MONITORING SUSTAINABLE DEVELOPMENT IN THE OIL SANDS REGION OF ALBERTA, CANADA, USING SPOT-5 AND ENVISAT ASAR AND MERIS IMAGERY

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ABSTRACT

The oil sands of northern Canada are among the largest known oil reserves in the world; the 174 billion barrels of established extractable bitumen reserves are equivalent to approximately two-thirds of Saudi Arabia’s known reserves of conventional crude oil [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 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 (Hatfield; Canada) leads a team working with Shell Canada Ltd. (Shell Canada) and Albian Sands Energy Inc. (Albian Sands) to provide EO-based geo-information services to support environmental management, monitoring, and sustainable development reporting for their oil sands surface mine operations. Imagery from Envisat ASAR and MERIS, and SPOT-5, were used in the development of trial services between June 2006 and April 2007, which aimed to support Shell Canada and Albian Sands in meeting their sustainable development objectives.

Based on EO image analysis, mine activity and vegetation habitat change information was provided for the 2006 Shell Canada Sustainable Development Report. The EO-based information provided was independently audited by PricewaterhouseCoopers (PwC), and assurance was received. The project team has also received an opinion from Sustainable Asset Management (SAM) on the scope for EO monitoring to contribute to best practices within the Oil and Gas and Basic Resources sectors, as part of assessments for the Dow Jones Sustainability Indexes.

1. INTRODUCTION

Corporate sustainable development (CSD) is now at the heart of business practices. Earth Observation (EO) from space has the potential to provide a global and cost-effective way to objectively measure progress towards sustainability of business activities. The European Space Agency (ESA) has begun working with large multinational companies to integrate satellite data into CSD reporting practices across a wide variety of industrial sectors.

Under the ESA Earth Observation Market Development Programme (EOMD), Hatfield Consultants (Hatfield; Canada) leads a team including: ACRI-st (France), Apolloni Virtual Studios (AVS; Italy), Dow & Associates (RTLC; Canada), PricewaterhouseCoopers (PwC, Canada) and Sustainability Asset Management (SAM, Switzerland), working with Shell Canada Ltd. (Shell Canada) and Albian Sands Energy Inc. (Albian Sands). The EOMD project, called the Earth Observation Support for Corporate Sustainable Development Reporting (EO-CSD) Project, aims to provide EO-based geo-information services to support environmental management, monitoring, and sustainable development reporting of the Shell Canada and Albian Sands mine operations in northern Alberta.

Shell Canada and Albian Sands are recognized business leaders in sustainable development; Shell Canada was included in the Dow Jones Sustainability Index for 2006 [2] and their 2006 CSD report is the 16th annual report prepared by the company [3].

1.1. Oil Sands Region

The oil sands region of northern Alberta provides a significant proportion of the world’s petroleum resources; the established 174 billion barrels of extractable bitumen reserves are equivalent to approximately two-thirds of Saudi Arabia’s known reserves of conventional crude oil [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 impacts. Currently, there are approximately 2,800 oil sands lease agreements within the Province of Alberta, totaling approximately 43,800 km². This is an area the size of Switzerland. By 2015, oil sands production is expected to reach 3 million barrels per day [4].
Albian Sands and Shell Canada operate the Muskeg River Mine and Jackpine Mine respectively, as shown in Fig. 1. As many as 16 other companies are operating, or planning to operate, oil sands extraction projects in the region, including global oil companies such as Exxon Mobil, Imperial Oil, Conoco-Phillips and Canadian Natural Resources Ltd.

**1.2. Sustainable Development Reporting**

Surface mining and SAGD operations cause disturbance to forests, wetlands, and river basin hydrology, resulting in significant land cover change, habitat fragmentation and potential loss of biodiversity. 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 [3]. Activities related to energy generation almost always have environmental impacts, and CSD means taking steps to reduce the environmental impact of operations, products and services. CSD reporting enables a company to address important issues with stakeholders, and to measure performance.

Shell Canada and Albian Sands’ geo-information needs are related to sustainable development reporting. Information required for Shell’s CSD reporting 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. Geo-information requirements for CSD reporting requires an understanding of the requirements of environmental managers within oil sands operations and the framework of CSD reporting. The Shell Canada 2006 CSD report has been developed in accordance with the 2006 guidelines of the Global Reporting Initiative (GRI) [5]. The GRI provides a framework for sustainability reporting, which includes a set of reporting guidelines to enable reporting on economic, environmental, and social performance.

**1.3. EO Trial Services**

The overall objective of the EO-CSD Project was to deliver EO-based environmental monitoring services to Albian Sands and Shell Canada to support environmental management, monitoring, and sustainable development reporting of their Athabasca oil sands mine operations, and to receive feedback on the viability of these services. An additional objective was to conduct outreach activities within the Oil and Gas and Mining sectors to further develop and promote EO based sustainable development services.

To achieve these objectives, EO trial services were delivered to Albian Sands and Shell Canada between June 2006 and April 2007. These trial services were designed to enable Shell Canada to report on GRI Environmental Performance Indicators [6], specifically:

- 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), EO imagery, and other data. The EO trial services 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 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.

The overall approach for the implementation of the EO trial services included:
- Data acquisition;
- Image pre-processing;
- Land cover classification;
- Extraction of quantitative information;
- Audit of the service; and
- Report in relation to GRI indicator.
The range of imagery acquired for the EO trial services was designed to provide information at various spatial scales of observation, from high resolution to moderate resolution. Frequent intervals of moderate resolution imagery enabled the potential for regional monitoring to be explored, including information on seasonal environmental dynamics. The capability of radar remote sensing was explored for change detection mapping. Identification of mine expansion using radar is based on significant changes in surface roughness, soil moisture (through de-watering) and vegetation cover that occur during mine development; in addition, buildings and other infrastructure may also be observed. While change detection approaches could be implemented with multi-year optical data, the assessment of radar for mapping change in mine activity is important, because cloud affected regions are potentially important geographical markets for EO services.

1.4. Audit
The information produced through the trial services was audited, following a financial auditing methodology, providing assurance that the data were produced using valid and thorough techniques. 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.

2. DATA
A total of 5 multi-spectral SPOT-5 images were acquired in 2006 to cover the entire northern oil sands region, an area of approximately 18,000km². In addition, 8 Envisat MERIS Full Resolution (FR) images were acquired from 2004 to 2006 covering the same region. Envisat ASAR alternating polarization (AP) images were also acquired: 1 image in 2004, and 2 images in 2006. A summary of acquired imagery is provided in Tab. 1. Other datasets were also obtained for pre-processing of imagery and GIS analysis; as shown in Tab. 2.

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Product</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPOT-5 (10 m)</td>
<td>Level 1A</td>
<td>29/06/2006</td>
</tr>
<tr>
<td></td>
<td></td>
<td>14/06/2006</td>
</tr>
<tr>
<td>Envisat MERIS</td>
<td>Top of Atmosphere (TOA)</td>
<td>26/06/2004</td>
</tr>
<tr>
<td>FR</td>
<td></td>
<td>14/09/2004</td>
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<tr>
<td></td>
<td></td>
<td>24/04/2005</td>
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<td>30/06/2005</td>
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<tr>
<td></td>
<td></td>
<td>18/09/2005</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Data set</th>
<th>Accuracy/Resolution</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Digital Elevation Model</td>
<td>1: 50,000</td>
<td>CDED Level 1 from Geobase¹</td>
</tr>
<tr>
<td>Mining Activity Lease Boundaries</td>
<td>N/A</td>
<td>Alberta Energy Utilities Board and Alberta Environment</td>
</tr>
<tr>
<td>Alberta Vegetation Index</td>
<td>1: 20,000</td>
<td>Alberta Environment/Sustainable Resource Development (SRD)</td>
</tr>
<tr>
<td>RAMP Land cover</td>
<td>1:100,000</td>
<td>RAMP (2005)²</td>
</tr>
</tbody>
</table>

² RAMP: Regional Aquatics Monitoring Program for the Athabasca Oil Sands

3. METHODS

3.1. Image Pre-processing
SPOT-5 and Envisat ASAR AP imagery were processed using PCI Geomatica v10. To reduce the effects of sun elevation and atmospheric conditions, SPOT-5 images were atmospherically corrected using the ATCOR2 algorithm [7]. Each SPOT-5 image was ortho-rectified and spatially referenced to UTM Zone 12 NAD83. The Envisat ASAR AP images were filtered using a 5x5 adaptive Kuan filter to reduce speckle. Individual images were calibrated to radar backscatter values (sigma naught) and the ortho-rectified and spatially referenced to UTM Zone 12 NAD83. The Envisat ASAR AP image products were spatially referenced to the Geographic Coordinate System WGS1984.

3.2. 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 (RAMP):
- Bare ground / cleared;
- Developed;
- Water; and
- Other / Non-oil sands.

The SPOT-5 imagery was classified using an unsupervised ISODATA classification, with the resulting image clusters allocated into one of the land cover classes.

MERIS FR images were classified using the Green Vegetation Index (GVI) for individual MERIS images using Eq. 1:

$$\text{GVI} = -0.290(B) - 0.562(G) + 0.6(R) + 0.491(\text{NIR})$$  \hspace{1cm} (1)

The following MERIS reflectance values (nm) were extracted and used to calculate GVI: $R = \text{Refl}_06$ or $\text{Refl}_08$, $G = \text{Refl}_04$, $B = \text{Refl}_03$, $\text{NIR} = \text{Refl}_014$. MERIS flags were also extracted for Water and TOAVI_Bright (Water or Developed Area). Thresholds were then applied to each GVI image to achieve the following classes:
- No Data;
- Dense Vegetation;
- Sparse Vegetation;
- Sparse Vegetation / Roads;
- Bare Ground / Developed;
- Developed;
- Water (Settling pond); and
- Bright (Water or Developed).

To separate oil sands activity from other activities (e.g. forestry), the mine surface lease boundaries obtained from the Alberta Energy Utilities Board [8] and Alberta Environment [9] were used. Developed or cleared areas within a surface lease boundary were considered oil sands related. In order to harmonize the classification images from MERIS and SPOT-5, a re-classification was completed according to Tab. 3.

<table>
<thead>
<tr>
<th>Re-classification</th>
<th>SPOT Classification</th>
<th>MERIS Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mine Activity</td>
<td>Water Developed Bare Ground / Cleared</td>
<td>Water Bright Developed Bare and Developed</td>
</tr>
<tr>
<td>Other</td>
<td>Other / Non-oil Sands</td>
<td>Sparse Vegetation / Roads Sparse vegetation Dense vegetation</td>
</tr>
</tbody>
</table>

Table 3. Re-classification of land cover into Mine Activity.

### 3.3. Change Detection

Change detection was applied using three 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 RAMP and the EO-CSD project, respectively. The second change detection was completed with the Envisat ASAR AP imagery acquired in 2004 to 2006. The final assessment was based on the integration of pre-development Alberta Vegetation Inventory (AVI) data from 1991, described in [10], 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 two change detection datasets created using thematic map products and SAR imagery were completed using GIS and image processing operations. The ASAR change detection was determined between the 2004 image and each of the images acquired in 2006, and also between each polarization (VV/VH), creating 8 output images. The CHDET algorithm, available through PCI Geomatica v10, first calculates the ratio of the two images, and then performs logarithmic scaling into dB values. In order to classify the expansion of mine activity, a single threshold was applied to the resulting change image based on visual image interpretation. A direct change classification approach was sufficient, because the land cover change within the lease boundaries was known to be related to vegetation clearance, which results in decreased surface roughness. Future development of settling ponds and other infrastructure may require a more complex change classification approach.

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.

### 3.4. 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.
3.5. 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.

4. RESULTS
EO-based information products performed in this study 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.

4.1. Land Cover Map
The land cover classes derived from the SPOT-5 and MERIS imagery enabled the production of accurate map products, within the context of usual constraints of spatial scale and errors of commission between natural sparse vegetation and mine activity classes. The completion of an accuracy assessment indicates an overall classification accuracy of almost 80% for the SPOT classification. Fig. 2 shows the SPOT-5 land cover map for the Muskeg River and Jackpine Mine surface lease areas. A land cover map derived from MERIS GVI imagery is presented in Fig. 3.

4.2. Comparison of Results
A comparison of June 2006 MERIS and SPOT-5 derived maps for the Muskeg River and Jackpine Mine found that the amount of overall disturbance was broadly in agreement. Tab. 4 presents the overall area of activity for the Muskeg River and Jackpine Mine extracted from both the SPOT and MERIS classification.

<table>
<thead>
<tr>
<th>Lease Area</th>
<th>Sensor</th>
<th>Mine footprint (Ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Muskeg River Mine</td>
<td>SPOT-5</td>
<td>4,497</td>
</tr>
<tr>
<td></td>
<td>MERIS</td>
<td>4,565</td>
</tr>
<tr>
<td>Jackpine Mine</td>
<td>SPOT-5</td>
<td>1,313</td>
</tr>
<tr>
<td></td>
<td>MERIS</td>
<td>1,444</td>
</tr>
</tbody>
</table>

Table 4. Comparison of overall mine activity for the month of June 2006

The MERIS classification over-estimated the mine activity by 68 ha compared to SPOT for the Muskeg River Mine, and 131 ha for the Jackpine Mine.

4.3. Change Detection
Fig. 4 provides a visualisation of the change detection capabilities of Envisat ASAR for the Shell Jackpine
Mine. The changes in the land cover associated with the vegetation clearance for the Shell Jackpine mine can be clearly identified in ASAR imagery.

A positive change threshold value of greater than 5dB was applied to the ASAR imagery to determine mine expansion.

Tab. 5 presents a comparison of incremental change related to mine expansion from 2005 to 2006 for both the Muskeg River and Jackpine Mine. The values are presented for change detection between the Envisat ASAR images and land cover classifications produced from the SPOT-5 imagery (current study) and Landsat Thematic Mapper imagery from 2005, available through RAMP.

<table>
<thead>
<tr>
<th>Lease Area</th>
<th>Sensor</th>
<th>Mine expansion 2005 – 2006 (Ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Albion Sands</td>
<td>ASAR</td>
<td>465</td>
</tr>
<tr>
<td>Muskeg River Mine</td>
<td>SPOT/Landsat</td>
<td>453</td>
</tr>
<tr>
<td>Shell Jackpine Mine</td>
<td>ASAR</td>
<td>1,140</td>
</tr>
<tr>
<td></td>
<td>SPOT/Landsat</td>
<td>1,335</td>
</tr>
</tbody>
</table>

Table 5. Comparison of mine expansion values from 2005 to 2006.

Note: the ASAR change detection was between 2004 and 2006, but the Landsat-based mine activity map was used to exclude all areas identified as developed in 2005 from the ASAR values.

The ASAR change detection over-estimated the mine expansion by 12 ha compared to SPOT/Landsat for the Muskeg River Mine and 195 ha for the Jackpine Mine.

Fig. 5 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.

4.4. Sustainable Development Indicators

The outputs from the trial services demonstrated that EO 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 derived by GIS.

EN12: Significant impacts of mine activities:
- Activity area derived by EO; and
- Vegetation habitat impacts derived by EO, GIS, and field data.

EN13: Habitats protected or restored:
- Reclamation and future EO monitoring.

EN14: Strategies, current actions, and future plans for managing impacts on biodiversity:
- EO and GIS are important tools for management of oil sands operations.

4.5. 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 trial 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.

5. 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 trial services have demonstrated the potential for EO to support sustainable development reporting in the mining and oil and gas sectors.

In the short term, there is considerable potential for EO-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 EO sensors and other spatial data can be used, in combination, to address CSD reporting requirements. In many cases, high resolution optical EO 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. The EO-CSD project has demonstrated that radar sensors can also provide information for CSD reporting, which is particularly important for services in regions with persistent cloud cover, for example southeast Asia. In regions such as the oil sands, where industrial development is taking place over large areas, MERIS imagery could play a role in high frequency monitoring of regional development.

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 and calibration of radar imagery are important; seasonality of optical imagery is also important, given the vegetation changes that occur in northern latitudes following snow melt. To detect mine activity expansion, image-to-image change detection is likely the superior approach to change detection, as demonstrated by the ASAR analysis.

5.1. Future Work

The information derived from Envisat and other sensors 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. Therefore, the EO-CSD project team continue to work with local Aboriginal communities to demonstrate how EO can be used as part of Shell Canada and Albian Sands corporate commitments to sustainable development.

The imminent launch of two active radar satellites, RADARSAT-2 and TerraSAR-X, is particularly interesting in terms of future application of EO for sustainable development services. The high resolution and polarisation capabilities of these sensors means that the detail of the imagery and information content may be appealing for use in mine management activities, and provide more confidence in the application for CSD reporting.

5.2. Outreach

As part of the EO-CSD project, an outreach plan was devised to take advantage of the position of the business leaders in sustainable development with the mining and oil and gas sectors.

As shown in Fig. 6, the approach uses regional and global organisations within the energy and mining sectors as channels to increase awareness of EO-based methods for sustainable development information gathering. In Canada, the project team engaged with the Mining Association of Canada (MAC; www.mining.ca) and the Canadian Association of Petroleum Producers (CAPP; www.capp.ca). At the international level, the same sectors are served by the International Petroleum Industry Environmental Conservation Association (IPIECA; http://www.ipieca.org/) and the International Council on Mining and Metals (ICMM; www.icmm.com). The global organisation also incorporating regional networks and providing the CSD function is the World Business Council for Sustainable Development.
6. ACKNOWLEDGEMENTS

The EO-CSD project team would like to thank the following individuals for their support and assistance in the project: Stephen Coulson and Pierre Philippe Mathieu, European Space Agency; Ashley Nixon and Rochelle Matripala, Shell Canada; Darrell Martindale and Christopher Tonkin, Albian Sands Energy Inc.; and Christine Schuh, PricewaterhouseCoopers.

7. REFERENCES


