VISUALIZATION OF GEOSPATIAL INFORMATION FOR SUSTAINABLE DEVELOPMENT DECISION MAKING

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ABSTRACT:

Visualization refers to various types of graphic representation of geospatial information ranging from static to dynamic presentation (cartographic visualization), to exploratory data analysis (scientific visualization). Visualization projects carried out by Natural Resources Canada focus primarily on the former: web-based, interactive, dynamic representation of information, suitable for effective communication of geospatial concepts in support of decision making. The general objective of the visualization projects is to explore, develop and implement visualization techniques capable of translating complex scientific information into a form that readily communicates sustainable development forecast scenarios to various user groups, in particular to policy decision makers in the federal government of Canada. Currently, a visualization project is being carried out within the Sustainable Development through Knowledge Integration Program of the Earth Sciences Sector of Natural Resources Canada. Previously, various visualization tools were developed to support knowledge communication about Canada's recently created northern territory, Nunavut. Several web-based visualization techniques were developed for effective communication of geospatial information. These include: integration of heterogeneous data, such as raster and vector geospatial data and textual social development information, dynamic representation of 2D and 3D data, intuitive interfaces, and others. This paper discusses the challenges involved in the promotion and use of geospatial data for sustainable development by decision makers.

1. INTRODUCTION

Canada's natural resources are important economic, environmental and social assets. To preserve these assets for future generations, the Government of Canada has adopted a strategy of sustainable development. The strategy involves all sectors of society, as the information needed for decision making is both vast and varied. Integrating data, information and knowledge from various regions of the country is essential.

Effective cartographic representation and advanced visualization techniques facilitate comprehension of large and complex volumes of geospatial data. Several visualization techniques capable of integration and interactive use of geospatial information within the Internet environment have been recently developed by the Natural Resources Canada. The ability of these techniques to effectively communicate geospatial information to decision makers has been tested in the new northern territory of Canada, Nunavut. These techniques will be described in this paper and issues related to the web-based implementation will be discussed. Further, the goals and assumptions behind initiation of a new project, Visualization of Integrated Knowledge for Sustainable Development Decision Making, are discussed and preliminary results in creating alternative user interfaces for the Georgia Basin Digital Library (GBDL) are presented. The new interfaces will facilitate the application of the GBDL for sustainable development decision making.

2. SUSTAINABLE DEVELOPMENT AT NATURAL RESOURCES CANADA

Natural Resources Canada is responsible for federal resource policies, and science and technology that support the sustainable development of energy, forest, minerals and metals sectors. The Department uses the United Nations Brundtland Commission definition of sustainable development. For the natural resources sector, sustainable development requires that social, environmental and economic considerations be integrated into resource development decisions.

2.1 Sustainable Development Strategy

Natural Resources Canada was one of the first departments within the Government of Canada to adopt a Sustainable Development Strategy (Natural Resources Canada, 1998). The second Natural Resources sustainable development strategy:

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“Now And For The Future”, provides an optimistic vision of the country for a new century, At the same time it acknowledges that the implementation of a sustainable development strategy requires ideas, determination and action on behalf of all Canadians, across all sectors of society (Natural Resources Canada, 2001). The third Sustainable Development Strategy “Moving Forward” formulates for the next three years a results-base action plan, guided by a unified, forward thinking vision and organizational commitment to sustainable development that encompass all of the Department's diverse activities and enables the Government of Canada to address the utilization of resources in a comprehensive manner, from a national perspective (Natural Resources Canada, 2004).

2.2 The Sustainable Development through Knowledge Integration Program

The Sustainable Development through Knowledge Integration (SDKI) program was initiated in June 2003. The program focuses largely on a number of issues related to Natural Resources Canada’s requirements for sustainable development. It builds on the concept that Earth Sciences Sector’s (ESS) geospatial information could and should be used to support decision and policy making. The SDKI program will move select components of the ESS's research, information and knowledge assets into the decision support environments of government, industry and the public. It will develop technology that facilitates integration of ESS information and knowledge assets, and will enhance Natural Resources Canada’s capacity to disseminate policy pertaining to Canada's mineral, energy and forestry resources and their responsible use (Richardson, 2003).

The Sustainable Development through Knowledge Integration program comprises several theme based application projects and two system and methods development projects. The theme projects are: Transport-Related Energy Sustainability in Canadian Urban Areas, Sustainable Management and Rehabilitation of Mine Sites for Decision Support, Forestland Disturbances Monitoring, and Mapping for Sustainable Development Planning and Reporting. The systems and methods development projects are: the PATHWAYS-Decision Support System for Sustainable Development and Visualization of Integrated Knowledge for Sustainable Development Decision Making (SDKI-Vis).

2.3 Visualization of Integrated Knowledge for Sustainable Development Decision Making

The SDKI-Vis project focuses on removing barriers to the effective communication of geospatial information to policy and decision makers. The project addresses the translation of quantitative science output into qualitative presentation – thereby demonstrating the results of modelling undertaken within the SDKI theme projects such as urban analysis, forest disturbances, mines, water and hazards. Forecasts resulting from SDKI themes will be presented using methods such as dynamic visualization or 3D interactive terrain representation. Additionally, it will identify, assess and publish a suite of advanced Web-based visualization techniques. More generic visualization methods could be applied to other programs conducted in the Earth Sciences Sector dealing with integrated knowledge based on geospatial data and information. The project also involves development of a long-term strategy for visualization primarily applied to the SDKI program, with potential links to other ESS programs such as Northern Development.

3.0 CARTOGRAPHIC PERSPECTIVE ON GEOSPATIAL VISUALIZATION

Throughout the ages, various types of maps and images have been used to communicate information. Societal change and rapid technological evolution have had a significant impact on how maps are produced, distributed and used. Today, maps have evolved from static representations of the world to 2D or 3D interactive digital representations. In addition to graphical representation, maps can now be enriched with multimedia through the addition of sound and animation, thus expanding the channels of information available to map users. These new era maps often themselves become a mechanism for data exploration and analysis, as new interactive distribution systems such as the Internet are increasingly used for their dissemination (Cartwright, 1999).

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). Cartographic visualization is not meant to replace traditional tools for decision-making, but both augment and enhance these tools.

One of the most fundamental issues in cartographic and graphic communication involves the suitability of the method used to represent data, i.e., graphs, charts, tables, maps, 3D representation and animation. For example, cartographers warn against using choropleth maps that distribute a risk evenly over a surface when in fact the risk is not homogenous to such an extreme degree that it follows the choropleth boundaries. Another issue is the use of visual variables, namely the hue, size, shape, value, texture and orientation of data symbolized (Bertin, 1983). Web-based visualization is no longer limited to 2D static maps but includes dynamic and 3D representations. In this case the visual variables described by Bertin are further extended to encompass 3D dynamic representation and Virtual Reality Modelling Language (VRML), which are dynamically linked with databases. Once the data is represented, the means of interaction must be considered to allow the user to manipulate variables to create different scenarios. The key to effective data exploration and analysis is the means of interacting with data through functional and user friendly interfaces.

4.1 WEB-BASED VISUALIZATION TECHNIQUES

This section discusses some of the techniques that were successfully used for the communication of geospatial information for Nunavut, Canada. Most of these techniques have been developed within a visualization project conducted by the Mapping Services Branch of the Earth Sciences Sector.

4.1 Mapping Services Branch Visualization Project

In April 1999 a new territory called Nunavut was created in Canada’s north. To commemorate the creation of Nunavut, the Mapping Services Branch published a special topographic map of Iqaluit, the capital city of Nunavut, and initiated two cartographic visualization projects. One project focused on developing various interactive visualization techniques suitable for presentation of topographic information of the region [http://maps.NRCan.gc.ca/visualization]. The second project

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focused on the representation of cultural and historic development of Iqaluit [http://maps.NRCan.gc.ca/iqaluit].

Communities in Nunavut use traditional knowledge while adapting to the global economy and modern technology. Their economic future is firmly linked to its renewable and non-renewable natural resources – mining and petroleum development, commercial fishing and hunting and eco-tourism. The increasing economic development activities of the region require large amounts of geospatial information. New types of maps and cartographic visualization are required for management of natural resources, the protection of the environment and for new economic activities such as eco-tourism. Mapping and geographic information processing are thus becoming a basic tool used by local authorities for effective economic and socio-economic development.

The goal of the visualization project was to develop innovative methods of web-based cartographic visualization suitable for communication of geospatial information. The methods include interactive multimedia maps which use sound, 3D animated maps, fly-bys, maps integrated with remote sensing images and innovative interactive interfaces.

4.2 Multimedia Maps with Voice and Sound

The multimedia and multimodal technologies that engage other senses such as hearing and touching are more effective in communicating information to users than simple graphics. The use of sounds lends itself well to the map of Nunavut. When the user clicks on a place name, the name of the place is spoken in Inuktituk, a native language of northern Canada. Figure 1 shows the audio-visual map of settlements in Nunavut. The voice files have been recorded to assure the correct pronunciation of place names. This created relatively large digital files thus for the general voice application it is preferable to work with text based voice generation.

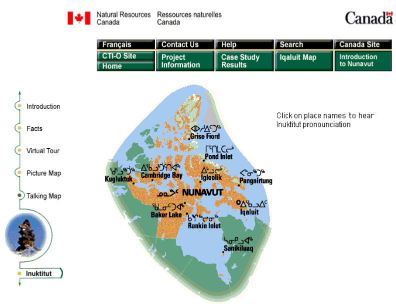

Figure 1. Audio-visual place name map of Nunavut.

The interface is based upon guidelines mandatory for all Government of Canada websites. The interface consists of primary navigational bar located at the top of the page, which provides standardized access to main sections of the project information structure. The secondary navigational bar provides access to subsections of the web site.

Research in the use of sound as cartographic information has applications other than spoken place names. Topography can be thought about as an auditory form. By modulating pitch, hill and slopes can be expressed by sound. Water cover might be given a splashing sound different than solid land. This concept has been successfully applied in another project carried out in Mapping Services Branch directed towards blind and visually impaired people [http://tactile.nrcan.gc.ca/maps-4-all]. In this case, multi-modal maps have been created based on Scalable Vector Graphics (SVG), which facilitate the addition of sounds and haptic (forced-feedback) effects to audio-tactile-haptic maps (Campin, 2003).

4.3 Interactive Cartography

Using interactive cartographic tools, a user can create their own displays by selecting information to be included on the map. Several commercial or open source systems exist which include this capability (see Figure 2). The research undertaken within the visualization project was focused on development of an effective interface that could facilitate integration of geospatial information.

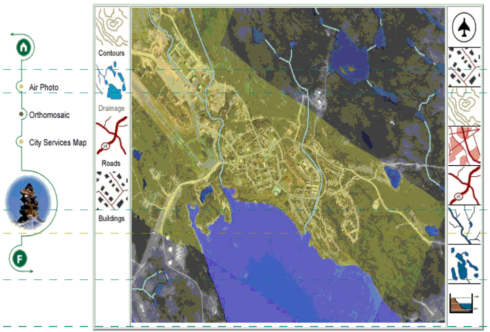

Figure 2. Data integration interface for selection of map layers.

One of the information integration techniques is the interactive layer selection method. Using JavaScript, a function was created to allow users to attach layers of information to the background image by clicking the icons on the left. Moving the cursor to the right permits user to temporarily superimpose other layers to the map background. Clicking on the central image displays all the data at a higher resolution. Figure 2 shows the results obtained by attaching the roads and then superimposing the buildings on the background image. The information integration technique could be further enhanced by accessing individual features based on the SVG methodology. This integration technique can be useful in displaying various options and scenarios for decision making.

4.4 Representation of Temporal Data

A clear advantage of portraying geospatial data using electronic media is the ability to effectively display the past and present distribution of various geographic phenomena, to analyze the patterns of change and to model the possible future scenarios. Historical maps and aerial photographs are good sources of data to examine the previous distribution of land use, and are a realistic starting point in discussing potential future developments.

The application selected for representation of temporal change is the historical and spatial evolution of Iqaluit, the capital of Nunavut. Historical aerial photographs taken at approximately ten-year intervals were assembled to portray the rapid growth of the city over 50 years (1948-2000). They served as a base for creation of historical city maps. The historical photographs

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and records provided additional information to reconstruct the development of Iqaluit to discover the factors influencing change, explain patterns in development of the city, and provide a cultural and social background. Figure 3 shows the user interface created to display historical orthomosaics, maps, photographs and 3D renderings of the terrain in the form of animations.

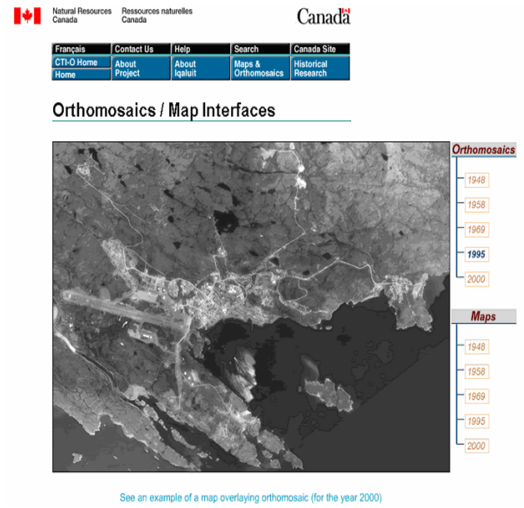

Figure 3. Historical and spatial evolution of Iqaluit.

Such cartographic products may serve many purposes including city planning, resource development, tourism, culture and education. Understanding development of Iqaluit over time is valuable for the education of youth and interesting for visitors and tourists. The implementation of the program in Inuktituk, the native language of the territory, received funding from the territorial government of Nunavut. However, on-line access to the web site in northern communities still faces some technical challenges. Suggestions have been made by users in Nunavut to adapt the application for a stand-alone kiosk-type presentation at a science centre to be located in the city of Igloolik.

4.5 Cartographic Animations

Cartographic animation refers to any simulated movement based on cartographic data. The animation may be passive, in which case the only control user has is the ability to start or stop the animation. The animation may be interactive and allow users to control movements such as rotation, pan and zoom or direction of the flight over terrain. In the visualization project, "Terrain Visualization Publisher" software from IQ Media was used. The animation of 3D data creates large data files for which streaming techniques should be used for optimisation of performance. The example of passive animation developed as a joint initiative between Natural Resources Canada, Science World and The Lunny Group is Canada Rover (shown in Figure 4). It illustrates and explains the draining of water polluted by a copper mine into the Howe Sound in British Columbia.

Compelling presentations of rendered landscape with animated fly-overs are effective tools for decision making in applications such as environmental protection, safety and security and natural resources management. In the SDKI-Vis project plans are to use Augmented Reality (AR) and Virtual Reality Modelling Language (VRML) for a more realistic representation of terrain data (Hedley, 2003).

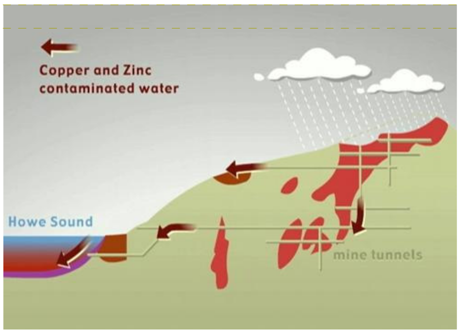

Figure 4. Passive animation from Canada Rover.

Selected techniques presented in this section will be used in an educational "GIS primer" product which is being developed by the Department of Indian and Northern Affairs to introduce concepts of visualization of geospatial information to decision makers.

5. VISUALIZATION AND SUSTAINABLE DEVELOPMENT DECISION MAKING

In 1994, the president of the Association of American Geographers (AAG) identified visualization as one of four main concepts for learning and decision-making in sustainable development. "…(W)e 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". Further stressed was the importance of implementing innovative means of technological and institutional change to foster greater inclusion of the geographical perspective in decision-making for sustainable development (Wilbanks, 1994).

Geospatial visualization has emerged as a tool for searching through large volumes of data, communicating complex patterns, 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. Geospatial information relevant for sustainable development often tends to be heterogeneous, complex, not directly comparable and correlated in ways that may not be apparent without the use of visualization techniques. Visualization is important not only in the development of information systems generally, but also as a tool to improve reliability of multiple sustainable development scenarios, as well as to improve the ability of non-experts to take advantage of the information presented.

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5.1 Spatial Decision Support Systems

Decision Support Systems (DSS) and Spatial Decision Support Systems (SDSS) can be defined as interactive, computer-based tools that use information and models to improve the decision-making process (Feeney et al, 2002). These systems have intuitive interactive interfaces, the ability to combine analytical models with data, the capability to explore alternative solutions, the support of a variety of decision making styles, and the ability for interactive and recursive problem solving (Densham, 1991). Decision support systems used to address complex issues such as sustainable development require a combination of structured (programmable) and unstructured (based on human decision) problem solving techniques. In a DSS, decision alternatives may be evaluated on the basis of multiple criteria (Malczewski, 1997). Decision-making stakeholders and technical specialists may range from novice to expert. Participatory decision support systems that facilitate collaborative decision-making result in more effective and equitable decisions (Jankowski and Nyerges, 2001).

The following sections will provide an example of a component in an evolving Decision Support System. The component is called the Georgia Basin Digital Library (GBDL) and it is an integral part of by the PATHWAYS decision support framework. GBDL was developed to facilitate decision making for sustainable development of Georgia Basin region of southwestern British Columbia Canada [http://www.georgiabasin.info].

5.2 Georgia Basin Digital Library

GBDL is primarily aimed at members of the local community within the Georgia Basin, as well as experts interested in issues of sustainable development (Talwar, 2003). It is composed of the following modules: News & Information, Local Stories, Ideas & Perspectives, Library Collections, and Future Scenarios. The two GBDL modules that display interactive Web maps are the Local Stories and Library Collections modules. At present, the SDKI-Vis project is working on the evaluation and improvements to the Library Collections module.

The Library Collections module uses Open GIS Consortium technologies [http://www.opengis.org] in a distributed environment to permit users to search metadata registries of the Canadian Geospatial Data Infrastructure [http://www.cgdi.ca] and visualize spatial data hosted by a wide-range of geospatial data warehouses. Layers of raster and vector geospatial data can be selected and combined for dynamic Web map creation (see Figure 5). Rudimentary functionality is available for zooming, panning, and modifying the order of layer stacking and displaying a locator/overview map. However, users cannot modify the selection of symbols and colours as they are based on a Style Layer Descriptor (SLD) usually developed by the data provider.

The map-based layer selection module of the GBDL Library Collections offers the user many map layers that can be turned on and viewed together. This open invitation to explore geo-referenced data from many dispersed databases can be a meaningful and powerful way to foster visualization. However, the invitation for unrestrained browsing can result in misrepresentation of information by users not familiar with the data integration issues such as working with data at various scales and projections. User interaction should be provided through a well-structured interface in order for exploration to increase curiosity rather than cause frustration. The work involving the Georgia Basin Digital Library will propose improvements to encourage browsing of the information, and to provide greater assurance that a user's explorations will be satisfying. The aim is to align the GBDL to the strategy of weightless, intuitive operation.

One example of a map interface from the Library Collections module of the GBDL, which the SDKI-Vis team is attempting to improve, is shown in Figure 5. While it is beneficial that the legend serve as the on/off control for each layer, this legend provides only the name of the symbol, while it also needs to reflect the symbol as it appears on the map. It would seem more useful to move the map navigation controls to the map, letting the user push and pull at the map image itself. Other icons could be re-ordered to make better use of screen space and to create relationships between the devices that control the display and the map itself.

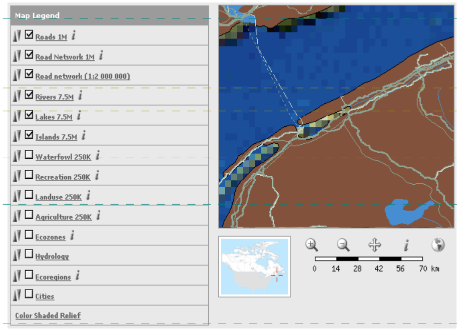

Figure 5. The existing Georgia Basin Digital Library interface

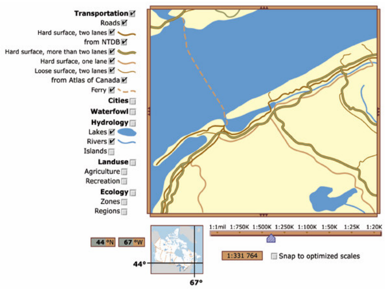

Figure 6. The proposed redesigned Georgia Basin Digital Library interface

The redesign and implementation of the new interfaces to the GBDL is being conducted in cooperation of the SDKI-Vis project and PATHWAYS project teams.

6.0 CONCLUSIONS

Innovative web-based interactive visualization techniques will facilitate access to information, integration of multi-source data, hypothesis testing and communication of integrated knowledge. Visualization tools, in particular user-friendly interfaces, can contribute to the increased use of earth sciences

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The applicability of the visualization methods and concepts developed within the Visualization of Nunavut and Visualization of Iqaluit projects have been endorsed by the territorial government of Nunavut. Local assessment of the Iqaluit web site resulted in several recommendations. The web site has potential to be used in the promotion of eco-tourism and for presentation of indigenous culture, especially in the local school environment. An opportunity was discussed to create a kiosk application at a Nunavut science centre. Further, the methods developed within the Visualization of Iqaluit project will be re-used as part of the educational material being developed at the federal department of Indian and Northern Affairs to promote use of visualization and geospatial information processing systems at the decision making level.

The techniques addressed within the Visualization of Sustainable Development Decision Making project are still in the early stage of development. However, the alternative design of interfaces for the Library Collections Module of Georgia Basin Digital Library has been accepted by the PATHWAYS project leaders as a viable direction for a new interface development.

The ever-increasing complexity of economic and social development and the interconnectedness of information needed for knowledgeable sustainable development decision making requires effective visualization methods capable of integrating, simplifying and unambiguously communicating geospatial information to wide audiences and stakeholders.

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maps are produced and distributed. Maps have evolved from static representation of the world, to digital, 2 or 3 dimensional and interactive presentations. In addition to graphical representation, maps have been enriched by multimedia. Multimedia is intended to expand the channels of information available to the users, through addition of animation, sound, and touch. These new era maps

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often become a medium for data exploration and analysis, and new distribution systems such as Internet are being increasingly used [Cartwright, 1999].

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As cartographic visualization

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is based increasingly on new technologies, the richness of human-to-human communication is often lost to the use of virtual environments which 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,

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cartographic visualization is not meant to replace traditional tools for decision making, but is there to both augment and enhance them.

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since technology offers a variety of choices to represent data

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, and it is crucial to select the appropriate method

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the northern territory of

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Nunavut has been established as independent self-government jurisdiction, thus giving its people ownership and control over land and resources. This historic agreement includes land claim settlements including rights to sub-surface minerals.

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as an important 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. Access 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. The visualization 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".

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the polluted by copper mine