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How GIS Technology Works and Why We Need SDIs

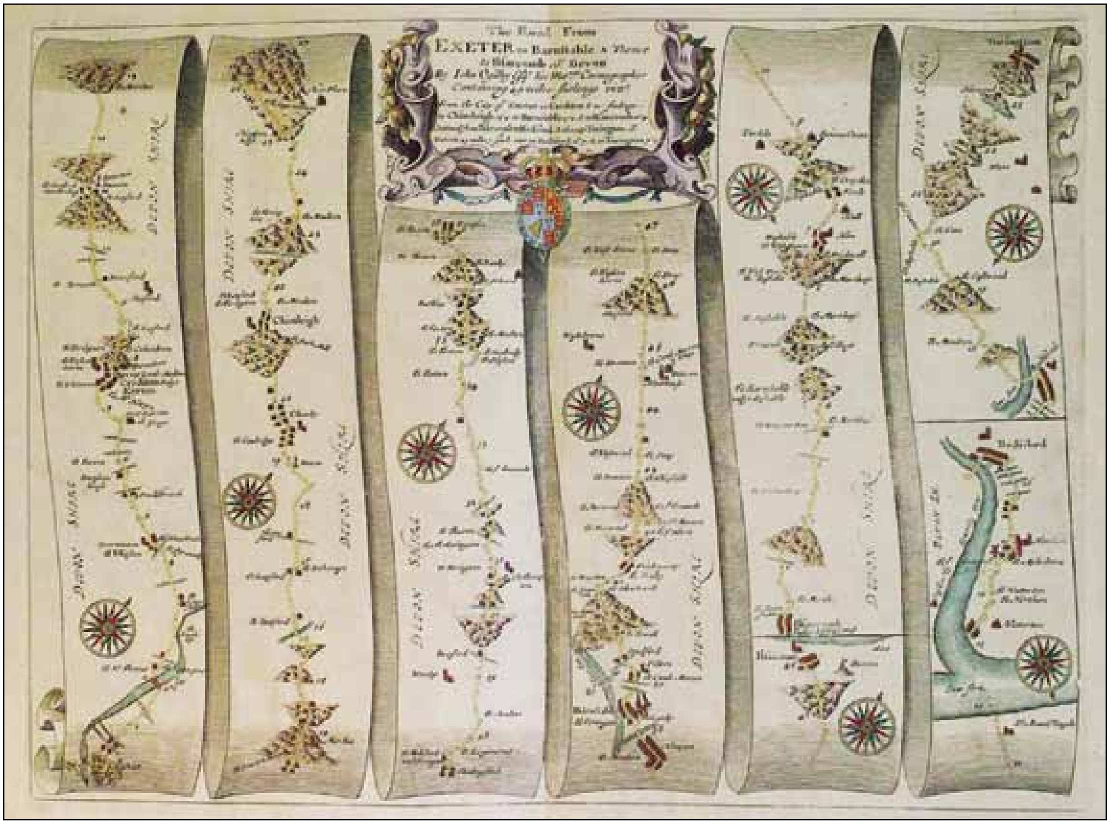

Figure 2.1

John Ogilby's 1675 route map from Exeter to Ilfracombe in England.

LOCATION, LOCATION, LOCATION

Geographic information identifies or describes locations on the surface of the Earth. In the past, such information took the form of paper maps. Now, geographic information can be stored digitally, allowing it to be processed by computers, and this has enabled the creation of many new applications.

Geographic information can consist of addresses, market research data, census data, health data, data on environment and natural resources, descriptions of transportation and utility networks, information on flows of goods, cadastral and land registration information, as well as data obtained by remote sensing from satellites in space.

The simplest way of presenting geographical information is the map. The oldest known maps date back thousands of years. Maps have been preserved on Babylonian clay tablets from about 2300 BC. Modern mapping dates from the Age of Discovery in the fifteenth and sixteenth centuries. This was also a time when more and more people were travelling around by themselves and required basic information in the form of road maps, specifically the kind produced by John Ogilby in England (figure 2.1). The science of cartography grew up around the production of maps.

Maps are widely used because everything that happens, happens somewhere, and knowing where something happens can be strategically important. Consequently, military considerations played an important role in the development of cartography. They were instrumental in the establishment of the Survey of India in 1767 and the creation of the Ordnance Survey of Great Britain in 1791.

Geographic information can be used to answer the following general questions:

- *Where is it?*—Location of a point on the Earth's surface
- *How far is it?*—Distance between two points on the Earth's surface
- *Is it near somewhere?*—Relationship between two points on the Earth's surface
- *In which district does it lie?*—Information about administrative areas
- *How can I get there?*—Information such as the quality of transportation routes and bus and train timetables

Three geometric concepts underlie these questions: **points,** objects whose location is specified by a set of coordinates; **lines,** connected coordinate points forming features such as rivers and roads; and **polygons,** areas bounded by connected lines such as administrative districts and areas of homogeneous land use or soil type (figure 2.2).

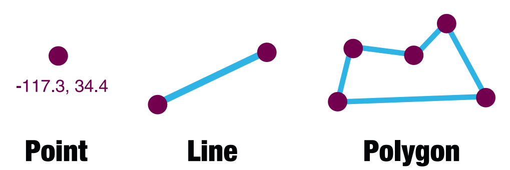

Figure 2.2

Points, lines, and polygons.

Figure 2.3

High-resolution image of the European Commission Berlaymont Building in Brussels. Courtesy of Digital Globe.

To answer the last of the questions on the previous page, attribute data about the nature and frequency of buses and trains is needed. Attribute data is typically statistical data related to points, lines, or polygons. Examples of attribute data include population census statistics, various kinds of survey data, as well as information related to individual addresses such as property valuation, vehicle registration details, and personal health records.

GEOGRAPHIC INFORMATION SYSTEMS

Geographic information systems (GIS) can be defined as computer systems for capturing, managing, integrating, manipulating, analysing, and displaying data that is spatially referenced to the Earth. They were first developed during the 1960s, but it was not until the mid-1980s that computers capable of handling the considerable amounts of data used in these systems came into being. In 1987 the British Government Committee of Enquiry chaired by Lord Chorley hailed the advent of GIS as "the biggest step forward in the handling of geographic information since the invention of the map" (Department of the Environment 1987 [paragraph 1.7]). Developments since that time have massively increased computer storage and handling capabilities, and the Internet has made it possible to transfer large amounts of geographic information from one place to another.

A detailed examination of the tasks that can be accomplished with this relatively new technology makes it easy to see just how powerful GIS really is.

Capturing. Capturing is the encoding of data into digital form, which enables it to be read by a computer. It includes map digitising, direct recording by electronic survey instruments, and the encoding of text and attributes of all kinds. It also includes the millions of images obtained by means of Earth observation technology. For example, figure 2.3 shows a high-resolution image of the European Commission Berlaymont Building in Brussels taken by the QuickBird satellite from 450 kilometres above the Earth's surface.

Managing. Managing is the creation of databases (collections of data) organised according to a conceptual schema. This is usually handled with the help of a database management system (DBMS), which is software used to organise the information. This software typically contains routines for data input, verification, storage, retrieval, and combination.

Integrating. GIS makes it possible to link datasets and to merge and combine different data for the same location (bus and train information, for example). This makes GIS an analytical tool that is fundamentally different from a conventional paper map.

Manipulating. GIS also makes it possible to manipulate large volumes of data for the same area easily and quickly. This capability gives GIS great potential for generating new products and services which add value to existing spatial data.

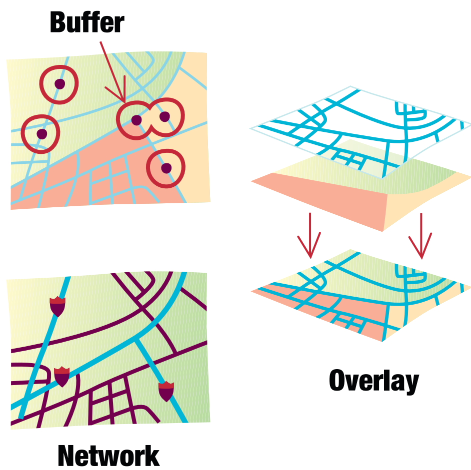

Figure 2.4

Buffer, network, and overlay.

Analysing. The basic analytical capabilities of GIS consist of overlays, buffers, and networks (figure 2.4). An overlay is the superimposition of two or more datasets that are registered to a common coordinate system. Buffers are regions of specified width around a point, line, or polygon. Networks are geometric or logical arrangements of nodes and interconnecting lines. GIS technology also facilitates the development of methods for exploring more complex relationships through mathematical models.

Displaying. Visualisation tools that can be used to display data held in a GIS include not only conventional maps but also graphs and three-dimensional models of surfaces and buildings (figure 2.5).

The benefits of GIS consist of quick and easy access to large volumes of data, the ability to select detail by area or theme, the possibility of linking one dataset with another, and the opportunity to analyse the spatial characteristics of an area as well as new kinds of output tailored to meet particular needs (Longley et al. 2005).

Despite these advantages, the Chorley Committee also concluded 20 years ago that the availability of GIS technologies was "a necessary, though not sufficient condition for the take up of geographic information systems to increase rapidly" (Department of the Environment 1987 [paragraph 1.22]). In other words, political and institutional barriers that currently restrict the use of GIS must be overcome. These include compatibility problems stemming from differences in definitions and formats as well as restrictions on access and the availability of data.

These barriers currently limit the effective utilisation and commercial exploitation of GIS technology, impeding job creation and economic development in the process. They also block opportunities for increasing the effectiveness and transparency of governments.

Figure 2.5

Three-dimensional visualisation from the Virtual London project. Courtesy of Michael Batty, Centre for Advanced Spatial Analysis (CASA), University College London.

To remove the political and institutional barriers blocking the widespread use of GIS, governments need to do the following:

- Ensure that data coverage is comprehensive, the same definitions and formats are used, and the timing of updates is consistent
- Promote interoperability between different datasets and different systems
- Reduce or eliminate restrictions on access and availability while protecting the intellectual property rights (IPR) of data owners and the privacy of data providers
- Disseminate information about what data is available and from what sources

From the early 1990s onward, governments all over the world have felt the need to create spatial data infrastructures. This need has been intensified recently by new technologies such as Global Positioning System (GPS) devices (which give individuals the means of calculating their coordinate references at different locations) (figure 2.6), satellite navigation systems for cars, and a new generation of mobile phone services that can also display map-based information. In addition, new Web-based geographic information services such as Google Earth make it possible for users to view different parts of the world at the click of a mouse. These developments mean that the majority of people, either knowingly or unknowingly, are now users of geographic information.

Figure 2.6

A member of a natural-resources agency uses a GPS device to assist with the monitoring of river levels in the northwest United States. Courtesy of Trimble Navigation New Zealand Ltd.

SPATIAL DATA INFRASTRUCTURES

There are clear parallels between SDIs and other forms of infrastructure. An infrastructure typically comprises the basic facilities, services, and installations needed for the effective functioning of a community or society. Infrastructures include transportation and communications systems, water and electricity services, as well as public institutions such as hospitals, schools, post offices, and prisons.

A spatial data infrastructure (sometimes called geographic information strategy, geospatial data infrastructure, or geoinformation infrastructure) is "the means to assemble geographic information that describes the arrangement and attributes of features and phenomena on the Earth. The infrastructure includes the materials, technology, and people necessary to acquire, process, and distribute such information to meet a wide variety of needs" (National Research Council 1993, 16).

The overriding objective of SDIs is to facilitate access to geographic information assets held by a wide range of stakeholders in both the public and the private sectors in a nation or a region with a view to maximising overall usage. This objective requires coordinated action by governments.

SDIs must also be user driven, as their primary purpose is to support decision making for many different purposes. SDI implementation involves a wide range of activities. These include not only technical matters such as data, technologies, standards, and delivery mechanisms but also institutional matters related to organisational responsibilities, overall national information policies, and availability of financial and human resources.

The SDI phenomenon. Since the term "spatial data infrastructure" was first used in 1991, about half of the more than 200 countries in the world have embarked on some form of an SDI initiative (Crompvoets et al. 2004). Given these circumstances, the term "SDI phenomenon" seems to be a reasonable description of what has happened in this field over the last 20 years. The original leaders in this field were mainly relatively wealthy countries such as Australia, Canada, the Netherlands, Portugal, and the United States, but SDIs are now being developed in all parts of the world. There are considerable differences among countries in terms of both the approach and the content of these initiatives (Masser 2005).

SDIs are under construction at both the national and the subnational levels of government and also at the supranational level. Their primary objectives are typically to promote economic development, stimulate better government, and foster environmental sustainability at all these levels. The notion of better government can be interpreted in several different ways. In rapidly developing countries such as Malaysia, it means better strategic planning and resource development. Planning, in the sense of a better state of readiness to deal with emergencies brought about by natural hazards, was also an important driving force in the establishment of the Japanese national SDI after the 1995 Kobe earthquake. In Portugal, on the other hand, the National Geographic Information System has played an important part in modernising central, regional, and local administration.

The most famous national spatial data infrastructure (NSDI) is the one that was set up in the United States by an executive order from President Clinton on April 11, 1994 (box 2.1). This directive set forth the main tasks to be carried out and defined time limits for each of the initial stages of the NSDI. It strengthened the powers of interagency coordination of the Federal Geographic Data Committee (FGDC), whose membership includes representatives from all the major federal departments with an interest in geographic information and the collection and management of such information. The executive order also required the creation of a national digital geospatial data framework of the most frequently used datasets, the establishment of a national geospatial data clearinghouse to increase user awareness of what data is available, and the facilitation of access to this data. The FGDC Clearinghouse has been one of the most obvious SDI success stories. The FGDC Clearinghouse Registry, for example, lists nearly 500 registered nodes within its network from the United States and other countries. These facilities have been augmented since 2002 by the creation of the Geospatial One-Stop portal to support the E-Government Initiative (figure 2.7).

Box 2.1

Executive order signed by President Clinton in 1994 establishing the U.S. National Spatial Data Infrastructure.

PRESIDENTIAL DOCUMENT

Executive Order 12906 of April 11, 1994

Coordinating Geographic Data Acquisition and Access: The National Spatial Data Infrastructure

Geographic information is critical to promote economic development, improve our stewardship of natural resources, and protect the environment. Modern technology now permits improved acquisition, distribution, and utilization of geographic (or geospatial) data and mapping. The National Performance Review has recommended that the executive branch develop, in cooperation with state, local, and tribal governments, and the private sector, a coordinated National Spatial Data Infrastructure to support public and private sector applications of geospatial data in such areas as transportation, community development, agriculture, emergency response, environmental management, and information technology.

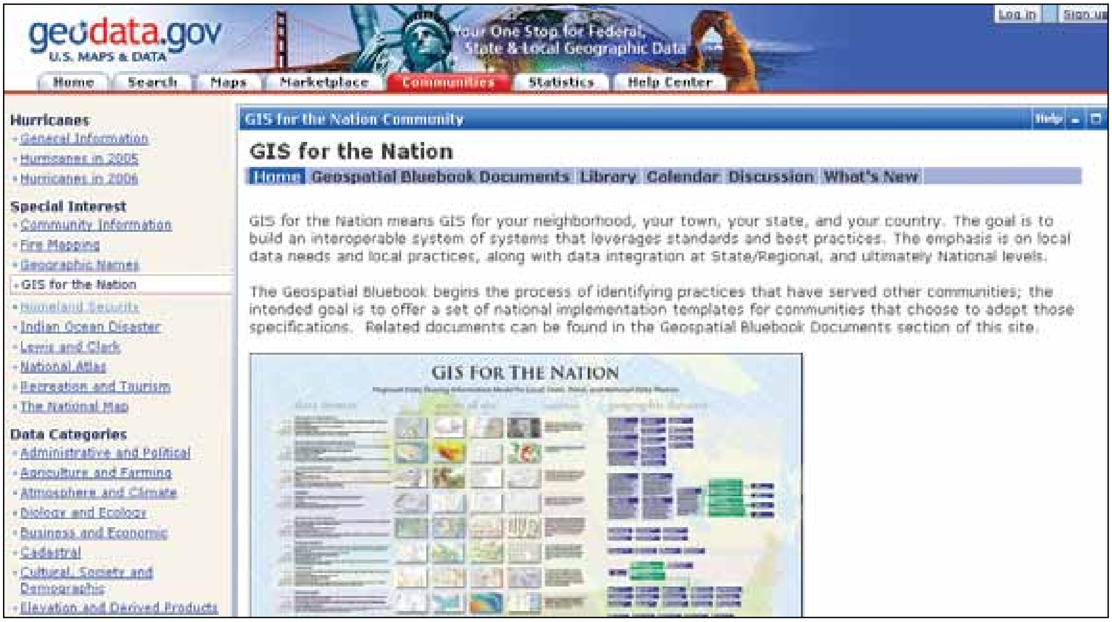

Figure 2.7

Geospatial One-Stop portal search page.
www.geodata.gov.

In contrast to the U.S. NSDI, the lead agency for the Canadian Geospatial Data Infrastructure (CGDI), GeoConnections, has always been a cooperative organization that seeks to involve all the stakeholders from different levels of government, the private sector, and academia, among others (figure 2.8). These interests are reflected in the composition of the GeoConnections Management Board and also in the membership of its constituent nodes such as the Policy Advisory Network. GeoConnections sees itself as a catalyst for successful implementation. There is also a strong industry connection between the CGDI and the Geomatics Industry Association of Canada.

Australia presents another model of SDI governance. The precursor of its Australia New Zealand Land Information Council (ANZLIC) was set up in 1986 as a result of an agreement between the Australian prime minister and the heads of the state governments who wanted to coordinate the collection and transfer of land-related information between different levels of government. Each of the members of ANZLIC represents a coordinating body within their jurisdiction: the Commonwealth Office for Spatial Data Management, the relevant coordination bodies at the state and territory levels, and Land Information New Zealand. In effect, ANZLIC has been developing some elements of the Australian Spatial Data Infrastructure (ASDI) since 1986.

Alongside developments such as these, a number of international regional and global agencies have been set up to promote capacity building and raise awareness of the need for governments to promote the creation of SDIs. These include bodies such as the European Umbrella Organisation for Geographic Information (EUROGI) and the Global Spatial Data Infrastructure Association (GSDI). The GSDI cookbook (Nebert 2004) has been widely distributed over the Internet and played an important role in capacity-building activities all over the world.

SDI components. The process of SDI development and implementation consists of four main components. As can be clearly seen in the Victorian Spatial Information Strategy (VSIS, Australia) for 2004 to 2007 (Department of Sustainability and Environment, Victoria, Australia 2005), the four components are the institutional arrangements that are required for delivering geographic information, tasks related to the creation and maintenance of fundamental datasets, procedures for making geographic information accessible, and ways of facilitating the development of strategic technology and applications (figure 2.9).

Institutional arrangements include matters related to the overall governance of SDIs as discussed above for the United States, Canada, and Australia, as well as the assignment of responsibilities for the custodianship of fundamental datasets.

Victoria's Vicmap gives some idea of the kind of data that is regarded as fundamental to most applications (box 2.2). It includes geodetic

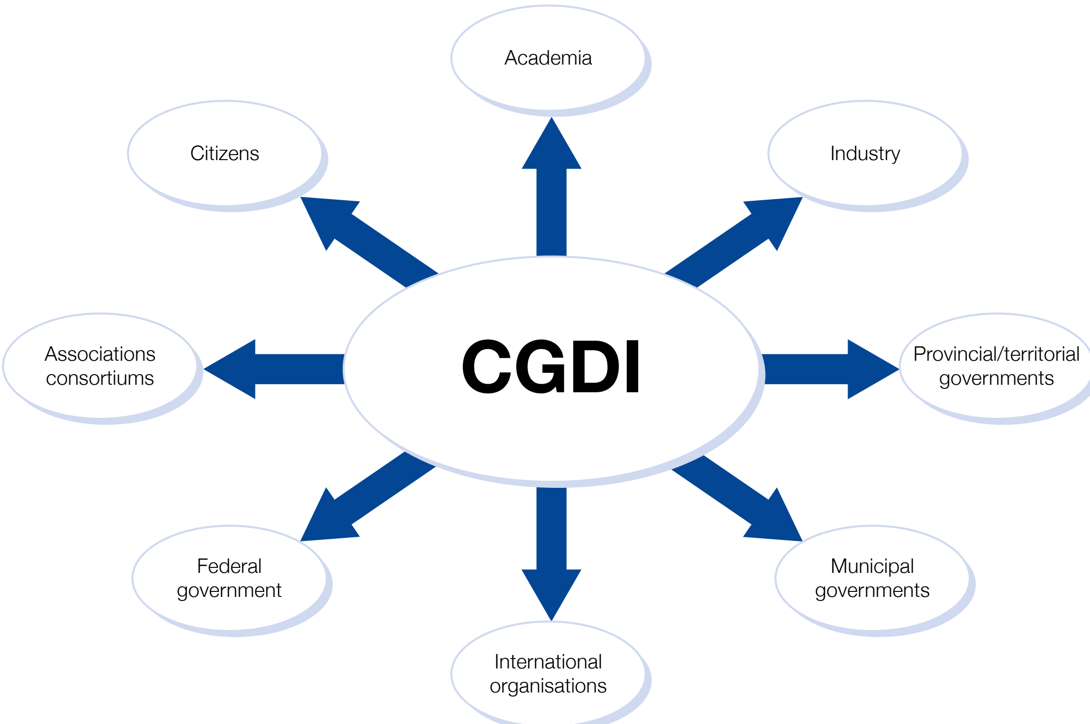

Figure 2.8

Stakeholders in the Canadian Geospatial Data Infrastructure (CGDI). Copyright Natural Resources Canada. Used by permission.

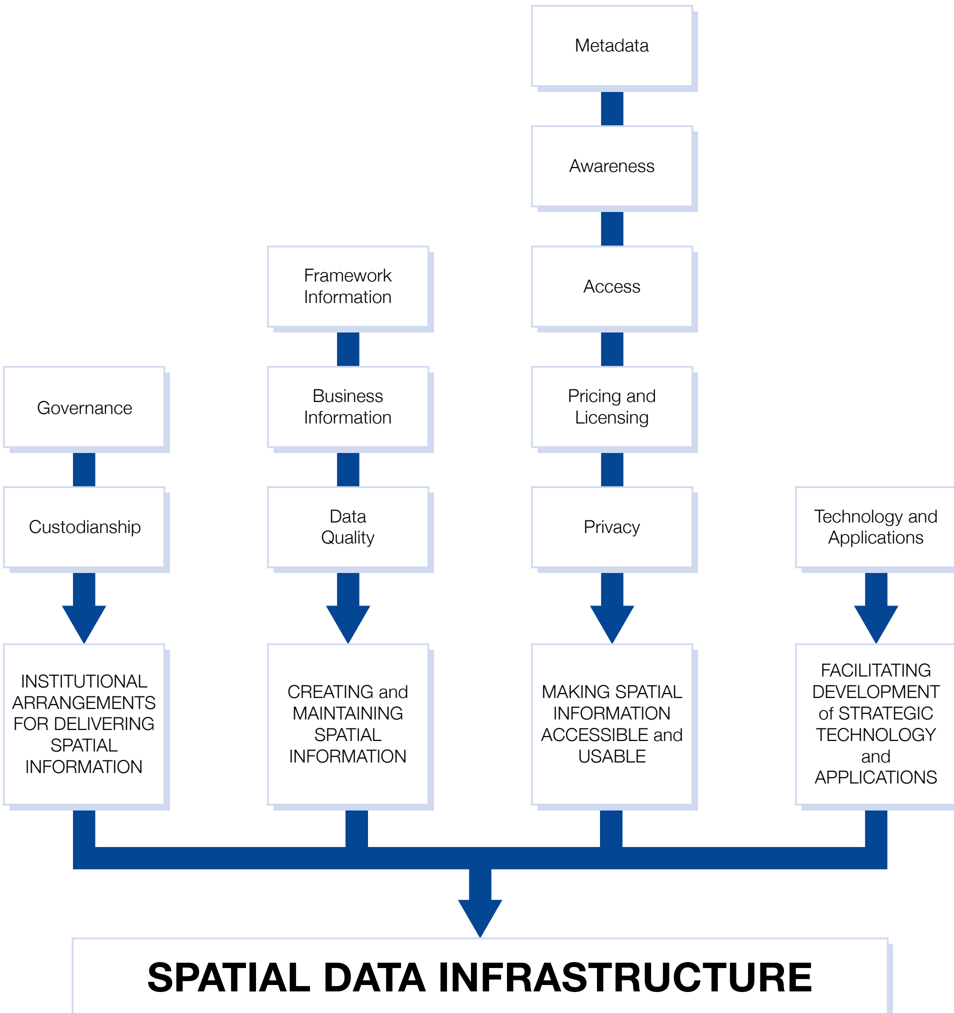

Figure 2.9

Components of Victoria's SDI. Courtesy of Department of Sustainability and Environment.

reference points, elevation and hydrographic data, addresses, administrative boundaries, and property and transport information.

The third component of SDIs is the need for metadata services to increase user awareness of what data is available and to facilitate access to this data. The recent development of spatial portals such as the U.S. Geospatial One-Stop opens up new possibilities for metadata services. Spatial portals can be seen as gateways to geographic information resources which allow users and providers to share content and create consensus. In the process of developing metadata services, it is also necessary to deal with issues such as awareness, access, pricing and licensing, and privacy.

The last component deals with technology and applications. Recent advances in technology as described above have dramatically altered the way in which spatial information is acquired and used. The only constant factor in this demand-driven environment is the need for data that is easy to access and independent of technology or software. This requires that the arrangements for data sharing and exchange be based on the concept of interoperability.

SDI costs and benefits. The costs and benefits associated with SDI development cannot be easily estimated with any precision. Nevertheless, it is clear that the tasks of SDI coordination and governance are relatively inexpensive in relation to the overall expenditure on geographic information, whereas the task of core digital database development is relatively

Box 2.2

Fundamental datasets maintained by the State of Victoria, Australia.

VICMAP DATASETS

Geodesy: More than 100,000 survey marks and a network of GPS stations, collectively known as GPSnet
Property: 2.5 million parcels and properties
Transport: Every road in the state, including forest trails, fire tracks, and property access roads
Address: Administrative boundaries, including locality, electoral, local government, and postcode
Elevation: Slopes, aspects, and contours
Hydrography: All water courses and features
Imagery: Aerial photography as well as Landsat and SPOT satellite imagery

expensive. The U.S. Office of Management and Budget has estimated that U.S. federal agencies alone already spend at least $4 billion annually to collect and manage domestic geospatial data, whereas the costs of supporting the FGDC and its work are less than 1 percent of this amount (Masser 2005, 47).

SDIs have economic, social, and environmental benefits (box 2.3). The most important economic benefit of SDIs is the promotion of economic growth as a result of an expanding market for geographic information products and services both locally and internationally. A PIRA International study conducted in 2000 for the European Commission (PIRA International 2000, 8–9) gives some indication of the value of public-sector information in the tightly constrained European market of that time. The findings showed that over half the economic value of public-sector information in 1999 (€68 billion) came directly from geographic information sources. This is equivalent to about 1 percent of the European gross domestic product. The findings also showed that the economic value of public geographic information resources in the less constrained U.S. market was €750 billion. With the easing of constraints through the development of SDIs, it might be expected that the size of the European market will move toward that of the U.S. market over time. Estimates of the growth of the commercial geographic information market are more readily available and have been on the order of 15 to 20 percent per year in recent years. The impact of an expanding market of this size on job creation is also considerable. Other economic benefits of SDIs include increased efficiency and lower operating costs for both public- and private-sector organisations due to wider access to geographic information and information-based services. These may also be considerable over time.

The most important social benefit of SDIs is the extent to which they create more efficient and more transparent governments at all levels as a result of the increasing availability of authoritative data to policy and decision makers. Another important social benefit stems from the opportunities that SDI data sharing creates for citizens to actively participate in the democratic process. Because they bring together data from many diverse sources, SDIs are also likely to lead to better arrangements for homeland security and more effective systems for emergency planning and response. There are also many operational benefits for social services, public health, education, and public safety from the more effective targeting of areas and groups with special needs.

SDIs can bring many environmental benefits, and they have an important role to play in promoting sustainable development throughout the world. At the national and local levels they provide the data required for effective management and monitoring of natural resources. They are particularly useful in coastal zones because of the extent to which they can integrate maritime and terrestrial data.

ECONOMIC BENEFITS

- An expanding internal market for GI products and services
- Greater competitiveness, more opportunities to export GI products and services
- Increased efficiency of both public- and private-sector organisations
- New opportunities for GI business applications and services
- Improved transport and infrastructure management systems

SOCIAL BENEFITS

- Improved national and local governance
- More opportunities to engage in the democratic process
- More effective homeland security
- Faster emergency response
- Opportunities to target groups and areas with special needs

ENVIRONMENTAL BENEFITS

- Promoting sustainable development
- Better natural-resource monitoring and management
- Improved coastal-zone management

Box 2.3

Benefits of SDIs.

CONCLUSIONS

In order for the enormous potential of GIS to be fully exploited, governments need to ensure that fully compatible and integrated databases are made available without restrictions on reuse of data, thus facilitating access to geographic information assets held by a wide range of stakeholders. Widespread implementation of SDIs will bring substantial economic, social, and environmental benefits.