INTERACTIVE WEB-BASED VISUALIZATIONS OF GEOSPATIAL INFORMATION FOR SUSTAINABLE DEVELOPMENT DECISION MAKING

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ABSTRACT
An ever increasing complexity of economic and social development and the interconnectedness of knowledge needed for sustainable development decisions requires effective visualization methods, capable of integrating, simplifying and unambiguously communicating information to various user groups. This paper presents selected visualization methods developed in the Visualization of Integrated Knowledge for Sustainable Development Decision Making project, carried out within the Earth Sciences Sector of the Natural Resources, Canada, in collaboration with Canadian Geomatics industry and universities. The techniques include: integration of heterogeneous information, visualization of change, web-enabled dynamic access and visual communication of information, and a map based collaborative decision making. Further, the paper presents the Department’s strategies to further sustainable development in application to the management of natural resources. Development of web-based interactive techniques capable to effectively communicate information in the Internet environment to decision makers and general audiences is illustrated by selected application examples.

SUSTAINABLE DEVELOPMENT IN NATURAL RESOURCES, CANADA
Sustainable development is everyone’s concern and responsibility. In a sustainable society built on modern decision making, everyone is a user and a producer of information and knowledge. At the community level, individuals, businesses and organizations need reliable information visualization tools to make decisions that increasingly integrate social, economic and environmental considerations. International institutions need information to measure the world’s programs toward environmental stewardship, fair trade, and acceptable living standards for all [Sustainable Development in Canada, 2001].

In Canada, sustainable development is the jurisdictional responsibility of all levels of government. Within the federal government, Natural Resources was the first department to adopt a sustainable development strategy within its mandate. The Sustainable Development Strategy is a key tool for addressing the challenges and taking advantage of the opportunities related to sustainable development through the Department’s policies, programs, science and technology, legislation, regulation and operations. The current sustainable development strategy communicates Natural Resources Canada’s commitment to sustainable development and clearly articulates the importance of Natural Resources Canada role in the Government of Canada’s sustainable development agenda [Natural Resources Canada, 2004].

The Sustainable Development through Knowledge Integration (SDKI) program [http://sdki.nrcan.gc.ca] focuses on a number of issues related to Natural Resources Department requirements for sustainable development. It builds on the concept that the Earth Sciences Sector geospatial information will effectively support decision and policy making. The SDKI program aims to move the sector’s data, information and knowledge into the decision support environment of government, industry and the public. It develops technology that facilitates the integration of earth science information and knowledge, enhances Natural Resources department capacity to implement the sustainable development policy and ensures the responsible use of Canada’s mineral, energy and forestry resources [Richardson, 2003].
One focus of this program is to adapt, develop and implement innovative data integration methods that enhance selected aspects of the earth sciences sector capacity to support the department in reporting against progress on the sustainable development strategy.

The Visualization of Integrated Knowledge for Sustainable Development Decision Making (SDKI-Vis) project focuses on visualization methods to remove the barriers to the effective communication of geospatial information to policy and decision makers. The visualization project is developing and implementing various cartographic techniques capable of integrating and representing geospatial and temporal data, information and knowledge. The specific user needs have been identified in consultation with SDKI application project leaders. Generic visualization methods developed within the project are applicable to other Earth Sciences Sector programs dealing with integrated knowledge based on geospatial data and information such as Geomatics for Northern Regions of Canada or programs related to climate change.

Making spatial decision support systems with a strong visualization component available to decision makers, stakeholders and the general public, will facilitate integration of information and the inclusion of principals of sustainability in the collaborative resource management decisions.

**VISUALIZATION AND SUSTAINABLE DEVELOPMENT DECISION MAKING**

In 1994, the president of the Association of American Geographers identified visualization as one of main concept for learning and decision making in sustainable development [Wilbanks, 1994]. “…we should recognize the growing power of the visual image in human communication in this age of information revolution. Across the world, the creation and diffusion of visual images is displacing the printed word as a triggering mechanism for issue identification, constituency building and agenda-setting. And visual images, including computer mapping and aerial photography, are increasingly used to identify threats to sustainability and to examine alternative paths. No other form of communication is as powerful among such a wide variety of audiences, including scholars who are trying to associate creative thinking with empirical observations”. The author further stressed the importance of implementing innovative means of technological and institutional change to foster greater inclusion of the geographical perspective in sustainable development decision making.

Throughout the ages, various types of maps and images have been used to communicate geospatial information. Today, technological evolution and societal change have had a huge impact on how maps are produced and distributed. Maps have evolved from static representations of the world, to two or three-dimensional interactive digital representations. In addition to graphical representation, maps can now be enriched by multimedia; through the addition of animation, sound, and touch, expanded channels of information are available to the users. These new era maps themselves often become a medium for data exploration and analysis and new distribution systems such as the Internet are being increasingly used for their dissemination [Cartwright, 1999].

New terms, such as geographic and cartographic visualization, multimedia, hypermedia, cyber cartography, etc. are being introduced to explain more precisely the new forms of representation and use of geospatial data. This trend emphasizes the benefits of collaboration with other related disciplines, such as geographic information systems, computer graphics, or human machine interfaces, which develops new forms of graphic communication. As cartographic visualization is based increasingly on new technologies, the richness of human-to-human communication is often lost as virtual environments can hamper spontaneous engagement. However, many researchers believe that the most dynamic and collaborative communication occurs when both high and low technology tools are used [Bosselmann, 1998, Al-Kodmany, 2001]. Thus cartographic visualization is not meant to replace traditional tools for decision making, but to augment and enhance them.

Visualization has emerged as a tool for searching huge volumes of data, communicating complex patterns and providing a formal framework for data presentation and exploratory analysis of data [Gahegan et al., 2001]. It combines the power of multimedia dynamic representation of spatial information with interactive engagement of users (experts and non-experts) to perform exploratory analysis. Data for sustainable development are characteristically heterogeneous, complex, inter-dependent, not directly comparable, and correlated in ways that may not be apparent without the use of visualization techniques. Visualization can serve as a tool to improve reliability of multiple sustainable development scenarios, and thus decision support, as well as to improve the ability of non-experts to take advantage of the information presented. Further, cartographic visualization can be used to effectively communicate spatial and temporal information in the Internet environment [SDKI-Visualization Project Report, 2003].
BARRIERS IN THE USE OF GEOSPATIAL INFORMATION FOR DECISION MAKING

Geographic information has been increasingly used in applications related to sustainable development primarily in application to resource management and urban planning. However, there are still significant barriers to the wide spread use of geospatial data for decision and policy making. The initial impediments are the inability to locate and integrate appropriate data, further issues include accessibility, interoperability, usability and effectiveness [Perdigao, 1998]. For geospatial information systems to be a useful decision making tool, the user requires a large amount of technical expertise. The typical decision maker usually does not posses these skills and therefore the expertise of an information system analyst is required to operate such systems. This precludes the decision maker from interacting with data at the level of knowledge discovery via interactive visualization. Therefore, development of simple visualization techniques based on intuitive interfaces is crucial to the increasing use of these tools by decision makers and by wide range of non-technical users, which are engaged in sustainable development.

The following sections present several visualization techniques that have been developed in Earth Sciences Sector, in the Visualization of Integrated Knowledge for Sustainable Development Decision Making project, in partnership with Canadian industry and universities. The following issues of information representation will be addressed: integration of heterogeneous data, visualization of change and effective communication of information in the Internet environment.

INTEGRATION OF INFORMATION

The information needed for sustainable development decision-making is both vast and varied. Sustainable development involves all sectors of society and incorporates economic, environmental, social and institutional components. It requires representation at various geographic scales ranging from local to global. Current web-enabled systems permit access to information from various distributed databases. Effective techniques for the integration of information are being developed in the SDKI-Visualization project. In the following sections, techniques to display integrated information are described. One example is a web-enabled visualization developed for the city of Iqaluit, the capital city of the Nunavut territory, the other examples are for the national capital region of Ottawa.

Interactive Map of Iqaluit:

An application developed for the City of Iqaluit is an interactive integrated city services map. The purpose of this visualization was to develop a concept of interactive web-based map capable of providing integrated information useful for locating current city services, such as, government offices, schools, shops, restaurants, hotels, etc. The existing city services map was converted into a digital form. Further, a database with types and names of services was created. Additionally, pictures of the buildings, where the services are located, were added.

The web-based interface, created using Java script, permits the selection of required services, searchable via spatial location or name and type of service. The selected service is then highlighted on a map, accompanied by the illustration of the building, where the service is located, (see figure 1 and [http://maps.nrcan.gc.ca/visualization]).

![Interactive City Services Map of Iqaluit](http://maps.nrcan.gc.ca/visualization)
This application was well received by the users (city planners, government agencies, educational institutions) and an additional grant has been obtained from the government of Nunavut to further develop web-based visualizations for the city (see section on Historical and Spatial Evolutions of Iqaluit).

Accessing maps via web-based enabled interface and linking them with additional information makes cartographic products more useful to people who are faced decisions such as the location of new services, expansion of the city in relation to environmentally sensitive areas or construction of new roads.

**Interactive Land Use Map of Ottawa:**

Another example of interactive, web-based display, of integrated information, is a land use map of city of Ottawa. This map was developed in cooperation with Dbx Geomatics, a Canadian company specialized in SVG (Scalable Vector Graphics) based mapping [http://www.dbxgeomatics.com/]. The SVG format is most suitable to create dynamic web-based visualizations in the Internet environment. It can be used to generate high quality interactive visualization at various scales with cartographically correct enlargement at multiple scales of representation. The large quantity of information can be organized in a flexible, user defined, structures and visualized in an interactive or predefined way [http://www.svgopen.org/2003].

The land use map of Ottawa contains the following information: Canada Land Use data for years 1981 and 1986 (created by Environment Canada, accessed via GeoConnections Discovery portal of the Canadian Geospatial Data Infrastructure [http://cgdi.gc.ca]; topographic data such as roads and street network, hydrography, names, etc. from GeoBase [http://www.geobase.ca], population data (from Statistics Canada [http://www.statcan.ca], Landsat 7 imagery from the Canada Centre for Remote Sensing [http://www.ccrs.nrcan.gc.ca] and census boundaries. The figure 2 shows the difference in urban build-up area change within a four-year period (from 1981 to 1986) with statistical information displayed for a selected census subdivision. This example has been developed for the SDKI application project on transportation energy related sustainability for an interactive visualization of land change in Ottawa area.

![Image of Interactive Land Use Map of Ottawa](image_url)

Figure 2. Web-enabled Visualization of Land Use Map of Ottawa - Links to Statistical Information

The functionality of this visualization includes, selective display of layers, interactive “roll overs” to display the names of the map features, related statistical information, and scale dependent generalization. Users can select information depending on their needs, via interactive legend. Despite the large amount of data, land use map of Ottawa is communicative due to the hierarchical and consecutively nested structuring and gradual display of the information.

The potential functionality of the SVG based mapping is the real time access and display of geospatial information selected based on attributes, from distributed, web-enabled, data services. The current limitation of SVG based visualization is that it is limited to the 2-dimensional data.
This visualization example was developed in support of a sustainable development application project, which focuses on sustainable use of energy in relation to urban sprawl issues. The example shows the increase of built up areas and the related statistics such as population data. Other sustainable development indicators can be calculated for various years to show the trends in development. Real time access to the latest imagery and attribute information will facilitate more informed sustainable development decision making.

**Three-dimensional Visualization of Ottawa Region:**

The following example of data integration is an interactive three-dimensional visualization of Canada’s capital region displaying the greater Ottawa area. The integrated representation is comprised of Landsat 7 imagery, road network and street patterns from GeoBase. These data are draped over a digital elevation model. Further, a city model, for the city centre area, is added showing three-dimensional buildings. Additional links are provided to the virtual representation of the interior of landmark buildings. Figure 3 demonstrates gradual, hierarchical information representation, with more detailed information appearing when zooming toward the city of Ottawa.

The visualization was produced using ERDAS Virtual GIS system. The functionality of the Erdas system visualization includes the generation of 3-dimentional perspective views, fly over the terrain, walk through the city model and virtual reality modeling to visit the interior of buildings. Users can interactively manipulate three–dimensional data or play previously generated animations.

![Figure 3. Three-dimensional Visualization of the Greater Ottawa Region](image)

The strong point of this visualization is its capability to integrate large amount of data into one presentation, and displaying it in sequence, which gradually discloses more detailed views. The inclusion of a third dimension contributes to more realistic representation of the terrain and permits visualization of such geographical phenomena as potential flood levels. Including city building models can, for example, facilitate understanding of the relationships between buildings and consumptions of energy. The simulation of the size and the location of the buildings in the city can be used to make decisions on reuse and minimization of land use in urban core areas.

**VISUALIZATION OF CHANGE**

A clear advantage of portraying geospatial data using electronic media is the ability to effectively display time dependent geographical phenomena, to analyze the patterns of change and to model the possible future scenarios. Historical maps, and multi resolution satellite and aerial imagery are valuable sources of data to examine the past utilization of land use and are realistic starting point in discussing the potential future developments. The representation of change is a vital element of the sustainable development decision making visualizations.
Visualization of Past, Present, and the Future:

The example of the visualization of past, present and future is based on historical topographic maps, and historical aerial photographs from the National Air Photo Library and future land development plans to portray the evolution of the city of Ottawa in the Lebreton flats area. This type of visualization was developed to communicate future land use plans and displayed past utilization of the area at the same time. In the application users can access, via external http link, additional information stored at the external location on the Internet. This external link has been created to communicate future information about the museum, which is currently being built in Ottawa. Potential visitors can tour the upcoming exhibitions which have been created in a virtual space.

Figure 4. City of Ottawa Land Use Transition

Sustainable development decision making requires communication of future plans to the general public as part of the consultation process and obtaining feedback from stakeholders. Such consultation if placed within the historical context leads to more informed decision making. Such interactive web-based visualizations can also be used to display various future scenarios to encourage public consultation and participation.

Animated Visualization of Change:

Historical topographic maps and aerial photographs provide a good base to analyze the evolution of geographic features. The next example is an animated visualization of the transformation of a hydrographic feature in the Ottawa river valley. Due to the increased water level in the Ottawa river and closely situated wetlands, a lake, which was portrayed on the early national topographic maps (years 1912 – 1979) has been transmuted into a bay, which is now part of Ottawa river.

The approximate outline of the hydrographic feature has been identified from historical maps and the precise delineation was extracted from aerial photographs. Figure 5 shows the feature extraction and delineation process. The visualization used is static comparison between two specific periods, as well as animated gradual transformation of the lake into a bay.
Figure 5. Changes in the Ottawa River Valley Wetlands

Historical maps and photographs provide a wealth of information about the past evolution of the ecological processes. Such historical information can be used to analyze the past changes and realistically predict the direction of future change.

COMMUNICATION OF INFORMATION

Decision makers and the general public who may not be experts in a given field need information, which has been verified by experts and local people, knowledgeable in a specific field. For sustainable development inclusion of all types of knowledge and perspectives is necessary. The decision makers are frequently removed from the operational level considerations and thus need synthesized information. Such information could be prepared beforehand and presented in a form, which is easy to comprehend. The incorporation of “narration” can facilitate the comprehension of the message, which experts are trying to convey to decision makers, as well as, to general audience.

Some of the visualizations developed in SDKI-Visualization project have been created in partnership with experts in the field and local population, to ensure that the traditional knowledge is incorporated. Working in partnership with local institutions assured applicability of developed methods and increased awareness of visualization tools.

Historical and Spatial Evolution of Iqaluit:

The government of Nunavut has endorsed the applicability of visualization methods, developed in the Earth Sciences Sector. It provided a grant to implement the selected methods, to portray the historical evolution of the city of Iqaluit (see figure 6 and http://maps/nrcan.gc.ca/ iqaluit). This application was co-financed by the Nunavut Department of CLEY (Culture, Language, Elderly and Youth) and was developed in cooperation with local organizations. The City of Iqaluit provided more recent data, which were integrated into the data from the National Air-photo Library. The narration to accompany the visualization of city of Iqaluit was developed by a historian. The narrative was further enhanced by interviews with local people who complemented the historical commentaries with traditional knowledge. A three-lingual web-site is being developed, to portray development of the city of Iqaluit from its inception, as local fishing grounds, to American military base, to a flourishing capital of the Nunavut territory.
For sustainable development decision making it is crucial that the information is communicated in the language of the local community. This helps to ensure greater awareness and participation of the local population in development decisions. Further, it facilitates technology transfer to regions that only recently begun to employ web-based technology.

**Changing Modes of Transportation in Downtown Ottawa:**

Another application, which illustrates the effectiveness of visualization to communicate to a general audience, is the history of the changing modes of transportation in the City of Ottawa. The visualization is based on historical aerial photographs amply illustrated by pictures of historical buildings. It communicates the interrelationships between land use and changes in modes of transportation. The geographic hypermedia based visualization includes a virtual tour of the original train station. The virtual reality model of the train station interior, has been developed by the scientists at the National Research Council and is available on the Internet [http://iit-iti.nrc-cnrc.gc.ca/projects-projets/vel-lev-demos_e.html].
COLLABORATIVE DECISION MAKING SYSTEMS

Sustainable development decision making should be based on a collaborative decision making principle, which includes the views and opinions of diverse group of users. The Internet enabled data conferencing can facilitate consultation needed for building a consensus between all stakeholders.

A Canadian geomatics firm, TGIS Consultants [http://www.geoconnections.org/projects/geoinnovations/2002/TGIS/default.TGIS.htm] developed software, for Internet teleconferencing using geospatial information. The GeoConference software allows distributed participation in collaborative decision making conferences, based on georeferenced material such as satellite images and maps. Session participants share a synchronized cartographic view to which they can add additional georeferenced data, either by contributing data layers or by making georeferenced annotations. The software provides a text channel for instant-messaging exchanges. Each participant has a unique cursor that is visible to other collaborators. Users can point and annotate the map, with changes occurring in real time. GeoConference can be applied as a collaborative tool throughout the lifecycle of activities and projects that use geographic information.

The functionalities offered by this software are useful for sustainable development decision makers. It facilitates both group decision support and real time discussion based on spatially referenced materials. The ability to annotate the map using points, lines, polygons and text, combined with the instant messaging function provides powerful analytical capabilities, consensus building and group decision making.

![Figure 8. Geo-conference Session Based on Simulated Earthquake Emergency](image)

The figure 8 illustrates an emergency preparedness exercise which simulates the response to a potential earthquake in the city of Quebec.

Consultation and consensus building among stakeholders is an important component of sustainable development decision making. The GeoConference can serve as a base for a distance consultation in diverse applications, such as, risk of land slides and flooding. This system is still in development but already has been used for emergency preparedness in the province of Quebec.

CONCLUSIONS

The web-based visualization methods discussed in this paper can be effectively applied for the sustainable development as well as for other applications. Several visualizations developed for the city of Iqaluit, have been already implemented and are successfully employed by the user community. Others, intended for the visualization of the city of Ottawa, are still in the development stage. The use of these visualizations has already been requested by the city of Ottawa to be
incorporated in a public exhibition, which has been organized to commemorate the 150th anniversary of the city.

The Internet provides a unique opportunity to remotely access, visualize and communicate geospatial information. Through the use of web-based visualization techniques the dissemination of geographical information, and user collaboration concerning sustainable development issues will be improved. Barriers to the wide spread use of geospatial information, such as incompatibility of formats and software are being overcome by development of interoperable open data processing methods and standards, which are promoted by the Open Geospatial Consortium. These developments will further accelerate the use of the Internet and increase the development of applications to facilitate sustainable development decision making.

The sustainable development of natural resources is an important priority of the government of Canada. The government’s sustainable development strategy cannot be accomplished without access to vast amount of geospatial and temporal information as well as related expert geographical and social knowledge. Various types of information related to social, environmental and economic development, need to be integrated and communicated to a wide variety of audiences. The visualization methods are becoming increasingly effective tools to integrate, analyze, summarize, and present spatio-temporal information for informed, sustainable development, decision making.

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