MINE DEVELOPMENT AND RECLAMATION: MONITORING SUSTAINABLE DEVELOPMENT USING SATELLITE IMAGERY[1]

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Abstract: Unlike conventional crude oil, extraction of bitumen in the oil sands region of Canada is conducted via surface mining and steam assisted gravity drainage (SAGD), which results in physical surface disturbance and indirect hydrological impacts. Environmentally responsible development of the oil sands presents significant challenges for the companies operating in the region, and provincial and federal regulatory authorities.

Under the European Space Agency (ESA) Earth Observation Market Development Programme (EOMD), Hatfield Consultants led a team working with Shell Canada Ltd. (Shell Canada) and Albian Sands Energy Inc. (Albian Sands) to provide remote sensing information services to support environmental management, monitoring, and sustainable development reporting for their oil sands surface mine operations. Imagery from several satellite sensors was used, including SPOT-5, Envisat ASAR, and Quickbird to support Shell Canada and Albian Sands in meeting their sustainable development objectives.

Based on image analysis, mine activity and vegetation habitat change information was provided for the 2006 Shell Canada Sustainable Development Report. Satellite imagery provides objective information on development and eventual reclamation of oil sands leases, and can expand annual sustainable development reporting on environmental performance, including cumulative development effects. The visual nature of the imagery products allows stakeholders to monitor progress on reclamation commitments. In the current study, traditional ecological knowledge documented by Fort McKay First Nation was integrated with the satellite imagery; the aim is to improve the ability of the community to monitor developments and reclamation on or near their traditional territories.

The image analysis methods and information provided was independently audited by PricewaterhouseCoopers (PwC), and assurance was received. The project team will receive an opinion from Sustainable Asset Management (SAM) on the scope for monitoring by remote sensing to contribute to best practices within the Oil and Gas and Basic Resources sectors, as part of assessments for the Dow Jones Sustainability Indexes.

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Introduction

Corporate sustainable development (CSD) is now at the heart of business practices. Activities related to mining and energy generation almost always have environmental impacts, and CSD means taking steps to reduce the environmental impact of operations, products and services. Sustainable development is the integration of economic, environmental and social considerations in the decision-making process across all business activities, while addressing short-term and long-term needs (Shell Canada Ltd., 2007a). CSD reporting enables a company to address important issues with stakeholders, and to measure and communicate performance.

Surface mining companies and resource extraction industries are often familiar with the use of remote sensing to provide an overview of mine development and for exploration purposes; for example, air photos and high resolution imagery of tailings, and medium resolution imagery for geological mapping. In this study, the application of remote sensing to support corporate sustainable development reporting demonstrates how remote sensing from space has the potential to provide a global and cost-effective way to objectively measure progress towards sustainability of business activities.

Under the European Space Agency (ESA) Earth Observation Market Development Programme (EOMD), Hatfield Consultants (Hatfield) recently led an international team working with Shell Canada Ltd. (Shell Canada) and Albian Sands Energy Inc. (Albian Sands) to integrate remote sensing data into CSD reporting practices. Shell Canada and Albian Sands are recognized business leaders in sustainable development; Shell Canada was included in the Dow Jones Sustainability Index for 2006 (SAM Indexes, 2007) and their 2006 CSD report was the 16th annual report prepared by the company (Shell Canada Ltd., 2007b). The project team included PricewaterhouseCoopers (PwC) and Sustainability Asset Management (SAM, Switzerland), who publish the Dow Jones Sustainability Indexes.

The *Earth Observation Support for Corporate Sustainable Development Reporting* (EO-CSD) project aimed to demonstrate:

- The potential of remote sensing to provide objective information on development and eventual reclamation of mine leases;
- That analysis of satellite imagery can expand annual CSD reporting on environmental performance; and
- Image products can allow stakeholders to monitor progress on reclamation commitments;

The project team also aimed to conduct outreach activities within the oil & gas and mining sectors to further develop and promote sustainable development services.

Oil Sands Region

The oil sands region of northern Alberta provides a significant proportion of the world's petroleum resources; the established 176 billion barrels of extractable bitumen reserves are equivalent to one-third of the world's known reserves of conventional crude oil. By 2015, oil sands production is expected to reach 3 million barrels per day (Department of Energy, 2007). The oil sands is one of the worlds largest mining operations, two-million tonnes/day are mined, which is expected to double in the next 10 years [Department of Energy, 2007]. Albian Sands and Shell Canada operate the Muskeg River and Shell Jackpine surface mines respectively are shown in Figure 1. Unlike conventional crude oil, extraction of bitumen is conducted via surface mining and steam assisted gravity drainage (SAGD), which results in physical surface disturbance and indirect hydrological changes. Surface mining and SAGD operations alter forests, wetlands, and river basin hydrology, resulting in significant land cover change, habitat fragmentation and potential loss of biodiversity. There is also a need to consider cumulative environmental land cover change as of oil sands activity. Extraction of the established oil sands reserves, more than three quarters of which would *in-situ* operations, could affect an area of 13.8 million hectares (21% of Alberta) and result in 11,454 km^2 of cleared boreal forest (Schneider and Dyer, 2006), although progressive reclamation would be undertaken.

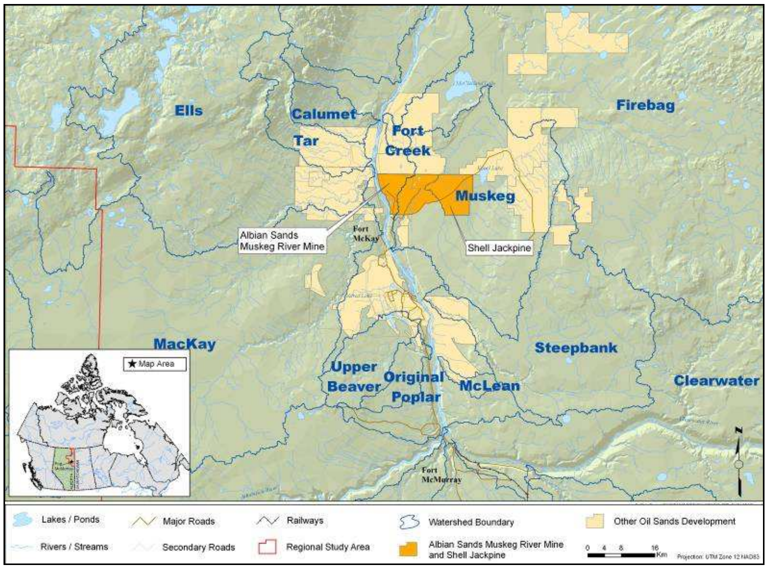

Figure 1. Northern Athabasca oil sands region, Alberta; Canada

Sustainable Development Reporting

A sustainable development report is an annual document that allows companies to address issues that matter to the company and to stakeholders, and to measure performance against a defined set of indicators. There is no standard approach to sustainable development reporting, but an increasing number of multi-national companies are following the guidelines established by the Global Reporting Initiative (GRI), which defines a series of social, economic and environmental performance indicators (Global Reporting Initiative, 2007). The revised GRI guidelines were launched in 2006, and the Shell Canada 2006 CSD report was developed in accordance with these guidelines.

Information required for Shell Canada’s CSD report is generated at source in the oil sands operations, transmitted through business unit management to corporate headquarters, and ultimately provided to the professionals involved in preparing the CSD report. The flow of information for the CSD report, from the business unit to Shell Canada, can only occur if relevant geospatial data are available and integrated into current environmental management systems and business processes. Therefore, understanding the requirements for CSD reporting requires an understanding of the needs of environmental managers within oil sands operations and the CSD reporting framework. The EO-CSD project focused on specific environmental performance indicators, but also on the larger issues of strengthening the transparency and accessibility of information provided to stakeholders. A particularly important stakeholder for Shell Canada and Albian Sands is Fort McKay First Nation (FMFN) whose traditional territory includes their oil sands leases.

Audit and Assurance

Auditing is an important component of a sustainable development reporting service, because the assurance of information for sustainable development reports provides confidence in the validity of the results. It is not mandatory to complete an audit in order to utilize the GRI framework; however, it is an important component if information is to be published in corporate sustainable development reports.

Data

The definition of an appropriate observation or measurement scale is an important issue for any remote sensing project. The measurement scale must capture the spatial variability of the land disturbance and reclamation processes that will be monitored. With remote sensing, the measurement scale is defined by the spacing, extent, and resolution of the imagery: spacing is equal to the pixel size; extent is effectively the sensor's swath width; and resolution is the smallest object or narrowest line a sensor can detect. In general, high resolution sensors have a smaller image extent, and the costs for high resolution data can be high if large areas are to be monitored. In the current study, multi-spectral imagery from the SPOT-5 and Quickbird satellite sensors were the main sources of satellite imagery, with supplementary imagery from Landsat TM and radar data from Envisat ASAR. A total of nine SPOT-5 (10 m multi-spectral) images were acquired on 14^{th} and 29^{th} June 2006 to cover the entire Athabasca oil sands region, an area of more than 2.5 million hectares. Pan-sharpened Quickbird imagery was acquired between 25^{th} June and 3^{rd} July 2006. Other datasets were also obtained for pre-processing of imagery and GIS analysis, as shown in Table 1.

Table 1. Ancillary datasets for image processing and GIS analysis.

Data set	Accuracy / Resolution	Details
Digital Elevation Model	1: 50, 000	CDED Level 1 (Natural Resources Canada, 2006)
Mining Activity Lease Boundaries	N/A	Alberta Energy Utilities Board and Alberta Environment
Alberta Vegetation Index	1: 20,000	Alberta Environment/ Sustainable Resource Development (SRD)
RAMP Land cover	1:100,000	Regional Aquatics Monitoring Program (2005)

Methods

The overall approach for the implementation of the EO-CSD project included: image pre-processing; land cover classification; extraction of quantitative information; audit of the service; and report in relation to a GRI indicator.

Image Pre-processing

SPOT-5 and Quickbird images were processed using PCI Geomatica v10. In order to facilitate quantitative and qualitative image analysis, the effects of variation in atmospheric conditions between images acquired on different dates, and areas within a single image, should be normalized. In addition, areas of cloud and haze should be masked. SPOT-5 and Quickbird images were atmospherically corrected using the ATCOR2 algorithm (Richter, 2006). Each image was ortho-rectified and spatially referenced to UTM Zone 12 NAD83.

Land Cover Classification

A land cover classification was completed using SPOT-5 imagery, according to the following classification system developed by the Regional Aquatic Monitoring Program (2007):

- Bare ground, including ground cleared of vegetation for pit development;
- Developed ground, including pit, roads, buildings, and settling ponds;
- Water, including rivers and natural lakes; and
- Other land use, including natural vegetation and non-oil sands resource activities.

The SPOT-5 imagery was classified using an unsupervised ISODATA classification, with the resulting image clusters allocated into one of the land cover classes. To separate oil sands activity from other activities (e.g. forestry), the mine surface lease boundaries obtained from the Alberta Energy Utilities Board (2006) and Alberta Environment (2006) were used. Developed or cleared areas within a surface lease boundary were considered oil sands related. The Quickbird imagery was used as validation data.

Environmental Performance Indicators

The monitoring services were designed to enable Shell Canada to report on GRI Environmental Performance Indicators (Global Reporting Initiative, 2006), specifically the following two indicators:

- EN11 – Location and size of land owned, leased, managed in, or adjacent to, protected areas and areas of high biodiversity value outside protected areas; and
- EN12 – Description of significant impacts of activities, products, and services on biodiversity in protected areas and areas of high biodiversity value outside protected areas.

In order to provide information that will assist in reporting against the GRI environmental performance indicators, it was necessary to develop a methodology to extract information using geographical information systems (GIS), satellite imagery, and other data. The methodologies were designed to provide a robust, repeatable approach for quantifying mine lease area, mine activity, and baseline and impacted vegetation habitats or land cover.

Change Detection

Change detection methods are important for CSD reporting, because detection of incremental change from year to year is required to monitor expansion of mining activity and progressive reclamation. Change detection was applied using two datasets to determine the expansion of mine activity and vegetation impacts. The first change detection was based on the two thematic mine activity maps for 2005 and 2006, produced by Regional Aquatics Monitoring Program (RAMP) and the EO-CSD project, respectively. The second change detection was completed based on the integration of pre-development Alberta Vegetation Inventory (AVI) data from 1991 (Alberta Environmental Protection, 1991) with the mine activity map for 2006 derived from SPOT-5 imagery. This was conducted to provide information on the impact of mine activity on specific vegetation communities. The AVI data were integrated with the mine activity classification data, derived from SPOT-5 imagery and converted to vector GIS format, using a standard Union process in ArcGIS. Once polygon area values had been calculated for the new polygons in the output layer, summary statistics could be calculated that presented area-based estimates of the impact of mine activity on vegetation communities within the mine surface lease area.

Analysis and Information Products

The land cover classification data and mine surface lease boundaries provide the opportunity to produce statistics quantifying mine activity area. The mine surface lease boundaries were intersected with the classification datasets using GIS (ArcGIS). The following summary statistics were produced:

% of lease containing mine activity;

% of watershed containing mine activity; and

% of activity compared to overall oil sands region.

Audit

Assurance for the trial services was provided through independent auditing by PricewaterhouseCoopers (PwC). The scope of the audit included the examination of processes and methods related to:

- Data acquisition;
- Image processing and validation;
- Results / outputs; and
- Process controls.

The audit was conducted through the preparation of a detailed audit file, which provided all the information and evidence required by PwC. As part of the evidence gathering process, the audit also included interviews with staff involved in the project, management, financial and information technology staff.

Results

Remote sensing information products based on SPOT-5 cover all active mine lease areas of the Athabasca oil sands region. However the results focus on the Albian Sands Muskeg River and Jackpine Mine surface lease areas, and sustainable development reporting information provided to Shell Canada and Albian Sands.

Land Cover Map

The land cover classes derived from SPOT-5 imagery enabled the production of accurate map products, within the context of constraints of spatial scale and mis-classification between natural sparse vegetation and mine activity classes. The completion of an accuracy assessment indicates an overall classification accuracy of 80% for the SPOT-5 classification. Figure 2 shows the SPOT-5 land cover map for the Muskeg River and Jackpine Mine surface lease areas.

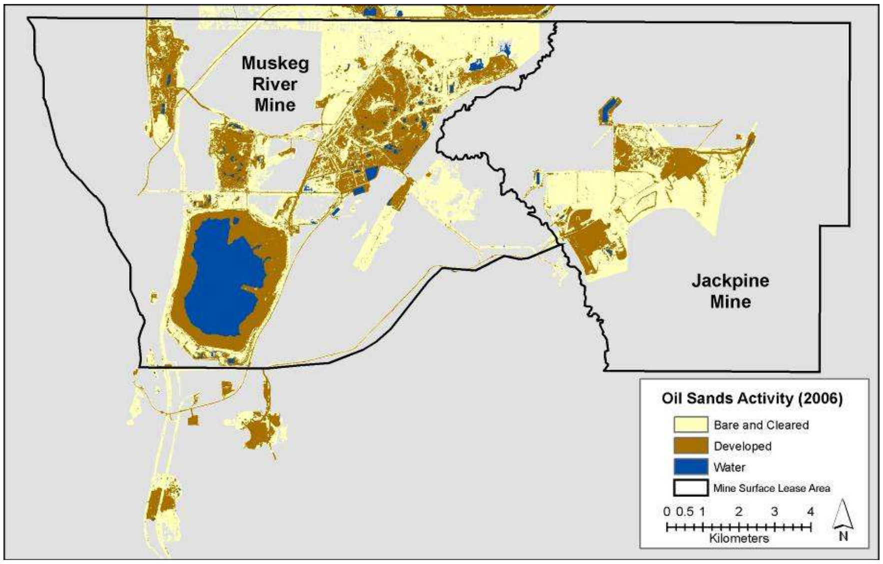

Figure 2. SPOT-5 land cover map for the Muskeg River and Jackpine Mine surface lease areas

Change Detection

Change detection can be visualised in tabular, graphical and image form. Table 2 presents statistics of change detection between the land cover classifications produced from the 2006 SPOT-5 imagery (current study) and 2005 Landsat TM imagery (Regional Aquatics Monitoring Program, 2005) for the Muskeg River and Shell Jackpine Mine. The table contains initial analysis on the extent of land cover change resulting from oil sands mines operated by Albian Sands and Shell Canada. The statistics also begin to address the footprint of Shell Canada and Albian Sands in relation to other activities within a watershed and the region as a whole. Figure 3 provides a summary of overall mine activity and impact of this activity on vegetation communities between 2005 and 2006 for the Muskeg River and Jackpine and Mine surface lease areas. The vegetation information is based on the AVI data. Figure 4 shows the potential for GIS visualisation software to provide accessible information on landscape change for stakeholders.

Table 2. Land cover change metrics for the lease, watershed and region: Total Area (ha), and Percentage of Landscape.

	Muskeg River Mine	Shell Jackpine Mine	Other Mines	Units
Area of activity (2005)	4,109.0*	0		hectares
Area of activity (2006)	4,496.3	1,312.8		hectares
Change (2005 to 2006)	+9.3	+100		percentage
Percent of Mine Lease Area (2006)	43.03	16.18		percentage
Percent of Muskeg River Watershed (2006)	2.45	0.92	3.99	percentage
Percent of Athabasca Tributaries Watershed (2006)	0.59	n/a	17.02	percentage
Percent of Athabasca oil sands region	8.2	2.4	89.4	percentage

Note: total oil sands activity in the entire Northern Athabasca oil sands region = 54,782 ha (RAMP, 2006).

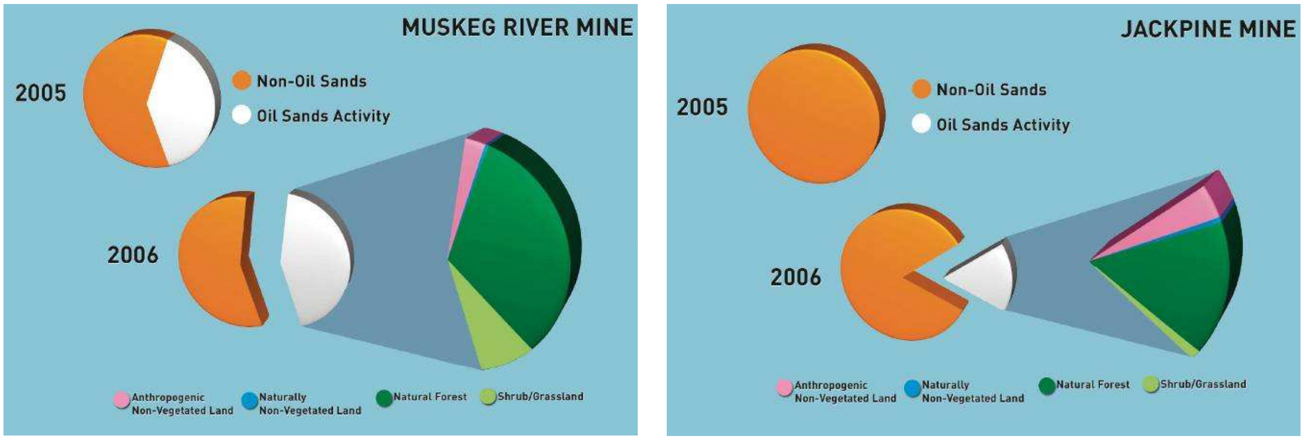

Figure 3. Overall mine activity and vegetation changes between 2005 and 2006

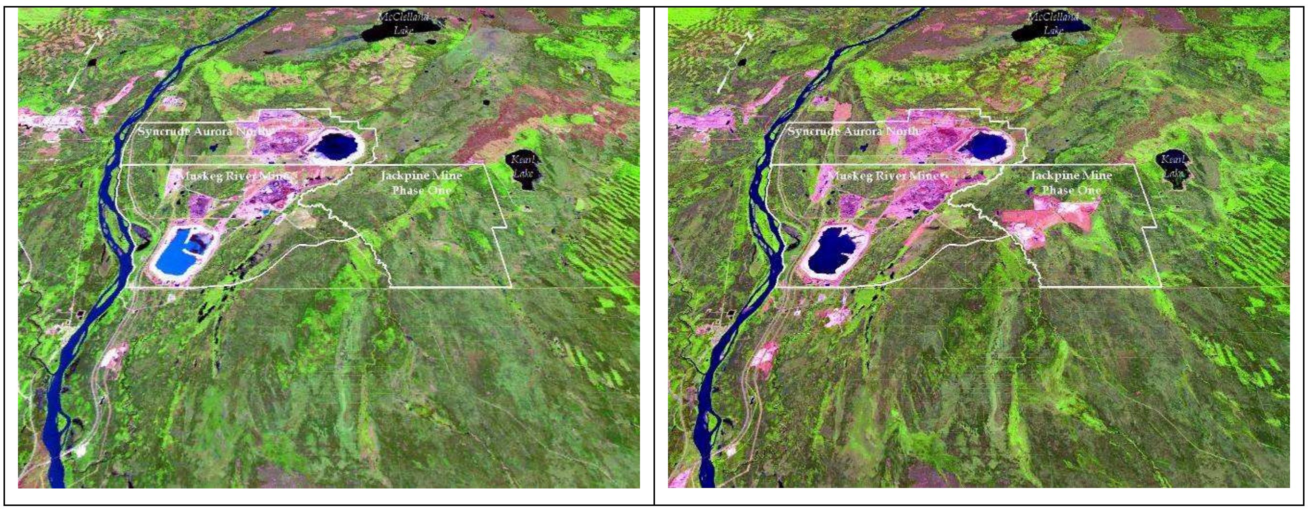

Figure 4. Visualisation of the Muskeg River Mine and Shell Jackpine Mine lease activity in 2005 (Landsat TM left) and 2006 (SPOT-5 right).

Traditional Ecological Knowledge

The information derived from satellite imagery is not only valuable for corporate environmental management purposes, but can also provide local residents with unbiased information regarding the impacts of developments in close proximity to their communities. The community of Fort McKay has recently established the Red Clay River GIS Program, which is a community-led initiative that has emerged following demonstration of GIS and remote sensing technologies under the EO-CSD Project. In 2006 and 2007, traditional ecological knowledge information is being collected with FMFN elders under the *Protected Areas Identification* initiative. Initial outcomes of this information collection process have been integrated into a GIS and overlayed with multi-temporal imagery to illustrate environmental changes in relation to traditional land use. More information is available on request.

Audit

Following the compilation of detailed audit files for the trial services, PwC conducted their evidence gathering process to ensure that the methodologies, processes and controls placed on the processing chain were valid. Once this was complete, assurance was provided for the remote sensing services, stating that:

- Original data were of high quality and needed minimal correction;
- Processes used were correct and in line with academic literature;
- The risks of errors mostly lie in steps that involve manual intervention, which were kept to a minimum;
- Calculation of statistics included appropriate quality control checks; and
- Sufficient evidence was collected to provide an assessment.

Sustainable Development Indicators

The outputs from the trial services demonstrated that remote sensing can contribute to Shell Canada's reporting on several Global Reporting Initiative Environmental Performance Indicators, including:

- **EN11: Location and size of mine lease area**: lease area is derived by GIS.
- **EN12: Significant impacts of mine activities**: mine activity area is monitored by survey crews as part of operational mine survey and planning. Using remote sensing provides transparent, objective information on the status of development and eventual reclamation oil sands leases. It allows stakeholders to monitor progress of reclamation commitments. Remote sensing and GIS can also expand annual reporting on environmental performance, allowing companies to begin to address their contribution to cumulative regional impacts.
- **EN13: Habitats protected or restored**: Using remote sensing provides transparent, objective information on development and eventual reclamation oil sands leases. Consultation with First Nations can identify important areas that should be protected from development.
- **EN14: Strategies, current actions, and future plans for managing impacts on biodiversity**: EO and GIS are important tools for strategic planning and management of oil sands operations.

Discussion and Conclusions

The EO-CSD project was a successful collaboration between a team led by Hatfield Consultants and two business leaders in sustainable development, Shell Canada and Albian Sands. The services have demonstrated the potential for remote sensing to support sustainable development reporting in the mining and oil and gas sectors.

In the short term, there is considerable potential for remote sensing based sustainable development services to be provided to companies in the oil sands region. These services have the potential to be offered in other geographical regions; this is an attractive prospect for large multi-national companies, because consistent service could be provided to many business units. The framework of the GRI provides the opportunity for the implementation of such a consistent service.

The EO-CSD project has demonstrated that a range of satellite sensors and other spatial data can be used, in combination, to address CSD reporting requirements. In many cases, high resolution optical sensors are desirable, because of the intuitive nature of the information present and the additional uses that such detailed imagery can provide, for example in mine planning. In regions such as the oil sands, where industrial development is taking place over large areas, the analysis of imagery could play a role in identification and management of cumulative regional effects.

An important component of CSD reporting is repeatability of analysis, to support the annual nature of the report cycle. Issues such as atmospheric correction of optical imagery are important; seasonality of optical imagery is also important, given the vegetation changes that occur in northern latitudes following snow melt. To document and quantify mine activity expansion, image-to-image comparison represents a superior approach to change detection.

Future Work

The imminent availability of imagery from high resolution active radar satellites, RADARSAT-2 and TerraSAR-X, is particularly interesting in terms of future application of satellite imagery for sustainable development services. The high resolution polarimetric data is not affected by cloud cover, which means that the detail of the imagery and information content will be applicable for mine monitoring.

Literature Cited

Alberta Environmental Protection. 1991. Alberta Vegetation Inventory Standards Manual Version 2.1. Alberta Environmental Protection Resource Data Division. Alberta Government

Energy Utilities Board. 2006. EUB Statistical Series Publication No. 44, a quarterly update of active oil sands schemes.

Global Reporting Initiative. 2006. G3 Sustainability Reporting Guidelines. GRI, Amsterdam. The Netherlands.

Regional Aquatics Monitoring program. 2006. Technical Report. Hatfield Consultants. West Vancouver Canada.

Richter R. 2006. Atmospheric / Topographic Correction for Satellite Imager. DLR report DLRIB 565-01/05, Wessling, Germany.

Schneider, R. and Dyer, S. 2006. Death by a Thousand Cuts: The Impacts of In-Situ Oil Sands Development on Alberta's Boreal Forest. Canadian Parks and Wilderness Society and the Pembina Institute.

Shell Canada. 2007b. 2006 Sustainable Development Report. Shell Canada Ltd., Calgary Canada.

Web Pages

Alberta Environment. 2006. Authorizations and Approvals, list of current status of oil sands development applications made to Alberta Environment.. http://envext02.env.gov.ab.ca/pls/xedp_apv/avwp_avwh1000_02.startup?Z_CHK=0

Department of Energy, Government of Alberta. 2006. Facts on Oil Sands. www.energy.gov.ab.ca/152.asp

Natural Resources Canada. 2006. Canadian Digital Elevation Data (CDED). www.geobase.ca.

SAM Indexes. 2007. Dow Jones Sustainability Indexes. http://www.sustainabilityindexes.com

Shell Canada Ltd. (2007a). Sustainable Development. www.shell.ca/sd/
.