the nature of the path's surface) that would never be collected by a commercial company. These data are made available to other users for route planning and navigation.

12.2 The users of early warning systems

12.2.1 Introduction to early warning systems

The WHO Collaborating Centre for Research on the Epidemiology of Disasters (CRED) defines natural disasters as events that either kill at least 10 people, affect at least 100 others and lead to a state of emergency being declared, or a call for international assistance to be given [24]. The annual occurrence of natural disasters continues to rise globally. And as vulnerability to disasters is also rising worldwide, the economic damage incurred and the number of people affected will continue to increase.

Disasters constitute a severe impediment to economic growth. This especially holds for economically less-developed countries: they have suffered more than 90% of all disaster-related fatalities and have been disproportionately burdened by the economic losses. Since around the year 2000, between 500 and 600 natural disasters have occurred annually somewhere in the world and these events routinely lead to global economic damage that is estimated to cost more than US$ 100 billion per year [55, 24].

The natural disaster that affects most people is flooding. In China, for example, by some estimates up to 200 million people were affected by flood events in 2007 alone. Most developing countries regularly experience some form of flooding, be it the result of storm surges along coastlines, the consequences of their annual rainy season, or due to snow melting in the mountains. There has also been a strong debate about hazards—which may lead to disasters—becoming more frequent and severe as a result of global warming. The changes we have already witnessed and that are projected to occur, affect various aspects of our environmental system. Those changes relate especially to general shifts in precipitation regimes that can either lead to stronger flooding or more severe droughts. In addition, countries such as Bangladesh, but also the Netherlands, have to cope with land subsidence, making coastal protection more challenging.

We can, therefore, expect especially flood-related disasters to get worse in the future. This trend is further intensified by increasing urbanization, as most urban areas are located close to the coast or major rivers [53]. Another factor is the growing global population. The poorer members of populations are increasingly marginalized. This forces them to settle in hazardous areas such as unstable slopes or flood plains, where even modest flooding could lead to a disaster. Such spatial marginalization is usually also coupled with socio-political marginalization, meaning that lack of access to education, adequate healthcare and sanitation, but also lack of access to financial resources and political (lobbying) power, lead to increased vulnerability [30].

Thus, there are many good reasons for studying flood-related hazards and working towards flood-disaster mitigation. This section describes how our GI science tools relate to these hazards, the users of such tools and data or the information they ultimately deliver. Two individuals are introduced who are not only studying flood-related hazards but who are actively involved in keeping people safe from flood events. We will learn more about how they do that and why they are frequent users of GI science.

12.2.2 Users of early warning systems

Asking who uses GI science on flooding leads to a surprisingly broad answer. In principle, anyone who has ever been affected by flooding or who has ever sought early warning information or advice on how best to cope with or recover from flooding is a potential user of GI Science. The information products do not have to be very sophisticated: anyone watching a weather forecast to learn about threatening rainfall situations or looking at a flood evacuation plan fits this description. At another level of sophistication, there are professionals who actually use geodata and tools to prepare those forecasts and plans.

We can, therefore, distinguish between expert users who are equipped to use raw data and sophisticated tools to create relevant information and more casual users—laymen—of this information. The latter group of users has little understanding of the models or data used to create the products intended for them. The sophistication of the professional group strongly depends on the technological means available, the funding needed to acquire the data and tools, and the technical capacity of staff. It is easy to see that there can be great differences in how flood hazard is being dealt with, especially between more and less developed countries. There are also comparable differences amongst lay users. In western countries it is normal for people to have internet access at home. They have ready access to large amounts of hazard-related information, as diverse as actual information on river levels, detailed local storm surge warnings or real-time rainfall radar maps. People in poorer countries, on the other hand, may only get some radio reports or information via community bulletin boards. The rest of Section 12.2 will focus on flood risk management to illustrate the use of geoinformation in early warning systems.

Olaf Neussner, a flood-risk specialist from German Technical Cooperation (GTZ) working in the Philippines.

Interview highlights

"Owing to limited availability and/or reliability of official geoinformation in the Philippines, we rely to a considerable extent on gathering data ourselves."

"Without maps, and the remote sensing and GISs to produce them, it would be very difficult to establish the Flood Early Warning System".

"...we would be happy if the official mapping agency would update the base map of the area (50 years old), and share their GIS file".

Olaf Neussner has been working in the Philippines for over 14 years and, together with national and regional organizations, has devoted much effort to flood-risk management. In his own words, he works towards reducing casualties and damage caused by river flooding in Region VIII of the Philippines (Leyte and Samar Islands). He explains: "We work on Flood Early Warning Systems (FEWS), and assist local governmental offices in the establishment of such FEWS. This includes the identification of flood-prone areas with GI Science tools". Olaf and his colleagues make use of EO data and geodata processing methods for hazard, vulnerability and risk assessment, as well as the actual forecasting of floods. They also integrate administrative data obtained from publicly accessible sources and from governmental agencies, such as maps of flood-prone areas provided by the Mines and Geoscience Bureau. Valuable input also comes from people in potentially affected areas themselves, thus bringing together the professional and lay users of GI Science.

The approach applied in the Philippines is similar to what is being done in other countries, although variable approaches to flood-risk management exist, as do solutions at different scales. The Netherlands has suffered greatly from major flood events in the past. After all, it is a country with a long coastline and in which some 15 million people live in areas that lie below sea level. Moreover, the Rhine and Waal rivers run through the Netherlands and may bring flood waters from neighbouring Germany.

12.2.3 Historical flood events

Europe's worst flood event in recent history occurred during a storm flood in the North Sea on the night of 31 January 1953, affecting mainly countries on the edge of the North Sea. The tidal surge exceeded 5.6 m above mean sea level, with the resulting flood and storm-driven waves spilling over and breaking through coastal defences. Fatalities included 1835 people in the Netherlands, 307 in England and 28 in Belgium; 150,000 ha, or nearly two entire provinces, were submerged. A photograph of the flood is shown in Figure 12.6.

Figure 12.6
Netherland's worst flooding in February 1953.

A more recent flood occurred along the Rhine/Waal rivers in 1995. The death toll was low (four people), but some 250,000 ha had to be evacuated and several billion Euros in damage was suffered. The Netherlands learnt valuable lessons from these events. An enormous engineering project, called the Delta Works, was initiated only days after the 1953 flood and a carefully maintained system of dikes to protect coastal areas has been set up. Figure 12.7 shows one of the massive barriers near Rotterdam that can be closed when a storm surge is forecast, principally to protect the areas around the mouths of the Rhine, Meuse and Schelde rivers.

Bas Overmars works at the Provincial Office of the Province of Gelderland, the region in the Netherlands that faces the highest risk of Rhine/Waal river flooding. He ex-

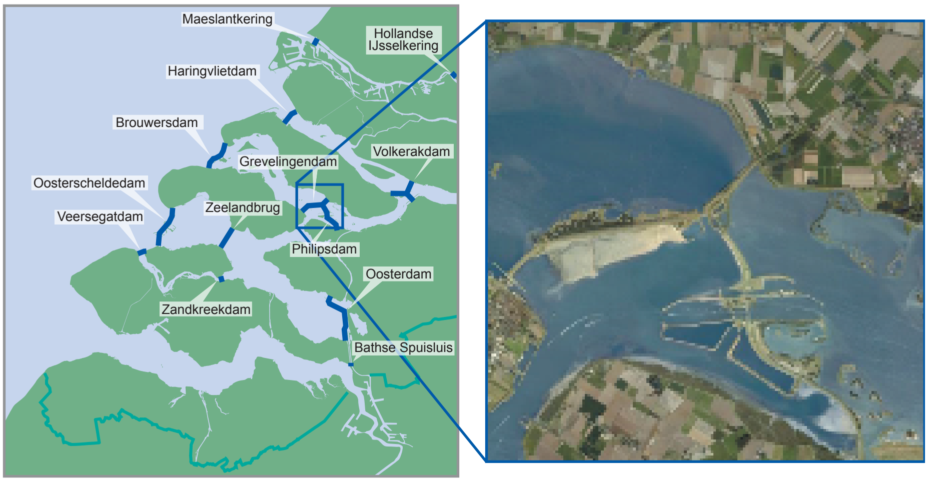

Figure 12.7
Dutch *Delta Works* to protect the heavily industrialized and densely populated western part of the Netherlands. Blue bars in the left-hand image are barrier constructions, such as the Philipsdam shown in detail on the right. Source: left [27], right [40].

plained that in general the river banks are heavily fortified with dikes (some of the 2500 km of dikes protecting the country border these rivers) and drainage systems. Still, flood management relies strongly on flood-model predictions and real-time data input such as precipitation and river gauge data from Germany. It also includes carefully planned evacuation scenarios, multi-agency cooperation plans and emergency drills. These are supported by effective communication channels, not least with the population that has the highest potential of being affected. Bas Overmars, highlights what the main purpose is of his flood-risk assessment and management work. It mainly involves acquiring knowledge of the water-cycle system and improving the availability of information for disaster mitigation during periods of high water levels in Gelderland (the Netherlands) and North-Rhine Westfalia (Germany). An important part of the programme is the organization of flood-response exercises. This ensures that the knowledge acquired is maintained within an organization. He emphasizes that it is important to describe such arrangements in written agreements.

12.2.4 The GI Science behind flood risk management

Both the Philippines and the Dutch example show that a number of types of geodata and tools are important in flood-risk assessment and risk management. Let us look at each of these in turn. What exactly is risk? Well, simply put, it is the resulting product of hazard and vulnerability. This means that we have a risk when a hazard, such as flooding of a certain magnitude and a certain periodicity, intersects spatially with what are called elements at risk (EaR). Such EaRs include people, but also their homes, their cars, the infrastructure they use and their industry; in short, anything that is of value and can suffer damage or destruction by the type of hazard under consideration. Thus the risk is high where we have a high concentration of high-value EaRs (e.g. major cities) and a large hazard. Note that this can result in a place that suffers from limited flooding several times per year having a level of risk that is similar to that of a place that can be hit by a rare but major flood.

To say anything about risk we must, therefore, have good knowledge of flood hazard. Such knowledge can be derived from historic records of flood events. Where we have a seamless record of flood parameters such as frequency, time of onset (i.e. speed at which the flood waters rise) and depth and duration of past floods, we can clearly establish the nature of the flood hazard we face, provided that the causes of the flooding have not changed significantly. This may not be the case everywhere, particularly in view of the climate-change related modifications to our natural systems. In addition, people have a tendency to straighten and dam rivers, clear forests that may otherwise absorb rainfall or slow down surface runoff, and seal the ground (e.g. pavements, buildings, parking lots), thus preventing water infiltration. This may lead to hazardous situations that change quite dramatically over time. A better way of understanding current flood hazards might be to use modelling techniques.

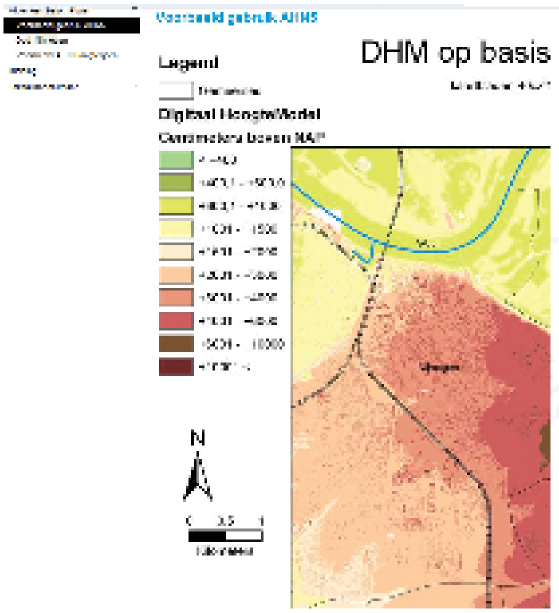

Figure 12.8
Digital surface model of the area around Nijmegen, the Netherlands. Source: [38].

Characterization and quantification of floods can be done with several hydrological and hydraulic models. For the Netherlands, a basin model can be used to estimate the discharge in a river as a function of rain and basin characteristics, e.g. shape, size, river cross-section, land cover and soils. Such a model produces at predefined locations along rivers hydrographs for rainstorms of a variety of periodicities (e.g. annual or 100-year floods). However, on flat and complex terrain, such as that of the Netherlands, this is not enough, as rising water will leave its river channel and spread out over larger areas. To understand such a situation, water flow over a dry surface in 2D space is modelled. To be able do this, a good digital representation of the terrain (i.e. DSM introduced in Section 4.5) is needed, one that includes above-surface features such as buildings, around which water would typically flow. An example of such a DSM is shown in Figure 12.8.

In the Netherlands, GI scientists are in the fortunate position of having a highly accurate DSM derived from airborne laser scanning (LIDAR) data that serves as input for the model. Laser scanning is ideally suited because it can obtain complex elevation information that allows the detection of both the top surfaces (tree tops, roofs, etc.) and the ground surface beneath vegetation. With appropriate filtering, a true representation of the ground elevation (DTM, see Section 4.5) can be derived. Or one can create an elevation model that retains all solid flood obstacles (buildings and other infrastructure) but has vegetation removed (since vegetation does not form an impenetrable barrier to surface flow). LIDAR's multi-elevation mapping approach becomes really useful where important structures, such as dikes, lie beneath vegetation. In the Netherlands such sophisticated modelling is already being done. Users of such a LIDAR-derived DSM do not necessarily have to be laser scanning experts. This is shown in a product that is developed by the Dutch provinces: an interactive risk map (see Figure 12.9). This map includes various data layers that the user can switch on or off. Also the extent of the map can be determined by the user by zooming in or out. Anyone interested in finding out the risk for natural disasters such as flooding can access the maps. Also other types of disasters e.g. human induced disasters due to storage or transport of chemicals can be mapped in this way by laymen.

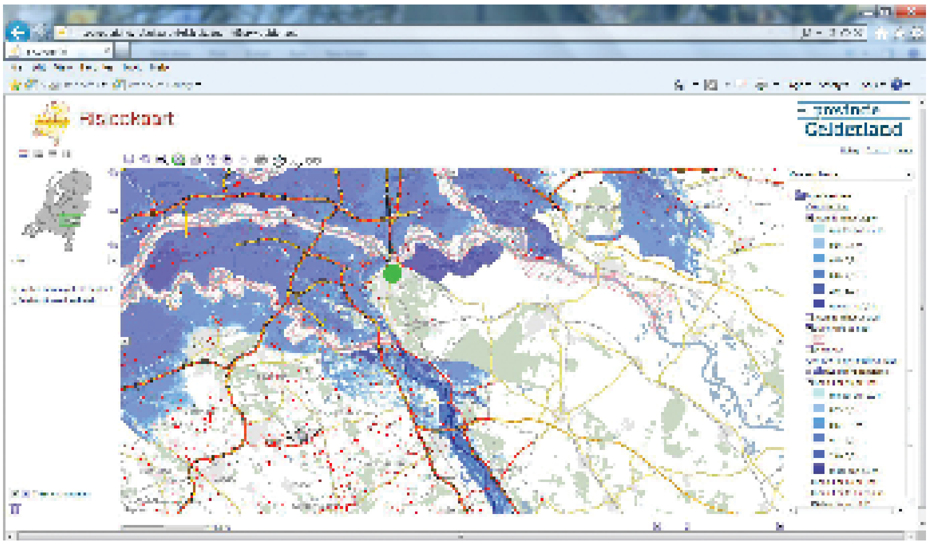

Figure 12.9
Flood depth in case there were no dikes. Flood levels presented are based on extremes that statistically occur once in ten years. The green dot indicates the city centre of Nijmegen. Only the Dutch territory is mapped. Source: `http://www.risicokaart.nl/`

Unfortunately LIDAR data is not yet acquired in all countries in the world. In the Philippines, for example, Olaf Neussner has to use other approaches. Owing to a lack of critical data and models, he cannot model flood scenarios. Therefore Olaf uses historical assessments of past floods involving observations from helicopter overflights or satellite images sensed during floods. High-water marks on buildings and existing flood-hazard maps are also useful input. This approach may be less accurate than the results of flood modelling, but it still provides a good approximation of the flooding a certain rainfall event can cause. Since Olaf also uses accounts from people who experienced a particular flood, it is more a participatory approach in which the latter lay users of flood-hazard information actually help professional users to create this information.

There are also historical sources of elevation information. Photogrammetric processing of aerial photos has provided accurate surface data. Where good topographic maps are available, an interpolation of digitized contour lines can provide digital elevation information. It does, however, not provide information on structures that have the potential to block water flow. Understanding and dealing with such potential data limitations is critical. For the areas in the Philippines for example, existing base maps are about 50 years old and existing hazard maps do not indicate the severity and probability of potential flood events.

To model flood hazard we also require land cover data, both to correct DSMs (e.g. to remove vegetation) and to extract surface roughness information. While topographic data can be considered to be relatively static, land cover data is more dynamic, especially in urban areas. Land cover data can be obtained from satellite image classification, as described in Section 6.2. In the Philippines, land cover information is often derived from medium-resolution satellite data (e.g. ASTER, SPOT). In addition, free information from Google Earth is also used.

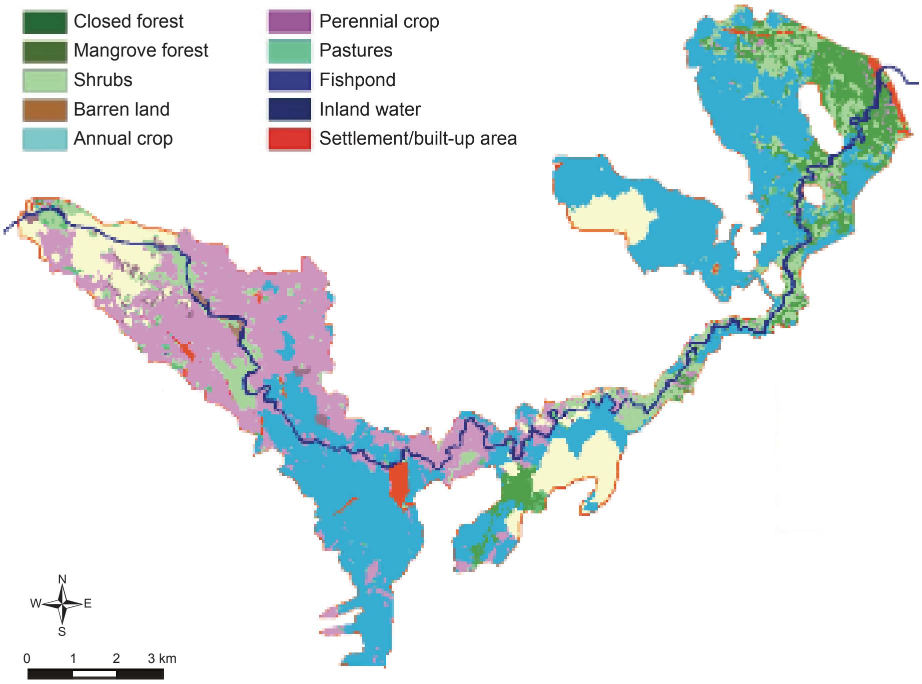

Figure 12.10
Satellite-image-based land cover classification of the area identified as being at risk of flooding by the Binahaan river (Philippines) (Source: Olaf Neussner, GTZ).

Remote sensing data are useful to address the Elements at Risk (EaR). To quantify risk related to each EaR we need to know its type, spatial location, how much it is worth, and how susceptible it is to a hazard of a given magnitude. EaR detection can be done using high-resolution image data, such as from Ikonos, Quickbird or aerial photographs, and is useful for a detailed assessment in urban areas (for more information on the utility of remote sensing in disaster-risk management see [54, 131]. Determining the value of a given physical feature, such as a building, factory or bridge, usually requires some auxiliary data, as this parameter is almost impossible to extract from image data. For detailed work, structural engineers need to be involved to determine how a given structure will respond to a hazard, such as a flood of a certain height, duration and flow speed. In addition, there are also other EaRs, such as agricultural fields, which, if destroyed, have to be added to the list of damage. Neussner and his group also use satellite imagery to determine the types of agricultural use in areas susceptible to flooding (Figure 12.10). To estimate accurately the number of people who may be affected under a given flood scenario, census data are needed. An alternative is to map the number and possibly types of buildings and use an average occupancy rate, which may be calibrated with some field knowledge [68].

12.2.5 Monitoring as part of an early warning system

In general, river height downstream is a function of water accumulation in the upstream catchment, typically the result of rainfall. Other situations are also possible in case of storm surges or flooding resulting from excessive precipitation that exceeds the capacity of the drainage system in an urban area. To measure the amounts of rainfall, it is easiest and most accurate to employ a network of rain gauges. In the FEWS run by GTZ for the Binahaan watershed, for example, automated rainfall gauges are used as well as local observers [81]. Those observers read the manual gauges and transmit the data via a Short Message System (SMS) to the operations centre. They do that twice a day under normal circumstances and more frequently during critical rain events. The same hybrid approach using manual observations and automated systems is used to monitor river water heights. The overall reliability of a fully automated system can be expected to be higher. However, the approach just described is necessitated by limited funds. Nevertheless, it also has the advantage that the people living in the watersheds affected feel a certain ownership of the system, as they are personally part of it.

In the Netherlands the situation is different. Flooding by major rivers is typically a consequence of large amounts of water accumulating in Germany, the result of precipitation or spring snow melt in Germany's south. The Rhine is a relatively large river, draining an area of some 220,000 km^2, about five times the entire area of the Netherlands. This means that data from the careful monitoring of the Rhine in Germany are used by the Dutch authorities to assess flood hazard and provide at least two days lead time before a flood arrives. Bas Overmars points out that the Dutch and German flood models are coupled. This means that Dutch authorities work closely together with their provincial and municipal counterparts in neighbouring North-Rhine Westfalia. So, flood modelling and evacuation planning occurs on the basis of a flood-system management rather than on the basis of political boundaries.

In countries such as the Philippines lead times are much shorter. This is because catchments that are the source of flooding tend to lie much closer to the areas that become flooded. In the Binahaan watershed warning times are only between about 3 and 10 h, depending on the location of settlements along the river. The warning time could be increased if Earth observation was used to monitor actual rainfall, instead of waiting for river gauges to show rising waters. For example, geostationary weather satellites, such as GOES or Meteosat Second Generation (MSG), estimate rainfall in near-real time in other parts of the world. These also provide data suitable for flash-flood detection. Another instrument specifically designed for estimating rainfall in tropical areas is the Tropical Rainfall Measuring Mission (TRMM). Since 1998 this satellite has been used to measure tropical precipitation and Neussner's group is looking into using its data as well. Thus Earth observation is also well suited to providing critical precipitation input data for modelling the flood potential of a given catchment.

12.2.6 Coordination and communication as part of early warning systems

As long as Earth observation data and flood models are only available to the organization in charge of flood monitoring, complete disaster avoidance or mitigation is not possible. Instead, the warning information needs to be shared amongst all organizations involved and, ideally, integrated with other relevant data, such as that on evacuation routes or sites where hazardous materials are used. In the Netherlands, the freely-available National Risk Atlas (`http://www.risicokaart.nl`, see also Figure 12.9) provides such risk-related base information. For real-time emergency situations, the Flood Information and Warning System (FLIWAS, `http://www.fliwas.eu/`) allows real-time integration of flood-related measurements and risk calculation and provides a decision-support tool for evacuation planning. People can also use an internet-based Evacuation Calculator to find out where they should evacuate to, and how long it will take them. This has been integrated into the Dutch Flood Management System. With the many uncertainties crisis managers face in an emergency situation in mind, diverse spatial information has been integrated into an evacuation scenario modeler (Evacu-Aid, Figure 12.10) that allows planning of the optimal evacuation strategy.

The Philippines Flood Early Warning System (FEWS) does not have such a level of automation. When precipitation and river-gauge data indicate an impending flood, the operations centre refers to an established flood-warning plan that has three levels, which are also known to the local population (Figure 12.12). Level 1 (alert) means there

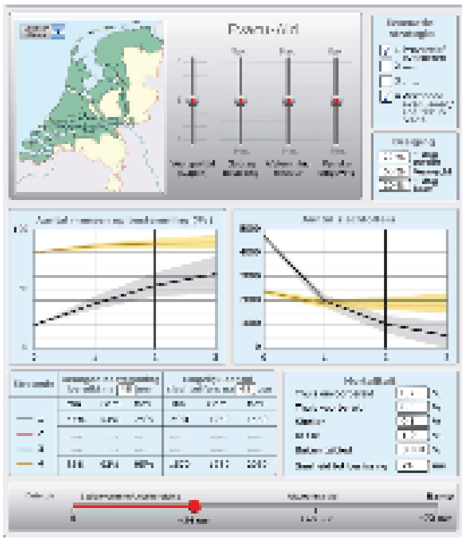

Figure 12.11
Evacu-Aid tool to assist crisis managers in the Netherlands when making evacuation decisions.

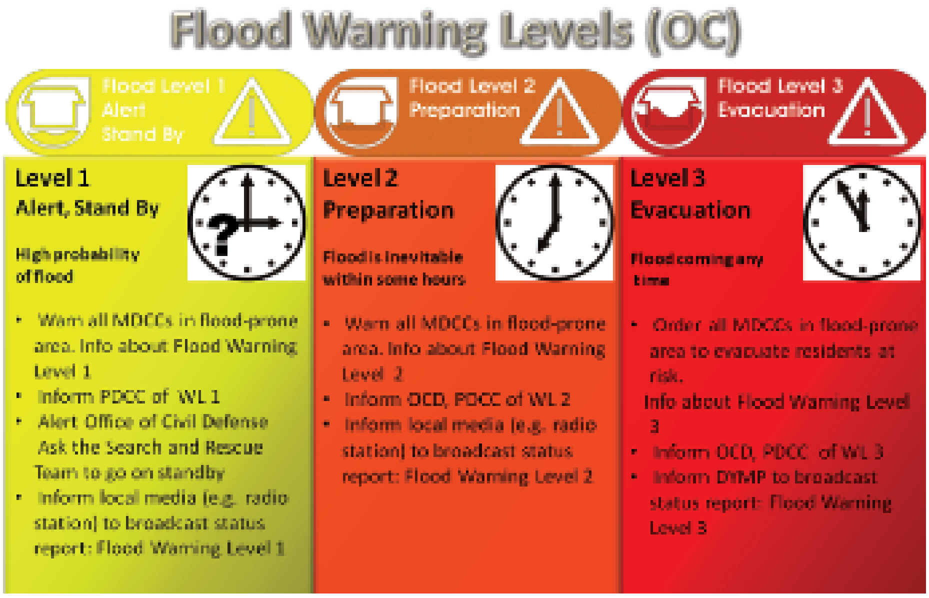

Figure 12.12
Simple three-level flood early-warning and evacuation plans that are part of the Binahaan flood early-warning system in the Philippines [81].

is a high probability of flooding, Level 2 (preparation) means that a flood is inevitable within several hours, while Level 3 (evacuation) indicates that flood waters can arrive at any moment. The operations centre then alerts disaster coordinating councils in the towns and villages. The actual warning of households is still frequently done via a megaphone or bells, a simple but effective system, and is the final stage in a process that relies heavily on RS and other GI Science tools. Both Neussner and Overmars point out that something as low-tech as drills are still critical. It should be ensured that everyone really understands how to behave in a situation of crisis but also to increase and retain relevant skills and knowledge amongst the cooperating organizations.

12.2.7 Future developments in disaster risk management

GI Science data and tools are already indispensable in disaster-risk management—and not just for flooding. Many people use them, often without any detailed understanding of the underlying science and technology. Olaf Neussner and Bas Overmars illustrated two rather different approaches to flood-risk management, although both rest heavily on geo-tools and both involve professional and lay users.

We can expect existing setups to improve, in different aspects and for different reasons. In the Netherlands even more detailed LIDAR-based elevation model called AHN-2 is nearly completed at the time of writing this book (summer 2012). This will lead to elevation data of 5 cm elevation accuracy. With computers becoming faster and models becoming better, flood models will become more accurate and more detailed. Increased availability of broadband internet access will enable an effective exchange of data and information, as well as real-time collaboration between organizations responding to disasters. It also means that the general public will have increasing access to diverse hazard-related information. This will have positive effects, such as an increase in general awareness of existing risks or developing hazardous situations. People will become more familiar with graphic representations of geodata. On the other hand, it does mean that crisis-management organizations will no longer be exclusive users of GI Science and that they will need to adapt their early warning and evacuation strategies to take into account situations where the affected population may be exposed to potentially conflicting information from different sources.

Countries such as the Philippines will benefit from better, more easily available and affordable image data, but also from free and open source software that frees up budgets for other components of the system. The increasing use of sophisticated EO data and flooding models shows the important role that modern geodata and tools can play. Until a few years ago, this was unthinkable in more peripheral settings such as the Binahaan area. Increasing access to GI Science products distributed via digital media (e.g. internet or mobile phone) also means that the number of lay users of GI Science in such economically less-developed countries is growing rapidly.

12.3 Monitoring coastal vegetation

12.3.1 Introduction to monitoring coastal vegetation

Sea-level rise combined with storm surges are potential hazards for communities in low-lying areas of countries such as the Netherlands or Thailand. From a historical (geological) perspective, the current rise in sea levels appears to be decelerating. Sea levels were -100 to -120 m during the last Glacial Maximum at 18,000–20,000 years BP, -15 m at 8000 years BP and -10 m at 6000 year BP [62]. In other words, the rate of sea level rise has decelerated from about 0.60–1.0 m/century to about 0.10–0.25 m/century (or 1–2.5 mm/year) at present.

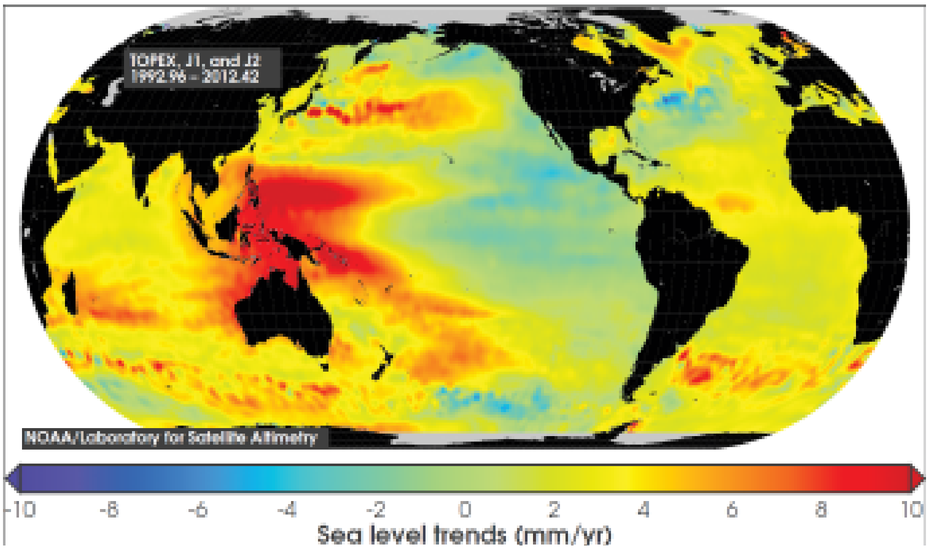

Figure 12.13
Sea level rise based on measurements from satellite radar altimeters. The local trends were estimated using data from TOPEX/Poseidon, Jason-1, and Jason-2, which have monitored the same ground track since 1992. Source: [83].

The IPCC estimates that the global average sea level may rise between 0.18 and 0.59 m in the next century [88]. Sea level changes are not equally distributed in space as can be seen in Figure 12.13. The effect of sea level rise may be accelerated in some regions while in other areas they may not. Acceleration occurs in the western part of the Netherlands and the southeastern part of the UK, as a result of gradual land subsidence as other land is lifted higher due to isostatic rebound after the disappearance of the glacial ice sheet from the last glacial period. This sinking of the land surface is further compounded in the Netherlands by:

- the annual extraction of natural gas (varying between 68 billion m^3 and 86 billion m^3 annually in 1990–2010) and petroleum (in 2007, 2.5 million m^3), which causes local and regional land subsidence of several decimetres [23] in areas above the gas fields;
- land subsidence of peat areas in the western part of the country, owing to drainage and subsequent oxidation of organic matter, where the extent of the subsidence is determined by drainage depth and the thickness of the peat layer.

As a result, some local regions may experience changes in sea level at a higher rate than the 0.18–0.59 m/century predicted by the IPCC, although other regions in northern Europe, such as Sweden and Denmark, are still rising after the unloading of the ice sheet; in these areas sea level is falling.

Coastal flooding occurs periodically along the European coastline. It was a particularly severe combination of high spring tides and a wind storm that resulted in the North Sea flood of 1953 (see Section 12.2). Fifty years later, an earthquake in the Indian Ocean triggered a tsunami with waves up to 30 m high along the coasts of most countries bordering the Indian Ocean. The height of a tsunami's waves is determined by a number of factors, including the size of the earthquake, the amount of ocean sediment displaced by the earthquake, and the length of the downslope along which the sediment travels. More than 225,000 people were killed in fourteen countries [110]. The damage and losses from the tsunami were substantial and coastal and rural communities suffered disproportionately high impacts, requiring central government assistance for their recovery.

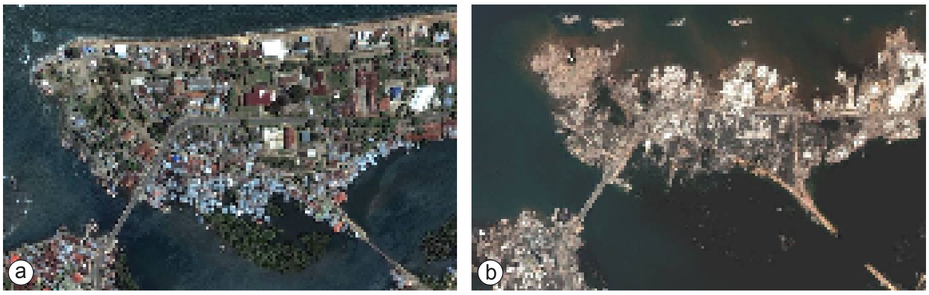

Figure 12.14
Two Quickbird images of the harbour area at Banda Aceh, Indonesia, showing the damage of the tsunami of December 26, 2004. (a) 23 June 2004, (b) 28 December 2004.

This disaster prompted a series of studies to examine whether soft defences provided by coastal mangroves are able to protect shoreline areas. Danielsen et al. [25] showed that mangroves give significant protection to some shorelines, where densities of more than 30 trees per 100 m^2 may reduce the maximum flow of a tsunami by more than 90%. In other words, sufficient width of intact mangroves can provide protection against tsunamis, while a degraded or widely spaced belt of mangroves offers little or no protection. Modelling shows that not only tree density is important: wave height is also critical. For example, the reduction effect of dense mangrove forest is decreased when waves are higher than 3 m. Indeed, waves greater than 6 m will destroy a mangrove forest. Then, there is no protective effect. The magnitude of energy absorption of tsunami waves by mangroves also depends on the stem and root diameters of trees, shore slope, bathymetry and tidal stage. Nevertheless, in this context Kerr et al. [56] concluded that "... the apparent association of vegetation area on mortality is in fact due to a tendency for more vegetation to occur at higher elevations and, not surprisingly, to the greater potential areal extent of vegetation given more available area fronting a hamlet. In other words, given hamlets of equal elevation and distance from the sea, differences in vegetation area did not mitigate human mortality caused by the tsunami... We see a genuine danger in overstating the protective capacity of vegetation, because it may lead to a false sense of security and eventually, when the next wave comes, to a lack of trust in science."

In response to such natural disasters resulting from tide and wave damage, the Netherlands and Thailand have developed different strategies for the monitoring, protection and strengthening of coastal defences. These defences (shown in Figure 12.15) include *soft*, or natural, barriers such stabilized sand dunes or mangroves and *hard* constructions built by engineers. Examples of the latter are dikes or tidal surge barriers such as those discussed in Section 12.2. Not only are soft barriers important for protection against storms and waves, coastal wetlands and dunes also function as remnants of natural ecosystems. Salt marshes are often valued as sinks for organic material, nutrients and heavy metals, since sedimentation of particulate matter takes place there; and for their important role in nutrient cycling, which contributes to water quality.

Salt marshes and coastal dunes also provide habitats for wildlife and are attractive natural environments for tourists.

Figure 12.15
Hard and soft barriers along the coast. Westkapelle, small town in the province of Zeeland in the south west of the Netherlands, is protected by dikes and dunes. Source: Rijkswaterstaat, `https://beeldbank.rws.nl`

To understand the close relations between coastal defence and nature conservation in the Netherlands it is important to realize that more than one-third of the country lies below sea level (see Figure 12.16). The Dutch coast consists for 80% out of sand dunes, locally in combination with extensive salt marshes and tidal flats, which, like mangroves elsewhere in the world, are part of the land's coastal defence system. Apart from an obvious role in flood protection, these coastal ecosystems play an important role in conserving national and European biodiversity. For example, more than half of current Dutch flora can be found in coastal dune areas, with approximately 10% occurring exclusively in these areas. For this reason, large parts of the Dutch dunes and salt marshes are nature reserves (see Figure 12.17).

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A similar situation is found along the country's main river systems. Melting snow or heavy rains in the upper catchment previously led to flooding in the Netherlands. In fact, 65% of the country would suffer from regular flooding if there were no dikes or dunes. The oldest dikes in the Netherlands were built in the 10th century and organized dune management dates back to the early 13th century. It is fair to say that the present shape of the Netherlands is the result of human activity. Another similarity with the coastal fore-dunes can be seen in the fact that many wetlands outside

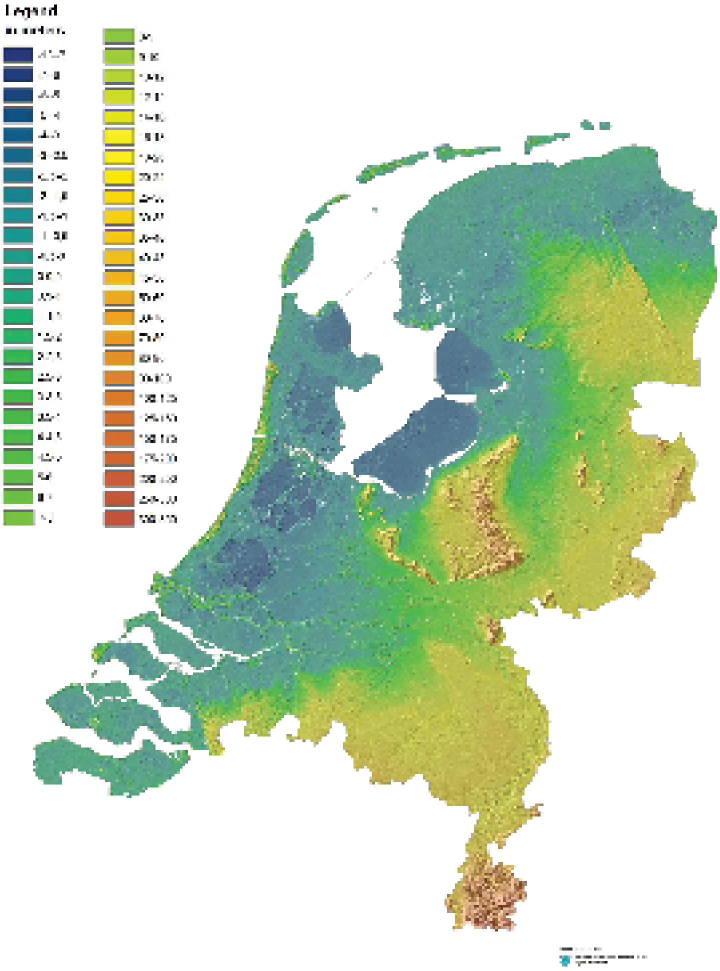


Figure 12.16
Elevation map of the Netherlands. Source: Rijkswaterstaat making use of the database "Actueel Hoogtebestand Nederland (AHN)"

the river dikes (in Dutch, uiterwaarden) have a nature conservation function and are subject to EU directives such as the European Water Framework Directive (EWFD) and Natura 2000. Nature development in these riverine wetlands is inextricably connected to flood-risk management.

Major cities such as Amsterdam, Rotterdam and The Hague, which together contain approximately 50% of the Dutch population, are located near the coast. The coastal region also contains major economic and industrial centres such as Rotterdam Europort and Schiphol International Airport and is the source of approximately 50% of the Dutch Gross National Product [17].

One of the prime tasks of "Rijkswaterstaat" (the Directorate-General for Public Works and Water Management), a department of the Ministry of Transport, Public Works and Water Management is to provide and organize protection against floods, so all coastal fore-dunes and salt marshes fall under its direct responsibility. In order to meet both coastal defence and nature conservation targets, Rijkswaterstaat has been using RS and GISs to map and monitor dunes and other coastal ecosystems since the early 1970s. For example, within the framework of the VEGWAD programme, every five years the vegetation of all salt marshes in the Dutch Wadden Sea region are mapped at

Figure 12.17
The Dutch ecological network: a planning for areas with a nature conservation function. Source: [45].

a scale of 1:1000 and stored in a GIS for monitoring purposes. Initially the maps were based on large-scale aerial photographs, but in recent years more advanced techniques such as Laser altimetry and other airborne scanners are being used (see Section 12.2).

Since Rijkswaterstaat is one of the first and largest users of RS techniques, for many years it has played a leading role in the RS and GIS community in the Netherlands. It has initiated and (co-)funded numerous EO research and operationalization projects, covering the whole spectrum of available EO techniques with possible (future) applications directly related to the primary tasks its home ministry.

As already stated, dunes and other coastal ecosystems have multiple functions. This has as a consequence that mapping and monitoring projects are always executed in close cooperation with other stakeholders, among them Government, NGOs, knowledge centres and national and local authorities.

Rijkswaterstaat incurs significant annual expenditure to map and monitor vegetation across a number of landscapes and ecosystems within the Netherlands. A land unit approach, based on visual interpretation of stereoscopic aerial photographs, and supported by field observations, has been developed by the Survey Department (Meetkundige Dienst). Though this approach is effective, Rijkswaterstaat wished to investigate further whether hyperspectral digital RS in combination with laser altimetry would increase the productivity and objectivity of the mapping procedure. ITC and Rijkswaterstaat developed a project that delivered a marked improvement in mapping.

Initially, 16 salt-marsh vegetation types in the Netherlands were identified based on existing knowledge within Rijkswaterstaat, each type having a characteristic spectral signature (see Figure 12.18, [103]). In addition, an understanding was gained about those parts of the electromagnetic spectrum that offer the greatest information content for discriminating between and identifying vegetation types.

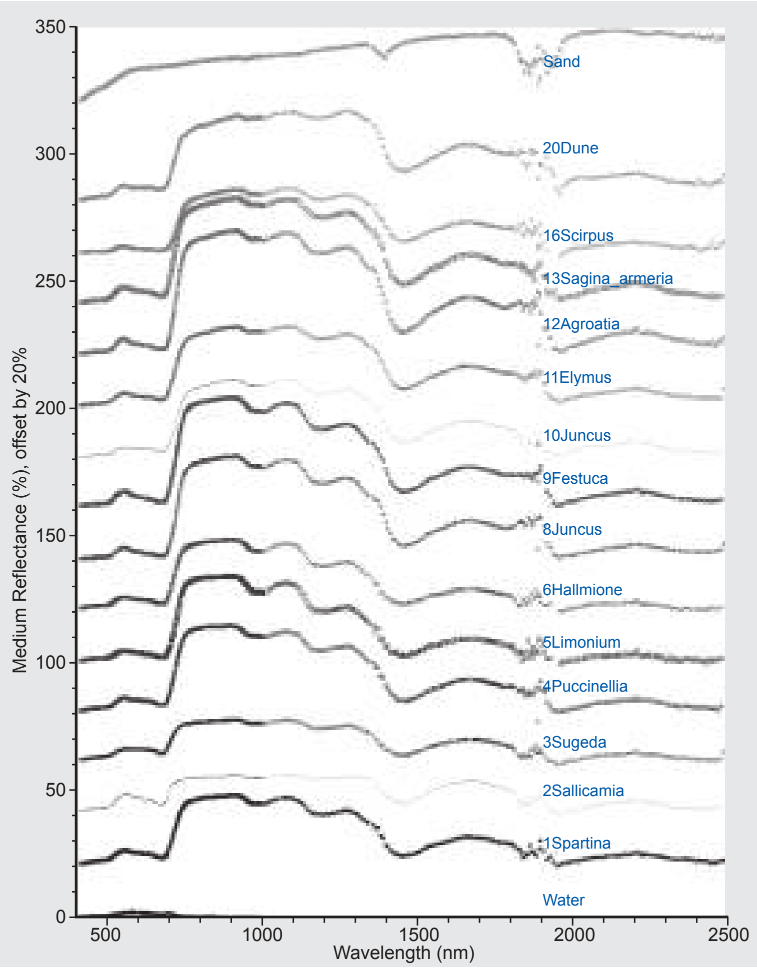


Figure 12.18
Reflectance profiles of salt-marsh vegetation types in the Netherlands [103].

From knowledge gained from ecologists working on coastal vegetation on the island of Schiermonnikoog, five input map layers were identified as being important for explaining the distribution of coastal vegetation. The first was a spectral-angle-mapper (SAM) supervised classification of hyperspectral (HYMAP) images. The other map layers, which were derived from a digital elevation model, represented elevation, slope gradient, aspect and topographic position. These layers were input in a raster-based GIS and then geometrically co-registered to a regular 3.5 m grid. From knowledge of vegetation distributions, the relationships between the vegetation units and the five data layers were quantified and used as rules for a rule-based expert system. The thematic layers accessed from the GIS provided data for the expert system to infer the most-likely vegetation unit occurring in any given grid cell. The vegetation map output from the expert system compared favourably with a conventional landscape-guided map generated from aerial photograph interpretation [104].

The main conclusions to be drawn from the testing of the technology developed to produce maps of the Dutch salt marshes were:

- the accuracy of vegetation maps produced using conventional aerial-photograph interpretation was 40%;
- the spectral-angle-mapper (SAM) algorithm used in combination with hyperspectral imagery was able to classify vegetation with an accuracy of 40%;
- ecological knowledge is available from field plots, as well as expert ecologists;
- ecological knowledge linking environmental variables to vegetation types could be captured in a set of expert rules;
- the addition of terrain variables to the hyperspectral imagery raised the accuracy of the map generated by the expert system to 62%;
- the overlaying of polygons from a 1997 vegetation map on the results of the expert system showed that, during the interpreting of aerial photographs, much of the ancillary information (elevation, slope, terrain position) was used when drawing lines to denote boundaries of vegetation units.

12.3.2 Solutions and future developments in coastal vegetation monitoring

The vegetation of coastal areas provides a range of environmental benefits. As a soft defence, it can be combined with hard defences to protect human infrastructure from storm events. GI Science provides essential tools for mapping soft defences, monitoring their condition and developing models of their future effectiveness under different land-cover scenarios and projected storm-surge impacts. Ongoing and future initiatives focus on improving mapping techniques and implementation of these in coastal defence systems as well as in nature conservation.

The ITC professional Masters students in the NRM programme of 2010 focused in their project work on mapping the habitat quality of the hen harrier. The hen harrier is a bird species whose decline and conservation status in Europe is of great concern. Because the hen harrier depends for foraging and breeding on a mosaic of open and closed vegetation, the ITC students mapped the vegetation structure on Schiermonnikoog (one of the Wadden islands in the north of the country). They collected vegetation structure samples in the field and classified digital false colour aerial photographs. One of these students, Sylvia Monica Kalemera, compared different methods of classifying vegetation structure based on RS techniques. See also Figure 12.19. Further improvement in classification accuracy will allow better predictions and more efficient coastal management to ensure both safety for people and protection of the hen harrier habitat.

ITC graduate Giles Jay Williams [128] estimated chlorophyll content in mangroves in East Kalimantan, Indonesia, based on hyperspectral techniques (Figure 12.20). Mangroves in Indonesia have suffered from logging and nutrient enrichment due to unsustainable shrimp farming and agriculture. Therefore, mangrove monitoring and measures to improve the state of the mangroves are necessary. In view of monitoring mangroves, chlorophyll content has a strong correlation with nitrogen and can therefore be expected to be a good indicator of mangrove health.

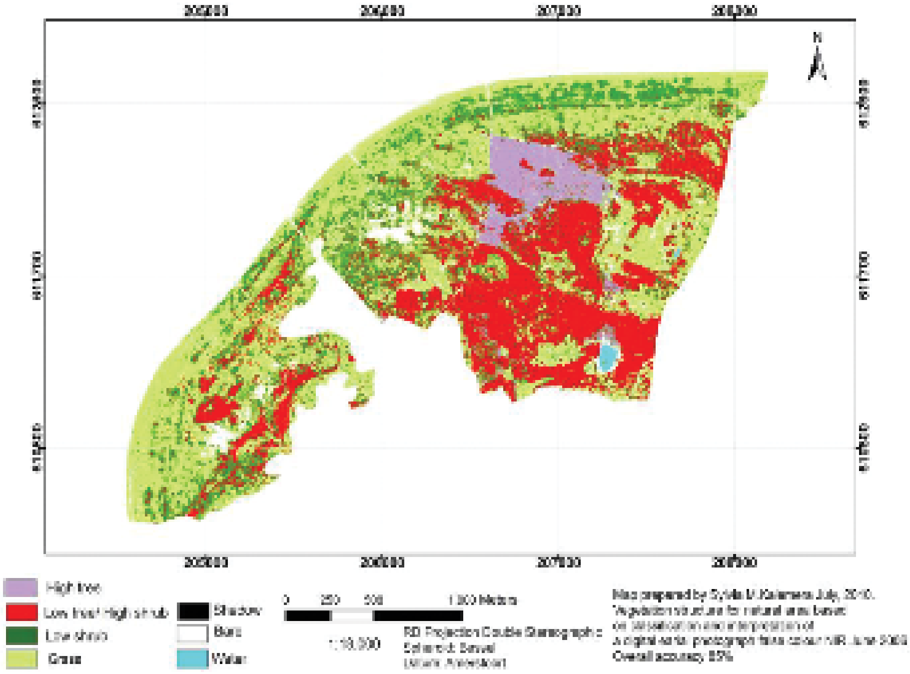


Figure 12.19
Vegetation structure map of a part of Schiermonnikoog, the Netherlands, in support of mapping the hen harrier habitat quality.

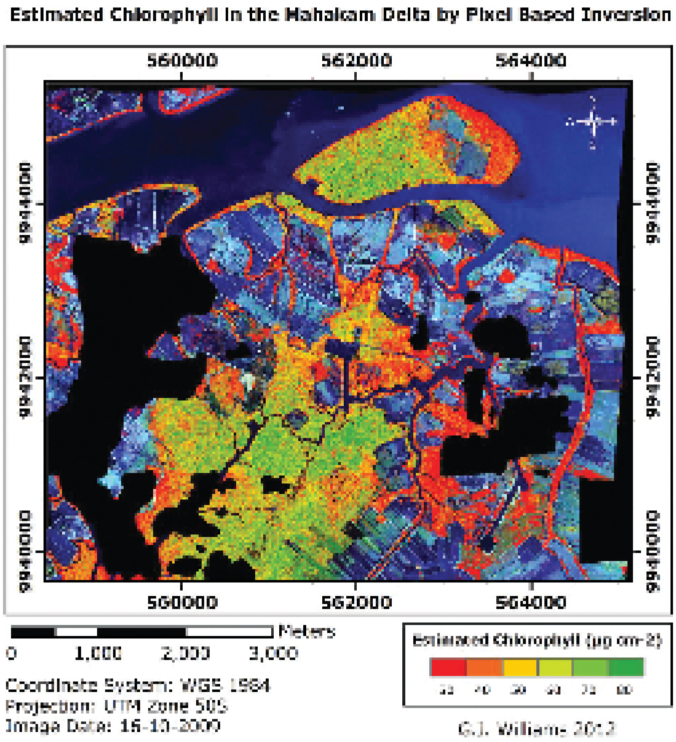


Figure 12.20
Chlorophyll mapping in a degraded mangrove area in East Kalimantan Indonesia. Source: [128].

Based on this study it was concluded that the created maps do not reflect accurately chlorophyll at specific locations. Several methodological problems were identified that need further attention. Nevertheless, such maps are indicative for determining spatial variations throughout the study area. Chlorophyll concentration was correlated with shrimp pond proximity and position relative to the coast.

Ongoing sea level rise and degradation of natural vegetation along coasts asks for well-targeted protection and conservation measures. That will only be possible with good-quality baseline information. Both recent studies show that further development of innovative EO and spatial analysis techniques is the way forward to monitor coastal vegetation with a higher level of accuracy.

12.4 Nature conservation

12.4.1 Introduction in nature conservation

Nature conservation aims to conserve nature areas and the ecosystems they contain. If not properly protected, nature areas could be converted into agricultural land or subjected to urban sprawl. Or they could be utilized to an extent that structurally damages the functioning of the ecosystem, for example through deforestation or overgrazing. Sometimes, "new" nature is created when agricultural areas are abandoned, when land is reclaimed from the sea, or when reforestation projects are carried out in degraded areas. Then, these areas also need proper management and protection. Overall, in all nature areas, nature conservation aims at ensuring that biodiversity in these areas is maintained, that natural processes in the system continue and that ecosystem benefits are retained.

Two situations are often found in nature areas. In the first situation, nature areas cover large expanses such as African game parks. In the second situation, nature areas are embedded in a land-use matrix of areas that are intensively or extensively used by humans. In the latter case, agricultural areas often surround the nature areas, although urban sprawl sometimes surrounds a park (e.g. Nairobi National Park). In both situations, to effectively conserve these areas, spatial information is essential for making the right management and conservation decisions. Spatial information can help in monitoring the status of the system, prioritizing areas requiring the most attention or investigating the connectivity and remoteness of isolated nature patches in the landscape matrix.

Collecting relevant spatial information for nature conservation is, however, not an easy task. Firstly, nature areas can cover large expanses of land or be embedded among other types of land use. In either case information covering large areas is required. Earth observation from aircraft and satellites has revolutionized the way data from large areas are collected in a consistent and repeatable manner. Secondly, changes in nature areas are often slow, making those changes difficult to observe instantaneously. Collection of long (in the order of decades) series of data is then necessary to quantify the rate of change in a natural system. Historical archives containing aerial photos and old satellite images provide a valuable resource for assessing the state of natural systems in the past. Finally, collecting field information based on point observations is often only useful when the point's exact geographical position is known—to be able to relate it later on to other spatial data sets. In nature areas, however, landmarks are not always readily available, making it difficult to pinpoint one's position. With the advance of small hand-held devices that can receive GPS signals, this task has been considerably simplified and accuracy improved. In short, geographical information is essential for nature conservation and collecting this kind of information has become easier and its quality higher with the advance of EO sensors and GPS devices.

12.4.2 Users and user requirements related to nature conservation

Nature conservation usually involves various stakeholders. To facilitate discussion between all stakeholders, to quantify the impacts on and from nature areas, and to prioritize areas and actions by the different stakeholders, nowadays it is essential to have access to spatial data from the nature areas and their surroundings. As they provide the means for processing that spatial data, GI Science tools have acquired a pivotal role in optimizing nature conservation.

Typical stakeholders in the field of nature conservation are non-governmental organizations (i.e. NGOs such as WWF and Conservation International). Other important players are national and lower-order governmental bodies (e.g. a state forestry department) and international bodies that originate from supra-national organizations such as the UN (e.g. the International Union for Conservation of Nature IUCN). These kinds of parties all have conservation of nature as a common goal.

There are other stakeholders that make claims on nature areas but they do not have nature conservation as one of their primary objectives. Indigenous people, for example, often claim land-use rights or ownership of areas that have been assigned a nature conservation status. Additionally, within a national government different ministries can claim responsibility for, and therefore authority over, the same piece of nature, e.g. a ministry of agriculture and a ministry of forestry. Next to various parties that make direct claims on using or managing nature areas, there are many parties that live next to these areas that are directly or indirectly affected by the natural processes occurring in these areas. For example, cattle herders living next to game parks sometimes experience loss of livestock by predators from the neighbouring game park, representing a negative effect of nature areas on surrounding communities. Positive examples of nature areas exist as well, for example where villagers are protected from landslides by forested slopes that retain and regulate the runoff of rainwater in a catchment area.

Surrounding communities often have a negative impact on nature areas, caused, for example, by poaching or illegal collection of fuel wood. But positive benefits also exist, for example where communities earn revenues as tourist guides and in return actively help in protecting the area. Finally, often research organizations also have an interest in nature areas: they often try to gain access to data from these areas and acquire permission to perform experiments and gather observations from within these areas.

For stakeholders with nature conservation as their primary objective, GI Science provides important tools for conservation management. In their discussions with other stakeholders, it often serves as a useful tool for communication and for making arrangements, e.g. to negotiate access rights to specific areas. And for the research community, spatial information often helps in finding relationships between natural processes that occur at the same locations.

Applications of GI Science in nature conservation are extremely diverse. Therefore it is impossible to describe all of them. This Section illustrates three examples of use and users of GIS and RS applications. Each of them deals with one of the major stakeholders in nature conservation: an NGO (Subsection 12.4.3), a government organization (Subsection 12.4.4) and a research organization (Subsection 12.4.5).

12.4.3 Use of spatial information by an NGO: Natuurmonumenten's vegetation-structure map of Witte Veen.

Natuurmonumenten is an NGO with 880,000 Dutch members. They manage over 100,000 ha of nature areas in the Netherlands. One such nature area is the Witte Veen, 10 km south of Enschede, which links up with a nature area in Germany. Hans Gronert, employed by Natuurmonumenten, explains: “Together with German colleagues we are trying to connect this area to the nearby nature areas of Aamsveen and Haaksbergerveen, as well as other neighbouring nature areas. Our management approaches are grazing with Scottish Highland cattle to keep the area open, removal of topsoil to maintain the nutrient-poor environment and the promotion of frog pools in agriculture areas as stepping stones for amphibians. To be able to set up our management plans and to monitor their effect we need vegetation-structure maps. A few examples of rare species that can be found in the Witte Veen area are the European tree frog, common cotton grass and blue gentian.”

Hans Gronert, a forester employed by Natuurmonumenten, is involved in nature management of the nature area of Witte Veen. His main task is to optimize and maintain the biodiversity of this area.

The Province of Overijssel needed to create new nature areas to establish the National Ecological Network (EHS), which has been set up to connect existing nature areas in the Netherlands. A large part of existing and future nature areas have been assigned as Natura 2000 areas. Natura 2000, the centre piece of EU nature & biodiversity policy, is an EU-wide network of nature protection areas established under the 1992 *Habitats Directive*. The aim of the network is to assure the long-term survival of Europe's most-threatened and valuable species and habitats. It comprises Special Areas of Conservation (SAC) designated by Member States under the Habitats Directive and also incorporates Special Protection Areas (SPAs), which they designate under the 1979 *Birds Directive*. Natura 2000 is not a system of strict nature reserves where all human activities are excluded. Although the network will certainly include nature reserves, most of the land is likely to continue to be privately owned and the emphasis will be on ensuring that future management is sustainable, both ecologically and economically. The establishment of such networks of protected areas is an obligation that the Netherlands need to fulfil under the UN Convention on Biological Diversity. Natuurmonumenten, the state forestry department, the provincial government dealing with nature areas and other conservation organisations work together to achieve this.

Natura 2000

One of the requirements for managing nature areas is baseline information such as insight in the spatial distribution of different vegetation types. Vegetation structure is an important habitat characteristic for many species and in support of biodiversity it is important to maintain diversity in vegetation structure. The vegetation structure map of the Witte Veen is shown in Figure 12.21. This map was produced by visual interpretation of an aerial photograph mosaic downloaded from Google Earth.

12.4.4 Use of spatial information by a government organization: the forest-cover map of Rwanda

The National Action Plan for Forests 2006–2008 in Rwanda was aimed at research and operationalization of the use of RS in forest inventories. More specifically the plan prescribed mapping forest resources in Rwanda at 1:25,000 scale. This included:

- making an inventory and estimate the location, area (of at least 0.5 ha in size), floristic composition, age, type (natural or not; public or private), soil type, density and health status of forests/woodlands using existing maps, aerial photography, satellite imagery and field data collection;
- monitor changes in the occupation of forest land over time;
- inventory, organize, standardize and centralize national geographic and other available databases on forests in Rwanda to allow interested institutions and

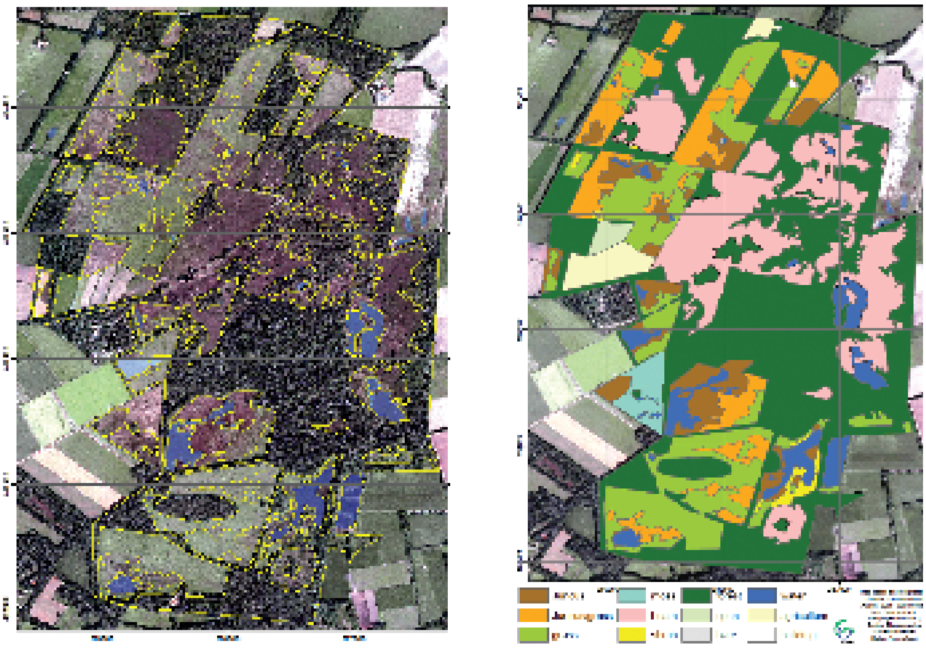


Figure 12.21
Delineation of mapping units (yellow) based on interpretation of an image obtained from Google Earth (left) and vegetation-structure map (right) after data collection in the field using mobile GIS.

decision-makers to easily access and update information that is critical for decision-making processes;

- develop a national GIS/RS-based information system for forests in Rwanda;
- develop capacity building in the application of RS and GIS tools and methods for forest inventory and mapping.

Claudien Habimana (right), Director of the Forest Unit, Ministry of Lands, Environment, Forestry, Water and Mines (Minitère), Rwanda, is listening to an explanation being given by a local farmer (left).

The satellite data used to map Rwanda's forests were ASTER, SPOT and TM images, the most recent (at the time of the described project) and cloud-free images being selected (see Figure 12.22).

From discussions with the Ministry officers, criteria for distinguishing forest types were drawn up. Forests in the humid region of the country were defined as areas larger than 0.5 ha with a tree cover greater than 20% and trees higher than 7 m. In the dry region (Akagera), areas in which trees were higher than 5 m were considered as forest. Coppices and young forest plantation, the latter comprising trees of less

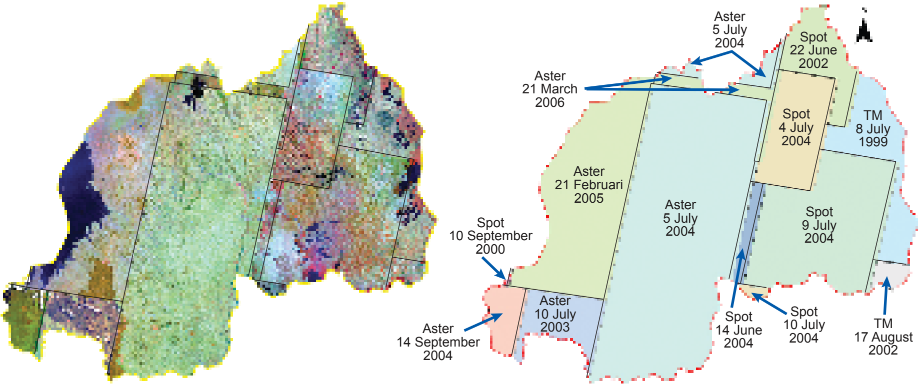


Figure 12.22
Coverage of most recent satellite images (at the time of the project) used for the forest classification in Rwanda.

than 7 m and covering 10–40% of the area, or trees higher than 7 m and covering 10–20%, were only found in the humid region. Bush was only found in the larger humid natural forests. In the case of bush, tree cover was defined to be less than 20% and in practice mostly less than 10%, with shrub covering more than 20% and high herbs and grasses. Bamboo and bush ridge forests were only found in the Parc National des Volcans. In summary, the following forest types were distinguished:

1. humid natural forest;
2. dry natural forest;
3. eucalyptus plantation forest;
4. pine plantation forest;
5. coppices or young forest plantation;
6. bush;
7. bamboo forest;
8. bush ridge forest.

Because of the substantial differences in terrain elevation, the images needed to be corrected with a DEM. Geocoding was done from topographical maps in accordance with the Rwandan coordinate system. The images were each classified separately with ERDAS IMAGINE into several classes and then re-coded into two classes: *forest* and *non-forest*. The large forest areas were selected from this classification and classified separately into the forest types listed above. Field data collection was carried out using hand-held GIS and GPS devices, allowing the location to be seen in the field in relation to the polygons, with the satellite image in the background. These data, collected over 4 missions, were classified into the forest-cover classes.

Based on the field observations and a first classification of images, the definition of classes was adjusted and a completely new classification of all images was made. New spectral signatures were selected and several classifications were made until the forest was sufficiently accurate classified. The occurrence of each forest type, expressed in km^2, is shown in Table 12.1.

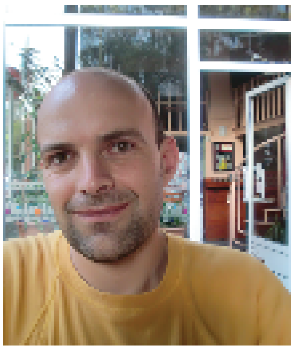
Table 12.1
The combination of natural forest, bamboo forest, bush ridge forest and forest plantations can be considered collectively as "forest". Hence, the proportion of forest covering the total area is 6.8%; bush cannot be considered as forest.

Forest type	**No. of polygons**	**Area (km^2)**	**Fraction** (%)
Non-forest	699	23,252	91.9
Bush	5584	343	1.4
Bamboo forest	8	44	0.2
Bush ridge forest	5	30	0.1
Dry natural forest	664	37	0.1
Humid natural forest	1430	798	3.2
Eucalyptus forest plantation	1164	306	1.2
Pine forest plantation	663	110	0.4
Young forest plantation or coppices	22768	392	1.5
Total	43,426	25,312	100.0
All forest	37,143	1717	6.8

12.4.5 Use of spatial information by a research organization: monitoring tree-line movement resulting from climate change and societal pressure

Users are interested to see what the state of their forests is for a variety of reasons, biodiversity management and carbon sequestration being only two. Carbon sequestration has become an important issue for forest managers because forests contain the bulk of the carbon of global terrestrial ecosystems and keeping the carbon in forests is an important measure for reducing greenhouse gas emissions. Increases in atmospheric CO_2 concentrations, and global warming of up to 2 °C, however, seem unavoidable, and these may also affect forest ecosystems. CO_2 fertilization (plants need CO_2 for photosynthesis) has a positive effect on plant growth. At higher latitudes and in mountain regions, where temperature limits tree growth, forests may also expand as a result of global warming. This would result in tree lines moving to higher altitudes. To monitor tree lines, RS products are ideal sources of information. Progression of tree lines and the rate at which they move can be calculated in combination with accurate DEMs and GIS systems.

The pastures around Osogovo Mountains, on the border between Macedonia and Bulgaria, provide a good example of tree-line movement. Bulgarian researcher and forest manager Dr Tzvetan Zlatanov is keen to know whether forests in this region will expand to higher latitudes as a result of global warming. This information is needed for at least two reasons. Firstly, for reporting in connection with the Kyoto protocol—the country has to account for changes in carbon stocks in their terrestrial biomass. Secondly, forest expansion in the mountains will occur at the expense of unique types of alpine vegetation and will, thus, have consequences for biodiversity. This needs monitoring too.



Dr Tzvetan Zlatanov, Forest Research Institute, Sofia, Bulgaria

A complicating issue is the societal change that is taking place in Bulgaria at the same time as climate change. Before the country became part of the Eastern Bloc (also called Communistic Bloc) countries in the 1950s, all pastures around the Osogovo Mountains belonged to private owners. Then in the 1950s, all land became state owned and most of the previous owners moved to the cities to take jobs in the country's industrial sector. When, after 1989 the democracy was reinstalled in Bulgaria, land was given back to its previous owners, but many of them had lost the know-how needed to manage their pastures properly. As a result, many of the pastures became abandoned land. Proper pasture management includes frequent mowing and summer grazing, which have adverse effects on tree establishment. When lands are no longer used, tree settlement is no longer hampered, allowing forest expansion (see Figure 12.23).

In order to monitor the movement of the tree line to higher altitudes in the Osogovo Mountains and to relate it to climate change, Dr Zlatanov has to correct for the effects

Figure 12.23
Garlyansko Zhdrelo Gorge in the Osogovo Mountains. Newly recruited trees above the tree line stand out clearly.

of land abandonment. On the other side of the Bulgarian border, in Macedonia, land abandonment has not taken place, because there the land always had remained private property. This area of the Osogovo Mountains is therefore ideal for a baseline study.

Calculating the rate at which the tree line moves requires high-quality DEMs and aerial photography. Historical photos of mountain slopes can also be very useful, as they give clear indications of where the tree line was previously positioned on the mountains. Together with recognizable features on slopes, the position of the tree line can be delineated in a GIS system, allowing further analyses. Differences in tree-line movement on either side of the Bulgarian–Macedonian border can then be attributed to differences between the socio-economic development of the two countries. In addition, the rate of change in Macedonia gives a clear indication of the effect of climatic change on tree growth.

12.4.6 Future developments and datasets for nature conservation

GI Science is widely used for nature conservation at various levels of detail, ranging from very specialized local applications to worldwide global investigations. Each level requires different types of spatial data and GI tools in order to achieve the required result. Therefore it is impossible to generalize data requirements of all different users. But, the three examples that have been presented in this section give some idea of typical applications in nature conservation at different scales and for different users.

Within nature conservation, GI Science provides tools for achieving the objectives set; the tools are never the end of a process. The examples also demonstrate that acquisition of spatial data is an important aspect of using GI Science in nature conservation. Data acquisition has been a considerable bottleneck for nature conservation in less-developed countries for many years, as field work for data collection is often expensive. Advances in EO and, over time, a reduction in costs have resulted in the availability of relatively cheap data sets that have been collected in a consistent manner. Nowadays, international efforts are being made to share and disseminate these data at all levels. To complete this section, a summary of some global data sets that are

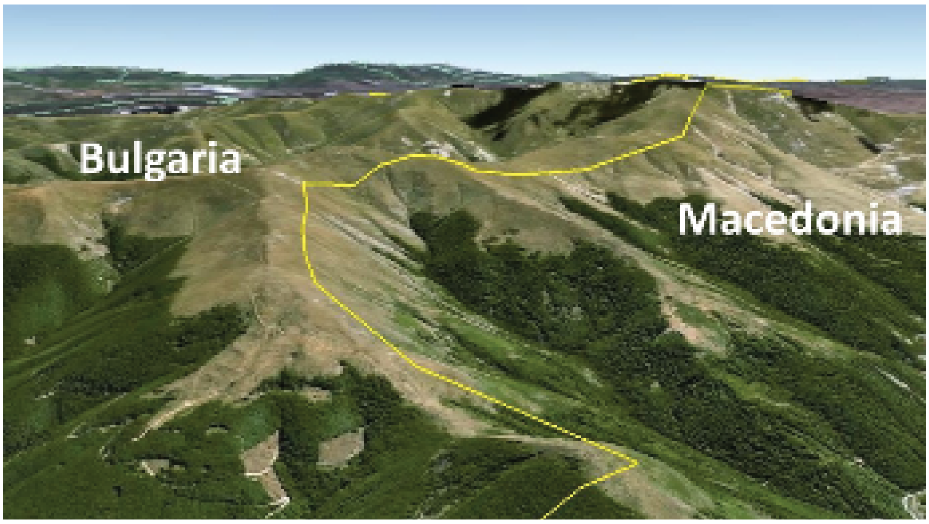


Figure 12.24
The Osogovo Mountain on the border between Bulgaria and Macedonia. The tree line is clearly visible on both sides of the mountain.

freely available on the Internet seems appropriate:

- Nature-GIS is a network that brings together different stakeholders of protected areas: users and experts in IT and nature conservation; see `http://www.gisig.it/nature-gis/`.
- IBAT for business is an innovative tool designed to facilitate access to accurate and up-to-date biodiversity information to support critical business decisions. The tool is the result of a ground-breaking conservation partnership between BirdLife International, Conservation International and the United Nations Environment Programme World Conservation Monitoring Centre; see `http://www.ibatforbusiness.org/`.
- The IUCN Red List includes a comprehensive assessment of the conservation status of the world's 6,000+ known species of frogs, toads, salamanders, and caecilians. Also included are key findings of the assessment, as well as individual species accounts, the IUCN Red List threat category, range map, ecology information, and other data for every amphibian species; see `http://www.iucnredlist.org/amphibians`.
- The Global Biodiversity Information Facility (GBIF) is an international organization that is working to make the world's biodiversity data accessible everywhere in the world. GBIF and its many partners work to mobilize the data, and to improve search mechanisms, data and meta-data standards, web services, and the other components of an Internet-based information infrastructure for biodiversity; data can be found and downloaded at `http://data.gbif.org/welcome.htm`.
- The Food and Agricultural Organization (FAO) of the UN provides a lot of statistics at country level; most data can be downloaded from the FaoStat website, at `http://faostat.fao.org/site/291/default.aspx`.
- Finally, the Earth Explorer by NASA gives a lot of information on several satellite products, some of which are freely downloadable; go to `http://earthexplorer.usgs.gov/`.

12.5 Information Exchange for Spatial Planning

Spatial plans have legally binding consequences for governments and their publics. They provide legal certainty and underpin local development. And they must be up to date, because those plans form the legal basis for what administrators, local government, the public and industry are or are not allowed to do in spatial contexts. Some Dutch municipalities started digitizing spatial plans in the early 1990s. During the nineties, government, industry and citizens increasingly recognized the significant potential of the Internet for the exchange of digital spatial plans. At the turn of the 21st century, the national exchange programme for digital spatial plans (DURP, in Dutch: "Digitale Uitwisseling Ruimtelijke Plannen") was born.

DURP

In this section, we highlight the problems that led to the creation of DURP and describe the legal and technical arrangements designed by DURP partners, in consultation with academia, industry and government, to solve those problems. We also highlight a pervasive characteristic of large-scale computerization programmes in government, both in the North and the South: the solution of old problems may bring new problems to the fore.

12.5.1 Introduction to spatial planning

In the Netherlands, the executive branches of municipal governments are responsible for spatial plans. Spatial plans are consulted before issuing a permit for a new building, or even to add a shed in one's garden. Municipal officers prepare these plans after an exhaustive search for all information pertaining to the land in question. All possible land uses are reviewed in the process, and preliminary plans are checked against the rules and frameworks laid down by the provincial and national authorities. The law stipulates that every citizen can have a say, and submit an appeal if necessary, at any stage during the development of a spatial plan.

In the year 2000, the Ministry of Housing, Spatial Planning and Environment, the Ministry of the Interior and Kingdom Relations, the Association of Water Boards, the Association of Dutch Municipalities and the Association of Provincial Authorities became partners in a national programme called DURP (DURP partners). Their aim was to improve the digital exchange of spatial plans. DURP partners framed the problem with (and solution for) spatial plans thus as follows:

DURP partners

"Do you recognize the following situation? Filing cabinets filled with physical plans and related amendments. Changes often take the form of sketches and paper stickers on the original plan. New municipal employees have a particularly hard time searching for plans before they are able to explain to citizens what they are allowed or not allowed to do on their land. Moreover, these plans are often more than 10-years old and must be updated under the new Spatial Planning Act (WRO in Dutch). If this situation is familiar to you, you will have no doubt as to why digital physical plans are needed."

12.5.2 User and user requirements

Users of spatial plans may be citizens, businesses or government bodies at all levels, including the country's 441 municipalities, 12 provinces, the Council of State and its DURP partners. Each of these users may make different demands on the spatial plans they access.

Citizens and businesses want low-cost access to spatial plans, together with convenience and clarity. For companies scouting within a large region for a new location upon which to expand their business, the search can be excruciating. The individual plans that together cover the region may well be all different. And they are often only available on paper, yet real-estate agents, notaries and public organizations, but also citizens and businesses, prefer to consult spatial plans on the Internet, instead of having to visit the municipal centres during office hours. Indeed, many users wish to consult not only municipal, but also provincial and national, plans via the Internet. In this general context it is also important to note that users expect, if not demand, that spatial plans, zoning regulations and provincial plans are all compatible.

Government officers charged with spatial planning (planners, lawyers and geo-ICT experts) consult with each other across different levels of government about zoning decisions. Often, other government agencies wish to offer their opinions on such matters. All parties involved are in favour of efficient cooperation, preferably via the Internet. So we are rapidly changing from sending piles of paper from the municipalities to provincial and other government organizations to communication via the Internet.

12.5.3 A new law

To tackle these problems, DURP partners agreed to initiate three new measures: new legislation, new technical standards and a spatial planning portal. On 1 July 2008, eight years after the establishment of the DURP partnership, the new Spatial Planning Act came into effect. The guiding principles for the new law were fewer rules, less central control where possible, and an implementation-oriented approach. "These are no empty slogans; they represent an actual simplification of the decision-making process in spatial planning, with due consideration for such important concepts as legal certainty and democracy. The new act ensures a clear division of labour. It distributes responsibilities and powers among municipalities, provinces and the national government in such a way that each tier of government can represent the interests entrusted to it to the best of its ability. [. . .] The new act aims at achieving the following objectives, inter alia: more efficient decision-making, improved enforcement and simplified legal protection in spatial planning. In short, the act will create an effective, decisive and goal-oriented spatial planning system in the Netherlands." [124]. All municipalities were required to make their plans digitally available at source by 1 July 2009. Due to implementation delays, however, the date was extended to 1 January 2010.

The new legislation in the *Besluit Ruimtelijke Ordening* and in a *Ministeriële Regeling* featured several innovations: spatial plans and the entire spatial planning process have to be digital; digital spatial plans have to be available to everyone; a paper copy must be made for archiving; when in doubt, the digital version of the plan overrides the paper copy; and, the digital version is considered to be the authentic version of the plan.

12.5.4 New technical standards

In 2008 DURP partners finalized a package of standards to enable the digital production and availability of all planning visions, spatial plans, decisions, regulations and orders [35]. The package consists of three standards: a Standard for Comparable Spatial Plans specifying main groups of land uses and area specifications; an Information Model for Spatial Planning for the new instruments and revised procedures; and a Standard for Accessibility to Spatial Instruments and seven practical implementation guides. Under the standards, to make a plan, for example, certain steps need to be followed:

- start with the application of SVBP where it concerns zoning plans and accommodation of plans;
- use the National Triangular Network when creating geometric objects;
- link objects with the IMRO using the practical guidelines;

- use the Standard for Accessibility to certify the provision of the design plan and the established plan;
- make available and publicize the certified plan according to the rules of the Standard for Accessibility.

12.5.5 New spatial planning portal

In part, the new spatial planning portal, which was launched on 1 June 2008, was set up to fulfil requirements that were laid down in the new Spatial Planning Act, but it nevertheless serves a massive, heterogeneous user population. The portal makes digital spatial plans publicly available via web services, covering the entire country for all tiers of government. "With the portal, the government aims at providing spatial plans to citizens, private organizations and government bodies in a transparent way. The site presents the complete and most recent situation at any location in the Netherlands in a reliable and clear way. Consequently, citizens and professionals will be able to integrally query spatial plans" [125].

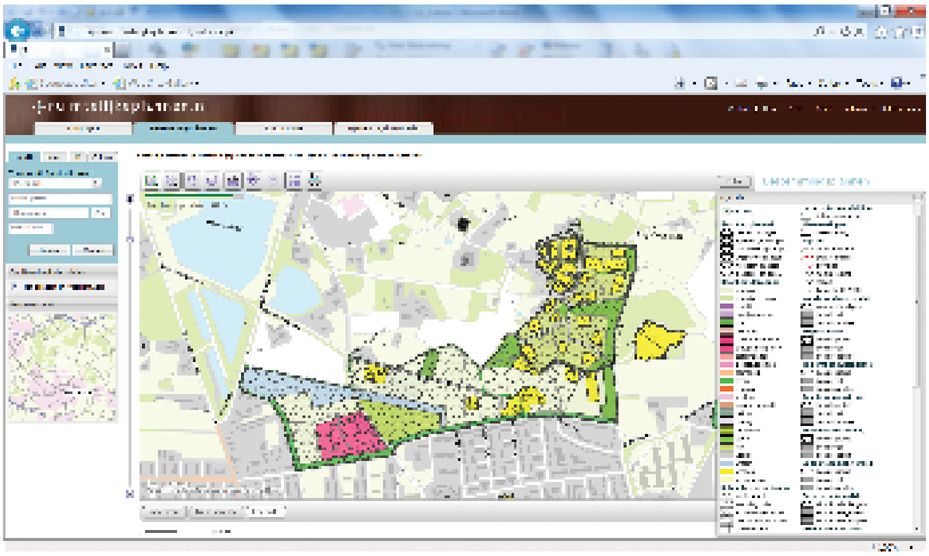


Figure 12.25
The Dutch spatial planning portal. The current spatial plan for a small area at the northern fringe of Enschede is shown. Screenshot was taken on 9 July, 2012 from: [100].

In July 2009, the intended beneficiaries of DURP's activities were asked whether their requirements were being met by the new arrangements. Apparently, these new arrangements had solved some of problems but new ones were created.

Citizens value the ease of querying standardized, comparable spatial plans at all levels of government via the Internet without having to visit various government offices. Municipal planners perceive the increased power accorded to them by the new laws as an improvement. In the past, a municipality drew up local plans and the relevant province approved them. Under the new law, the municipality draws up and approves the plan. In cases of conflict, the province may appeal to the Council of State. Municipalities are content with the reduced decision powers of the province in cases of conflicts with citizens. And provincial planners are comfortable with the power shift to municipalities under the new law. Municipalities decide based on local interests; the province safeguards provincial interests and cannot just interfere when it disagrees with a local plan.

Both the province and the municipality value the efficiency of the appeal process (if the plan needs to be defended in court). In the past, the province had to defend in court plans made by the municipality that the province was often unfamiliar with. Under the new law, the municipality defends its own planning choices. The power shift towards the municipalities reduces the province's work load and allows it to re-deploy provincial employees (previously tasked with the approval of municipal plans) to other work more relevant to the province (e.g. making local physical plans of provincial interest, such as projects to provide infrastructural elements that span more than one municipality).

Both municipal and provincial planners expect more efficient cooperation under the new law. First, the time needed to develop a plan has been reduced from one year to 22–24 weeks. Second, digital plans enable integration with other spatial data (e.g. plans at the province level). Third, because of its reduced power, the province now has an interest in communicating future provincial plans to municipalities in a timely manner. And in the past, the province could reject a municipal plan that had not been justified in the proper manner, an action the municipality felt was "useless", since it did not have any bearing on the content of plan [36].

Now a citizen can only appeal to the Council of State against an "unfair" municipal decision. This new practice has disadvantages. First, citizens may not trust the municipality to decide "objectively" on their case because municipal employees, who are usually themselves locals, may have a personal interest in certain locations within the municipality. Second, an appeal to the Council of State is not free of cost, in contrast with an appeal to the province, which in the past was cost free. As a result, citizens may be discouraged to exercise their right of appeal. Third, in the past, an appeal to the province had to be processed within six months. Under the new law, the Council of State does not have this obligation and it can take more than a year to process an appeal. In summary, cost and time issues may discourage citizens from appealing municipal decisions they perceive as unfair.

A fourth disadvantage concerns perceived loss of discretionary power. In the era of analogue plans, municipal planners had the freedom to assign any type of land use to a certain area and to apply any system of symbols to the plan. The new standards curtail these freedoms. With the new digital plans, only 23 predefined land-use types are now allowed, while the accompanying symbols are standardized centrally and prescribed by the ministry responsible for planning. Municipal planners may perceive this as limiting their discretionary power to make subtle judgments, based on local knowledge, regarding land use.

Fifth, and finally, provincial planners expect losses of efficiency in cases where they reject a municipality's plan and have to submit an appeal to the Council of State, a process that may take at least a year. The Council of State still works using analogue processes, so provincial planners may need to transpose plans to paper when pursuing an appeal. Under the old arrangements, it was both within the interests and expertise of the province to remove errors before plans achieved a legally binding status. Under the new law, the province has no interest to check for errors. Quality assurance of plans rests entirely with municipal employees, who may lack the technical expertise required for quality assurance, especially in small municipalities.

A similar case of massive government informatization can be seen in the Bhoomi (meaning land) land records project implemented in the state of Karnataka, in India, in 2001. Several pressing problems were solved by the Bhoomi project but new ones emerged. By October 2004, over 22 million farmers had received a digital copy of their land record for the first time. Digital copies of land records can now be obtained on payment of about 30 US cents at decentralized locations (kiosks), where kiosk operators run and maintain the system at a local level; long waiting periods, the need to make several visits and *unofficial payments* to intermediaries are things of the past. For every transaction, kiosk operators authenticate themselves with bio-logon metrics on Indian-made machines that look a lot like an ATM and are easy to use. The Bhoomi project improved the quality of service to citizens, simplified the administration of land records, achieved financial sustainability and curbed corruption. The Bhoomi project was judged to be so successful that other Indian states decided to replicate it. However, problems arose after implementation that had not been foreseen.

In many parts of rural India, a lower-level functionary is often the only government representative with whom citizens interact. Bhoomi eliminated these functionaries in the name of efficiency. Shifting citizens' access from lower (village) level to higher (state) level officials may provide freedom from the fraudulent practices that lower level officials have so often been discredited with, but it exposes the villager to more complex state processes at a higher level. The effect that this may have on citizens' freedom is not obvious. "Most of the Indian development planners are still fixated on increase in national incomes and they now also want the state to play a minimal role, in line with what some influential international donor agencies would recommend, and this gets reflected in their technology design choices. This is particularly true of the Bhoomi project of Karnataka, where ICT use is directed for improving government service delivery by reducing the role of lower-level government functionaries [...]. The desire for technical solutions to development problems should not take on a life of its own where we forget that development is about people and what they think and how they feel matters." ([94], page 276).

12.5.6 Future developments

Researchers and seasoned practitioners alike agree on the way forward: bottom-up, incremental implementation, with enough latitude to make adjustments to original plans and fix new, unforeseen problems, may be key to the success of large government informatization programmes such as DURP and Bhoomi ([20, 108, 94, 116]). These programmes never start from scratch. They wrestle with the inertia of the "installed base"—old processes, old tasks, old organized practices—and inherit the strengths and limitations of that base. Bottom-up strategies need to link the old and the new in interoperable ways. The "old" significantly influences how the "new" can be designed and how new practices can be scaled up. A "cultivation" approach—emphasizing practices already in place—may be wiser than a "construction" approach that focuses on centralized, top-down planning. Implementation of large informatization programmes in the North and the South is not a well-defined process with preconfigured beginning and end states, but an ongoing process of ecological change, characterized by "unanticipated effects" and "drift", reflecting our all-too-human inability to fully anticipate future events.

12.6 Participatory use of GIS

12.6.1 Introduction to participatory GIS

When discussing route planning in Section 12.1, we saw many different considerations to be taken into account when deciding upon how to get from point A to point B. One road may lead through an urban development with traffic, factories and landfills, while another may pass through a forest and meadows. Which route would a user prefer? Would she or he prefer the forest road even if it is 20% longer? Or maybe even if it is 50% longer? Is it a daily commute to work, or is it a day's outing? All these factors matter.

Many more considerations come into play when a user aims not just to choose the best route, but when that user actually has to build a new road, where hundreds of jobs and millions of euros are at stake, and with an impact that will last for centuries to come. Similar concerns arise for any major project that can affect people, habitat or ecosystems. In many countries, such projects require an Environmental Impact Assessment (EIA)—a legally binding procedure of assessment of all possible environmental, social and economic outcomes of the proposed activity. The purpose is to make sure that no important consequence of a project is omitted. The importance of EIAs has been recognized for several decades. The International Association for Impact Assessment (IAIA: `http://www.iaia.org/`) is a global network of over 1600 members working to promote best practices in the use of impact assessment for informed decision-making about policies, programmes, plans and projects. IAIA defines EIA as the "process of identifying, predicting, evaluating and mitigating the biophysical, social, and other relevant effects of development proposals prior to major decisions being taken and commitments made".

12.6.2 Requirements for participatory GIS

The Netherlands Commission for Environmental Assessment (NCEA: `http://www.eia.nl/`) emphasizes that public participation is key to the EIA process. This process should record the impact, alternatives and comments from the public in a report, which should be binding when making the final decision, and the public should be informed about that decision. In European Directive 2001/42/EC (also known as the Strategic Environmental Assessment (SEA) Directive) "on the assessment of the effects of certain policies, plans and programs on the environment" requires a formal environmental assessment of all activities that are likely to have significant effects on the environment. Authorities that develop and/or adopt such an activity must prepare a report on the likely significant environmental effects of that activity, consult with environmental authorities and the public, and take the report and the results of the consultation into account during the preparation process and final decision-making for the plan or programme.

The Aarhus Convention (`http://www.unece.org/env/pp/welcome.html`) takes the process one step further, linking environmental rights and human rights. The convention acknowledges that we have an obligation to future generations. It stipulates stakeholder involvement as a prerequisite of sustainable development, links government accountability and environmental protection, and focuses on interactions between the public and public authorities in a democratic context. It gives the public open access to information about development projects and relevant data.

Since EIA/SEA is a stakeholder-driven process, it sets additional requirements on how research is conducted and how results are delivered. The assessment will be successful and actually used only if it is open and transparent. As we may be dealing with mixed interests and priorities, which can easily result in disputes and even court hearings, it is important that data, methods, analytical tools and results are open to scrutiny, well documented, and reviewed. This immediately requires that the study be scientifically rigourous and defendable. Ideally, the analysis should be peer reviewed and adopted by the community. In reality this may be hard to achieve, because of time constraints and the increasing variety and complexity of projects. To a certain extent this can be compensated for by making the study adaptive, iterative and interactive. By establishing and maintaining the assessment as an on-going open process that can be reinitiated when new data, specifications, concerns or priorities arrive, we can compensate for the inevitable uncertainty and imperfection of existing analyses. Obviously, at any stage of the project it is always important that all the deliverables are easy to interpret, understand and visualize.

12.6.3 Participatory GIS in EIA: The case of the Via Baltica highway

So how can EIA be performed and how can spatial information help? Suppose we are considering building a new highway, as was the case in Poland where the Via Baltica highway was proposed as a major improvement for accessibility between the EU's Central European nations (Figure 12.26), only to be suspended in 2007 owing to fears of irreversible ecological damage to important nature sites protected under EU law. Apparently, although several economically and environmentally more-sound alternative routes existed, they had never been considered as acceptable alternatives by the decision-makers. A systemic, spatial method for generating efficient transportation alternatives should take into account environmental regulations and concerns. At the same time it should integrate equally important considerations such as transport system efficiency, safety, socio-economic demands, and technical and financial viability as well as supporting stakeholder involvement throughout the whole planning process. To address this need, a participatory GIS interface was developed using spatial multi-criteria evaluation and network analysis to enable an objective comparison of various route alternatives [57].

Assessment criteria reflect stakeholder concerns and a wide variety of impacts arising from infrastructural development. For the Via Baltica project, representatives of environmental NGOs, Polish government bodies, independent research institutes and universities, as well as private consultants, were approached to provide a list of criteria relevant to the project. A wide range of criteria were considered, such as current traffic densities, national and landscape parks (and reserves) that should be protected, proximity to wetlands and peat bogs, proximity to urban areas, proximity to hazardous areas, risk of accidents in urban areas, location of highly fertile agricultural soils, intersections with water bodies, intersections with secondary roads, and proximity to economic zones. These criteria were grouped according to overall sustainable development objectives into four main themes: (1) transport efficiency, (2) ecology, (3) social impact and safety, and (4) economic costs and benefits.

Clearly, for different stakeholders the importance of each of these criteria was different. Each group of stakeholders was asked to give their preferences and as a result four different policy visions were defined by assigning different weights to each of the criteria themes (Table 12.2). One vision reflects equal importance of the criteria while the other visions reflect stakeholder opinions.

With these policy visions in mind, a series of suitability maps was generated. Spatial Multi-Criteria Analysis (SMCA) is a process in which the geospatial data sets representing the different criteria and weights described above are combined to prepare a routing suitability map for each of the four policy visions (Figure 12.27). Such a suitability map provides a continuous geographic surface, with each pixel value of this surface indicating the overall suitability value for routing the highway through that

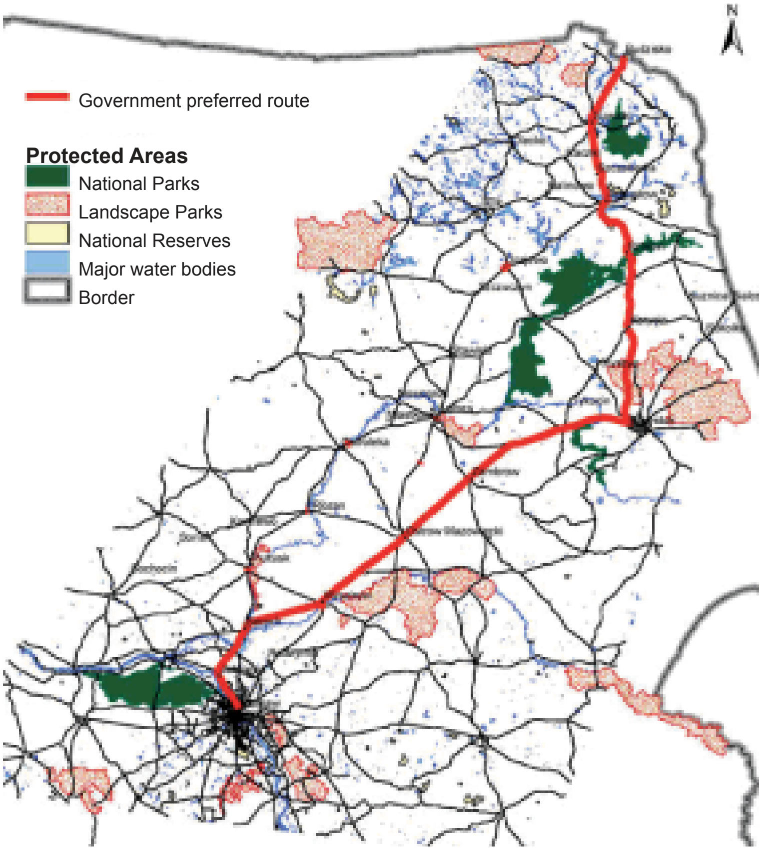


Figure 12.26
Part of the Polish road network with indicated in red the alternative preferred by the Polish government.

Table 12.2
Different visions, themes and their weights as used in the Via Baltica corridor study.

Themes	**Policy visions**			
	Equal	Social	Ecology	Economy
Transport efficiency	0.25	0.27	0.27	0.27
Ecology	0.25	0.06	0.52	0.06
Social impact & safety	0.25	0.52	0.15	0.15
Economic costs & benefits	0.25	0.15	0.06	0.52

pixel.

Next, based on the suitability maps of the four visions a network of existing roads was brought into a GIS. In the Via Baltica study, four optimal routes were generated, one for each of the policy visions. It was shown that all four optimal routings had less impedance and were also shorter than the Polish government's preferred route (see Figure 12.28). In addition, each of these alternative routings would also satisfy the EU's environmental laws and enjoy a high degree of stakeholder satisfaction.

The developed methodology provides decision-makers with a tool that enables them to make more rational and transparent decisions. However, it is not always clear how to make such decisions and how to bring together the conflicting values and priorities of different stakeholders. Environmental NGOs will be unhappy with any alternative other than one based on ecological priorities. Local governments will be promoting so-

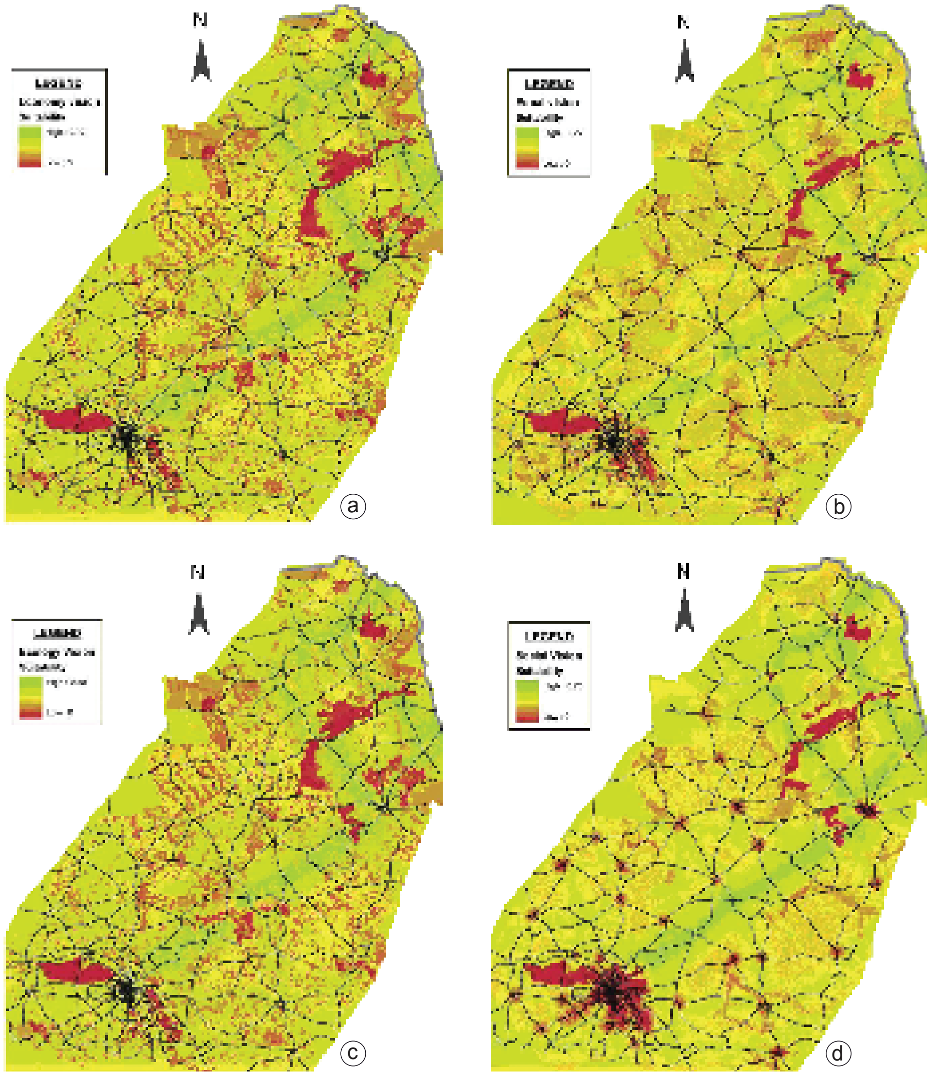


Figure 12.27
Suitability maps for the Via Baltica route according the four policy visions.

cietal values, while a national government will most likely be concerned with overall economic efficiency. How can these different, possibly conflicting, views and opinions be reconciled?

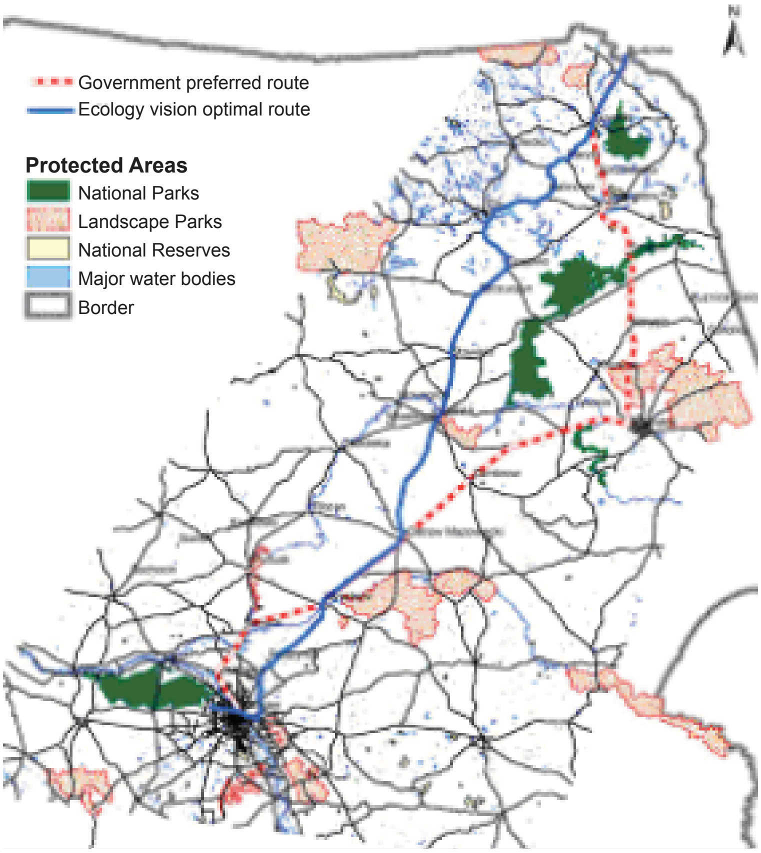


Figure 12.28
Route preferred by the Polish government (red) versus the ecology vision route (blue).

From EU Birdlife International [9]:	Recently the Polish government decided to route the highway via Lomza, which is not only the environmental sound option but also valid on economic, traffic and societal grounds. Konstantin Kreiser, EU policy manager at the BirdLife European Division commented: "This case shows once more that conflicts between nature conservation and infrastructure development can be solved through proper planning and political will—unfortunately it took the authorities seven years to learn this lesson as far as Via Baltica is concerned". Dr Helen Byron, a senior RSPB international site casework officer, added: "Sadly, this doesn't mean our work is over entirely—we still need to protect sites along the "old" Via Baltica route and ensure that construction on the new route goes ahead so that this isn't just a paper victory. But this is an absolutely fantastic step forward, ensuring a brighter future for the wildlife of this naturally diverse region".

An approach that can help communicate information between disparate and possibly conflicting groups of stakeholders is known as *participatory modelling*. Models of all kinds—spatial and non-spatial, dynamic and static, quantitative and qualitative—

participatory modelling

always have been used in the EIA process. In most cases, however, modelling is conducted by a group of professionals, and if stakeholders are involved they are brought in either as a source of information (opinions, data, expertise) or to peruse modelling results. A model that is mainly developed externally to the process is, therefore, often treated with distrust and suspicion. Model uncertainties and insufficiencies can be easily "blown up" and exaggerated, especially if there are controversial opinions or if "inconvenient" decisions have to be made. The recent debate on climate change exemplifies this clearly: no action was taken for a long time under the pretext that model results were "uncertain".

At the same time, as anybody ever involved in modelling would confirm, a model itself is an extremely powerful tool for learning and understanding. When a model is built, the system has to be carefully analysed, the key data need to be considered, and all the most important links and connections need to be evaluated. Participatory modelling, with its various types and clones, has emerged as a powerful tool that can (a) enhance stakeholders' knowledge and understanding of a system and its dynamics under various conditions, as in collaborative learning, and (b) identify and clarify the impacts of solutions to a given problem, usually related to supporting decision-making, policy, regulation or management.

Let us consider the example of Lake Champlain in Vermont, U.S.A., which has been receiving excess-nutrient runoff for the past 50 years owing to changes in agricultural practices and rapid development of open space for residential use (Figure 12.29). The effect of excess nutrients has been most dramatically witnessed in bays such as St. Albans Bay, which became eutrophic and turned green from algal blooms every August [46].

The watershed feeding St. Albans Bay is dominated by agriculture, but it is also affected by population growth in surrounding urban areas. In the 1980s, urban point sources of pollution were reduced by upgrading the St. Alban's sewage treatment plant and, at the same time, agricultural non-point pollution was addressed through implementation of "best management practices" (BMPs) on 60% of the farms in the watershed. The cost was US $2.2 million [113].

Despite the considerable amount of money and attention paid to phosphorus loading in St. Albans Bay, it still remains a problem to this today. The focus has remained primarily on agricultural sources in the watershed and, as a result, this has caused considerable tension between farmers, city dwellers, and landowners with lake-front property. Residents blame farmers for applying too much fertilizer and manure, and farmers blame residential dwellers for maintaining too many lavish lawns, the untreated storm water and the creation of impervious surfaces. As always, the brewing discontent is exacerbated by regulations. The Lake Champlain total maximum daily load (TMDL) of phosphorus allocated to the St. Albans Bay watershed required a 33% reduction of total phosphorus flows to the bay [84]. How should this reduction be shared between farming communities and urban residents?

This was not an easy problem to solve because it concerned non-point source pollution generated over a vast watershed that was then transported to the lake along a variety of pathways. Statistical, mass-balance and dynamic landscape simulation models were used to assess the state of the watershed, and the long-term accumulation of phosphorus in it, and to describe the distribution of the average annual phosphorus load to streams in terms of space, time and transport processes. A participatory modelling effort was conducted to apportion the total load of phosphorus among all sources, including their diffuse transport pathways, and to identify the most cost-effective interventions needed to achieve target reductions. A group of stakeholders were invited to participate in the two-year research process and were engaged in the

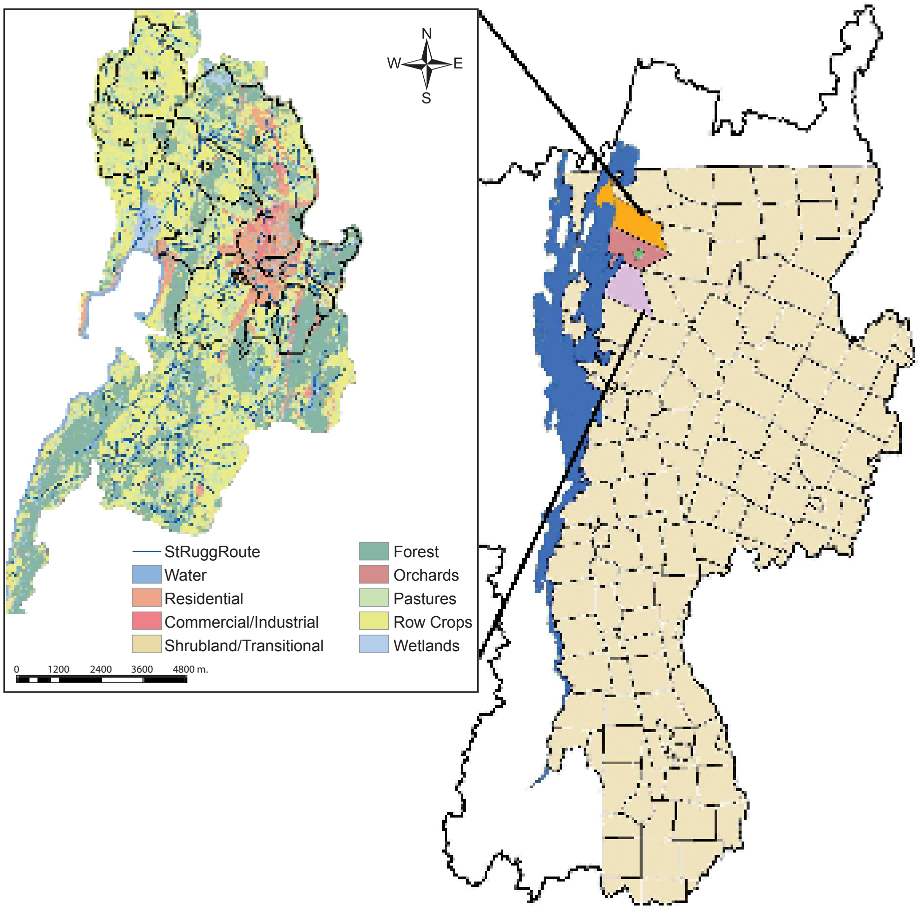


Figure 12.29
Lake Champlain and St. Albans Bay and its watershed (Vermont, U.S.A.).

research at multiple levels, including water quality monitoring, soil phosphorus sampling, model development, scenario analysis, and future policy development [34].

The participatory process started with a "Hydrology 101" crash course, in which stakeholders were introduced to the concepts of watershed hydrology and learned what factors can impact water quality and quantity. After that a fairly complex Landscape Modelling Framework [129] linked dynamic local models into a spatial grid of cells to describe how water and constituents are moving across space (Figure 12.30).

Watershed interventions that matched to most significant phosphorus sources and transport processes were identified with input from stakeholders and evaluated with the landscape model (Figure 12.31). Stakeholders were then invited to identify various interventions and formulate scenarios for future watershed development. Some 18 scenarios were identified, with the stakeholders having the best knowledge of what would be feasible for this particular area. The model was then used to compare the effect of various management scenarios on phosphorus loading (Figure 12.32).

Modelling results suggested that the St. Albans Bay watershed accumulates phosphorus over the long-term, primarily in agricultural soils. Dissolved phosphorus in surface runoff from the agricultural landscape, driven by high soil-phosphorus concentrations, accounts for 41% of the total load to watershed streams. Direct discharge from farmsteads and storm water drains, primarily from road-sand wash-off, were

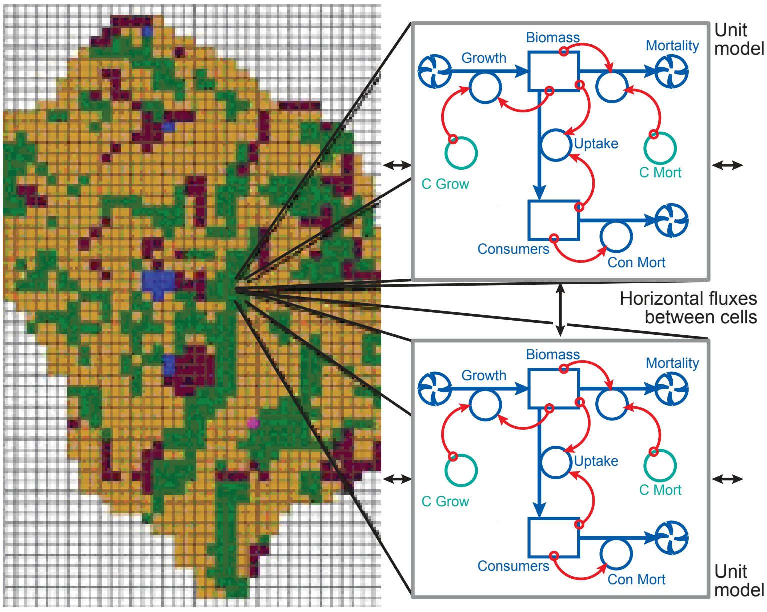


Figure 12.30
A raster map of the St. Albans Bay watershed with local processes described by process-based models.

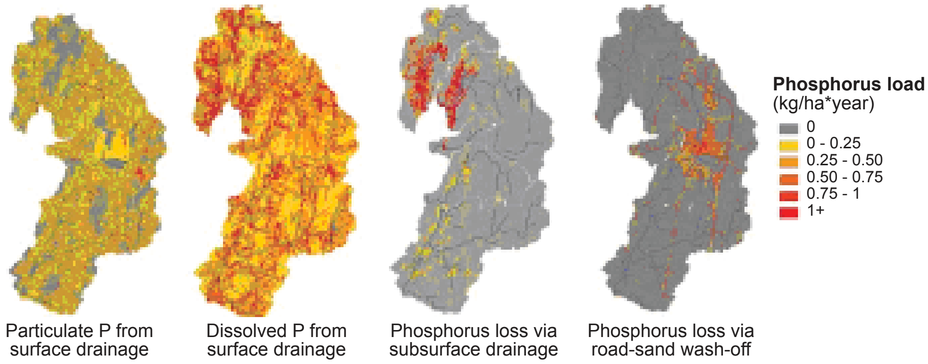


Figure 12.31
Sources of phosphorus loading identified from the spatial landscape model.

also found to be significant sources. Spatial optimization algorithms were then applied to identify the best mix of interventions at different locations to improve the overall efficiency, while minimizing total costs.

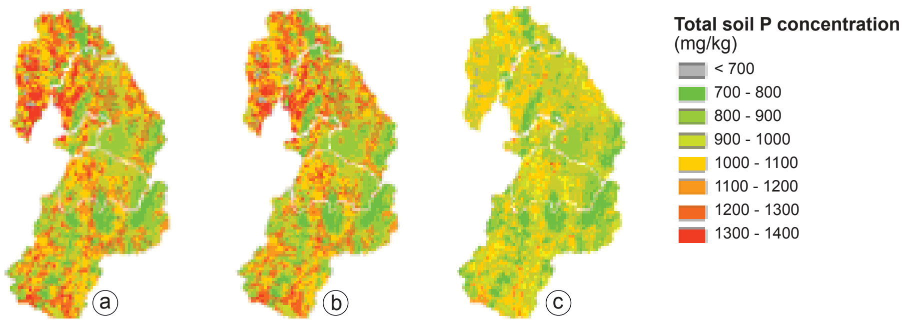


Figure 12.32
15-year scenario runs with the model. a) Base run; b) Fertilizer elimination scenario; c) Fertilizer elimination and reduced manure scenario.

The participatory modelling approach used in this study led to the identification of different solutions than stakeholders had previously assumed would be required. The approach also led to greater community acceptance and use of the modelling results, as demonstrated by local decision-makers being prepared to implement some of the solutions identified to be most cost-effective.

One of the keys to the success in this project, as with any participatory approach, is that the community participating in the research was consulted from the very beginning of the project and was urged to set project goals and identify the specific issues to be studied. In the St. Albans project stakeholders were engaged in the decision-making process through knowledge provision, model selection and development, data collection and integration, scenario development, interpretation of results, and development of policy alternatives. Engaging participants in as many of these phases as possible and as early as possible—beginning with setting the goals for the project—drastically improves the value of the resulting model in terms of its usefulness to decision-makers, its educational potential for the public and its credibility within the community.

From stakeholder interviews in the St.Albans project [34]:	"It brought people together in a non-confrontational manner. That was key, I thought. It wasn't that we were coming together to discuss what the farmers were doing, or what the city folk were doing. We were coming together to just say this is what is happening without any blame being placed on anybody." "Tying pieces of information together was an important aspect of this process."

12.6.4 Future developments in participatory use of GIS

The drive towards participatory decision-making is primarily fuelled by the increasing realization that the more humans impact the environment and the more they attempt to manage natural resources, the more complex and less predictable the overall socio-ecological system becomes. And the harder it becomes to find the right decisions to be made and to choose best management practices. Participatory modelling helps to "level the playing field" for decision-making by providing a common pool of knowledge and data that are delivered in the process of shared learning by the stakeholders. Participatory modelling can also improve communication between formerly disconnected groups of stakeholders, providing a common language for interaction and resolving disputes, which leads to more consensus and easier decision-making, as well as better decisions.

The St. Albans example shows how EIA and SEA call for an elevated role for users in the decision-making process. In this case, by engaging users in the process rather than bringing them in only to receive the end-product, the standard flow of delivery was changed. For EIA, we need user input upfront: we need them to define the scope of the study and the main goals, issues and scenarios that need to be analysed. Moreover, by keeping users engaged in a participatory modelling effort we ensure their "buy-in" for the results of the study, we help them better understand the issues and the various links and value sets of other, possibly conflicting, parties. This can help user communities to resolve disputes and make better, mutually acceptable decisions.

12.7 Concluding remarks on users and user requirements

Whether it concerns land or sea, demand for GI Science has always been high. GI Science products and services have become easier and cheaper to access. And as their usability improves, we have seen an ever-increasing interest and rapid uptake of the technology by many users. What was once exclusively the domain of scientists and engineers is becoming accessible to non-specialists who wish to navigate easily between locations or access, analyse and use spatially and temporally referenced information. The range of products, services and data described in this chapter highlight the breadth and depth of information available and the delivery mechanisms through which those services and information can be accessed.

Technology is rapidly developing. Even a technophobe will be aware that developments in science and engineering are changing how we interact, discuss, make decisions and act. Most information used for decision-making, governance, design and debate is referenced in space and time. As such, GI Science is becoming readily accessible, and its availability is still increasing.

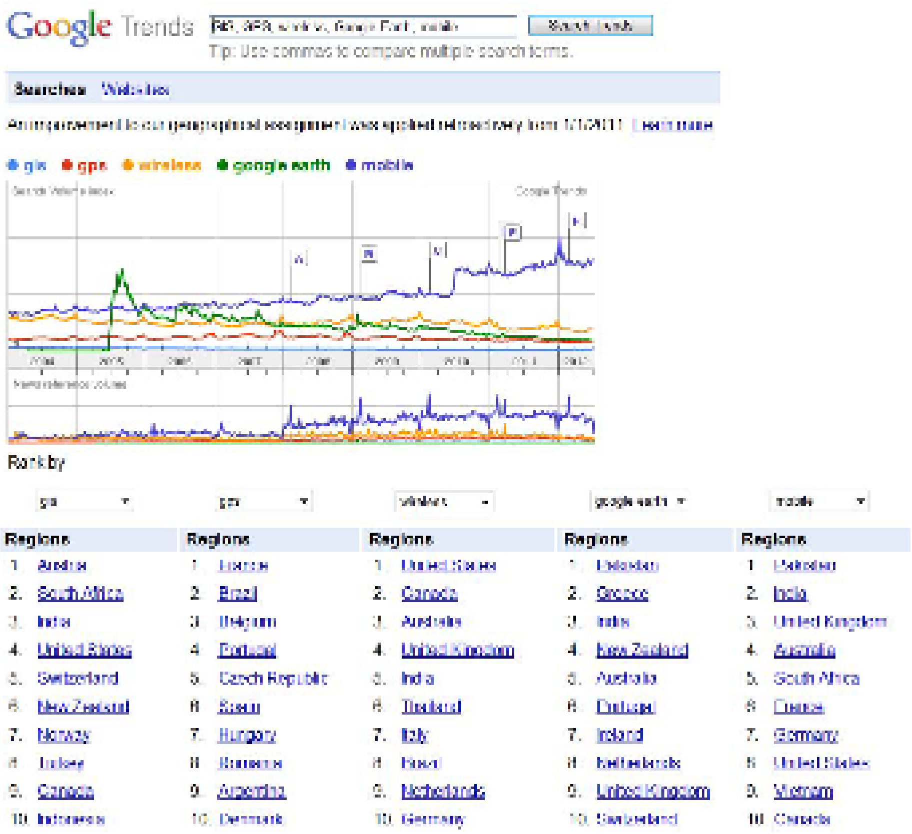


Figure 12.33
Google trends. Screenshots of Google trends combined in an analysis of keywords.

Two technologies that impact our lives, and are central to GI Science, are the Internet and wireless (mobile) communication. As a Google trends analysis indicates (Figure 12.33), while GISs are of relatively low interest to the Internet community and the news media, the number of times the term *mobile* is searched across the web is increasing. New technologies such as Google Earth tend to initially peak and then stabilize. Practical GIS tools, such as GPS, are more frequently researched by the Internet community and the news media. The combination of Internet and wireless/mobile technology enables users to easily access GI Science applications (think of Google Earth on mobile devices). Real-time updating of GI Science applications (e.g. updates on traffic flows while driving, see Section 12.1) is another example of a clever combination of wireless technology and GISs.

Information and warnings about possible or impending natural disasters such as floods may be accessed on the Internet via mobile devices (Section 12.2), while *hard* coastal defence systems may be activated (e.g. storm-surge barriers) and vegetation monitored using RS, resulting in action taken to strengthen *soft* defence systems (Section 12.3).

GI Science offers tools to assist in complex decision-making in society (such as spatial planning or environmental impact assessment for a newly proposed development as described in Sections 12.4 and 12.5). We have illustrated the importance of:

- providing information to stakeholders;
- creating a platform for interaction and discussion about possible scenarios and alternatives;
- detailing concrete outcomes resulting from proposed actions; and
- allowing users to participate in decision-making processes.

Where the future will take users of GI Science is difficult to gauge, but it will be on the one hand defined by users, by their needs and their priorities and on the other hand by technological development. Tools to observe and sense the environment will become smaller, cheaper and ubiquitous, generating volumes of online data that will dwarf the volume of data and information currently available. What is even more important is the new methods and analytical tools of the future that will allow users to "wrap" this information into useful and meaningful outcomes that will be easy to visualize, interpret and understand. Here, GI Science plays the critical role to generate information out of the data, and to generate downstream products out of primary products. Development of methods to do so is crucial to remaining "afloat" and being able to "swim" in this rising sea of information.

Wireless (mobile) technologies will continue to improve in speed and capacity. Georeferencing of personal information by place and date is generating huge databases of spatial information that are available to central governments and large IT companies such as Google and Microsoft. Almost everything can be mapped nowadays, whether it concerns medical records, travel movements, financial transactions, monitoring by surveillance cameras in public places or along roads, or simply the location of one's mobile phone. The geo-component of data, and innovative ways of analysing and visualizing these data, and then turning them into information, gives much scope for further research. A new and fascinating development may quickly become standard technology. An example is mapping the digital relationships between all of someone's friends on Facebook via the touchgraph map (see Figure 12.34). Friends who have a very close connection to you are closer to the centre of the graph than those who have fewer connections with you. And, in general, those who are more connected are relatively close together in the graph while others who are hardly or not in contact are at opposite ends of the graph. These networks will most likely further develop and become the key of new uses of GI Science.

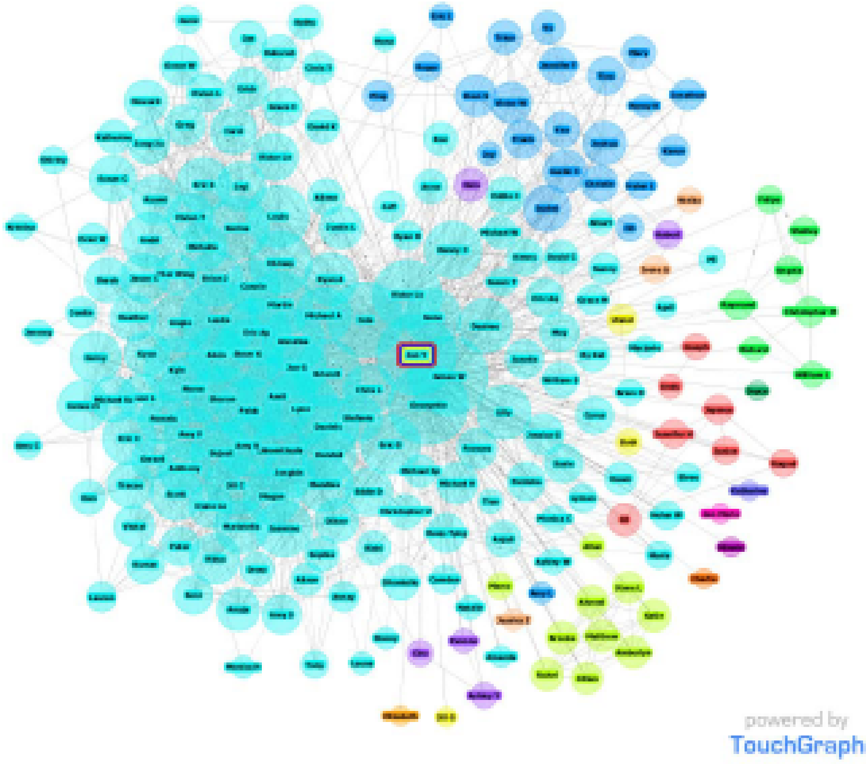


Figure 12.34
A touchgraph facebook map.
Source: [50].