

# COMPILING A GEOSPATIAL DATABASE OF EXISTING OIL SANDS INDUSTRIAL FEATURES FOR ALBERTA ENVIRONMENT

C.J. Bampfylde, DPhil<sup>a</sup>, S. Hughes M.Sc<sup>b</sup>, D. Page<sup>c</sup>, B. G. Purdy PhD<sup>a</sup>,  
S. Stanley B.Sc, Post Dip. Env<sup>b</sup>, A. Syed, M.Sc<sup>b</sup>

<sup>a</sup> Alberta Environment, Oil Sands and Clean Energy Policy Branch, 12th Floor Baker Centre,  
10025 – 106 Street, Edmonton, AB, T5J 1G4 - caroline.bampfylde@gov.ab.ca, brett.purdy@gov.ab.ca  
<sup>b</sup> Hatfield Consultants Partnership, 200-850 Harbourside Drive, North Vancouver, BC, V7P 0A3 Canada -  
shughes@hatfieldgroup.com, sstanley@hatfieldgroup.com, asyed@hatfieldgroup.com  
<sup>c</sup> Alberta Environment, Geographic Information Office , #211 Provincial Building,  
4920 - 51 Street, Red Deer, Alberta, T4N 6K8 - don.page@gov.ab.ca

## Commission I, WG I/3

**KEY WORDS:** Remote sensing, GIS, geodatabase, satellite, oil sands, Alberta, landcover, land use

### ABSTRACT:

As part of an on-going initiative to develop a clearer understanding of the impacts of oil sands development on the environment and support annual reporting processes, Alberta Environment initiated a project to create a Geospatial Database for Existing Oil Sands Industrial Features. This project included a range of landcover/land use assessments of surface disturbance and reclamation features in the 2000s, 1990s and 1980s.

The primary objective of this project was to create a geospatial database of oil sands disturbance and reclamation features derived from recent (2007) and historical (1998 and 1985) data. The source data included satellite imagery, orthophotos, conservation and reclamation reports (CnR) submitted by oil sands operators, and a series of other ancillary GIS data supplied by Alberta Environment. The project employed the following steps:

- First, 2007 oil sands CnR reports were examined and landform features were digitized from geo-referenced maps. The resulting data were used to refine an initial landcover classification of 2007 multi-spectral SPOT-5 imagery to create a final landcover/land use classification dataset.
- Second, 1998 oil sands CnR were examined and landform features were extracted from geo-referenced maps for that year. The resulting dataset was again used to refine an initial landcover classification of Landsat-5 imagery from 1998 to create a final landcover/land use classification dataset.
- Finally, 1985 oil sands historical documents were examined and landform features were extracted from orthophotos from the 1980s. As above, the resulting dataset was used to refine an initial landcover classification of Landsat-5 imagery from the 1980s to create a final landcover/land use classification dataset.

The project deliverables included designing, building, and populating an ESRI ArcGIS file geodatabase with 2007, 1998 and 1985 satellite image mosaics, orthophotos, oil sands project boundaries, and derived landcover/land use feature datasets. Methodology documents were also completed for this project.

## 1. INTRODUCTION

### 1.1 Project Objective

Alberta Environment initiated a project to create a Geospatial Database for Existing Oil Sands Industrial Features to develop a clearer understanding of the impacts of oil sands development on the environment and to support annual reporting processes. The primary objective of this project was to design and populate a geospatial database of oil sands disturbance and reclamation features derived from recent (2007) and historical (1998 and 1985) data. The source data included satellite imagery, orthophotos, conservation and reclamation (CnR) reports submitted by oil sands operators, and a series of other ancillary GIS data supplied by the Alberta government.

### 1.2 Project Overview

This project involved delineating study areas, creating an orthophoto mosaic, georeferencing CnR report maps, defining project 'footprints', building SPOT and Landsat satellite image mosaics, conducting ISODATA image classification, producing the landcover/land use datasets, developing and populating a spatial geodatabase, and documenting methodology.

### 1.3 Project Area

The project area involved the boundaries of the active oil sands projects for each year studied (2007, 1998, and 1985) within the Lower Athabasca Planning Region in the northeastern portion of the province of Alberta, Canada.

## 1.4 Data Inputs

A number of spatial datasets were used as inputs to the analysis in this project. These data are listed below with their source shown in brackets. All source vector data were in ESRI Shape file format. Images were received as TIFF files.

### Oil Sands Project Study Area

- Oil Sands Agreement Boundaries (Alberta Energy)
- List of Active Oil Sands Projects [Alberta Environment (AENV)]

### Orthophoto Mosaic

- Air Photos, Cut-lines, DEMs [Alberta Sustainable Resource Development (ASRD)]

### Oil Sands Project Footprints

- Base Features – Roads, Facilities, Pipelines (ASRD)
- Raw Pipes, Digitally Integrated Dispositions and Land Status Automated System Purpose Codes (ASRD)
- Cut-blocks (ASRD, Alberta-Pacific Forest Industries Inc)
- Conservation and Reclamation Reports (AENV)
- Reclaimed features, some disturbed features (individual oil sands project operators – Suncor, Syncrude, Opti-Nexen, EnCana, Imperial, CNRL, Devon)
- Hydrography (Natural Resources Canada)

### Satellite Imagery Mosaics

- Landsat Imagery [U.S. Geological Survey (USGS) EROS Data Center]
- SPOT Imagery (ASRD)

### Initial Landcover Classification

- ALPAC Enhanced Wetland Classification (Ducks Unlimited)
- Alberta Vegetation Inventory and Phase 3 Forest Inventory (ASRD)

## 1.5 Software Used

Two types of software packages were used to perform the analysis in this project: remote sensing (image processing); and GIS.

SPOT-5 and Landsat-5 satellite imagery were processed using PCI Geomatica Version 10.2.

The KLT ([www.kltassoc.com](http://www.kltassoc.com)) softcopy photogrammetric software was used for aerial triangulation and orthorectification of the 1:60,000 black-and-white scanned air photos from the 1980s.

The OrthoVista ([www.orthovista.com](http://www.orthovista.com)) software was used to create the mosaics and complete tonal balancing of the orthophotos.

GIS analysis and cartography were performed using ESRI ArcGIS version 9.3 (<http://esri.com/software/arcgis/index.html>).

## 2. METHODOLOGY

This project employed a two-step image classification process to define landcover/land use. First, the ISODATA (Iterative Self-organizing Data Analysis Technique) unsupervised classification method was used to create the **initial landcover** information (natural, cleared, bare ground, water, and cloud/shadow). Second, the oil sands project ‘footprints’ dataset was used to generate **land use** information. GIS integration of these two datasets produced the **final landcover/land use Level 1 and Level 2** classifications.

The project methodology consisted of the following tasks:

1. Delineate oil sands project study areas;
2. Process SPOT and Landsat satellite imagery;
3. Mosaic the SPOT and Landsat satellite imagery;
4. Conduct ISODATA image classification with class allocation to produce the **initial landcover** classification;
5. Orthorectify and mosaic air photos;
6. Georeference CnR report maps;
7. Extract project ‘footprints’ and capturing attributes for a oil sands footprint dataset;
8. Execute GIS integration to create **final landcover/land use Level 1 and Level 2** classification; and
9. Design and populate the spatial geodatabase.

Each task is described in the sections below, and the following flowchart (Figure 1) provides a summary of the processes applied.

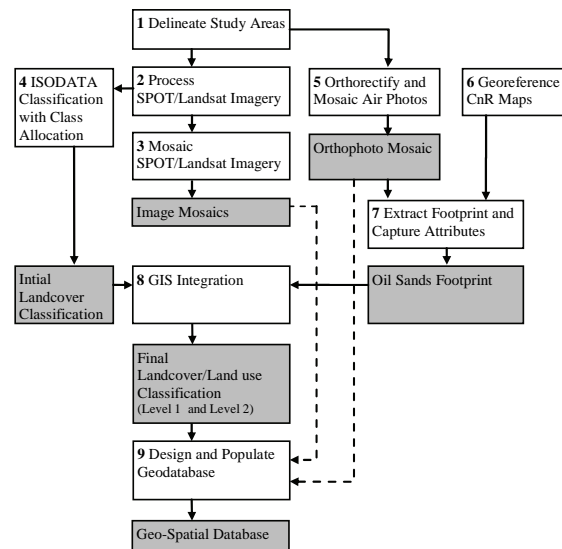


Figure 1 Flow chart of processes applied

### 2.1 Delineate Oil Sands Project Study Areas

In collaboration with AENV, study areas were delineated based on active oil sands projects for each year examined. Using the Alberta Oil Sands Agreements, polygons were selected and dissolved to create one boundary for each active oil sands project. There were 27 active oil sands projects in 2007, five

project in 1998, and four active oil sands projects in 1985 that were included in this study.

## 2.2 Process SPOT/Landsat Imagery

SPOT-5 and Landsat-5 TM multi-spectral (MS) imagery were processed to create image mosaics and landcover classes for 2007, 1998 and 1985.

**2.2.1 SPOT/Landsat Images Used:** Fifteen individual SPOT-5 images were used for 2007. A total of 12 and nine individual Landsat-5 images were used for 1998 and 1985 respectively.

**2.2.2 SPOT/Landsat Data Pre-processing:** Prior to mosaicking, the SPOT images were orthorectified to the 10TM projection (NAD\_1983\_10TM\_AEP\_Forest). The spatial resolution of the individual SPOT-5 MS image frames and mosaic was 10 m x 10 m.

Landsat data were ordered as pre-processed products, which were radiometrically corrected and orthorectified by the USGS, and delivered in the Universal Transverse Mercator (UTM) projection. Individual Landsat images were projected from UTM to 10TM projection prior to mosaicking and classification. The Landsat MS image frames and mosaic were re-sampled to a 30 m x 30 m pixel size using a Nearest Neighbour re-sampling kernel.

## 2.3 Mosaic SPOT/Landsat Imagery

The SPOT images and Landsat images were each mosaicked to provide continuous image cover of the oil sands development areas using the following processing steps:

1. Create cut-line;
2. Mosaic baseline SPOT/Landsat scenes;
3. Mosaic remaining scenes;
4. Clip to the study area; and
5. Export to GeoTIFF and JPG2000 formats.

False colour composite SPOT and Landsat image mosaics were produced for use in ArcGIS, with the following selected spectral bands producing a pseudo-natural colour image:

**SPOT:** bands 4, 1, 2 (mid infrared, infrared, and red spectral bands to be displayed as Red, Green, Blue)

**Landsat:** bands 5, 4, 3 (mid infrared, infrared, and red spectral bands to be displayed as Red, Green, Blue)

## 2.4 ISODATA Classification with Class Allocation

An unsupervised ISODATA classification was performed for each of the individual SPOT and Landsat images. The ISODATA classification groups image pixels into a user-defined number of spectrally-similar classes based on statistical criteria. 50 ISODATA classes were defined in this project.

After ISODATA classification, the following steps were completed to create the **initial landcover** classification:

1. Class Definition;
2. Class Allocation; and
3. Manual Editing and Masking.

**2.4.1 Class Definition:** The following landcover classes were defined for this project (Figure 2):

**Natural:** land area not affected by oil sands operations within an operator's lease area; all vegetation is included in this class.

**Cleared:** land where trees, shrubs, and low-lying vegetation have been removed. Some vegetation re-growth may be present.

**Bare Ground:** land where no vegetation exists, e.g., bare soil or rocks. Bare ground can result from oil sands, other anthropogenic activities such as forestry or other mining, or may be due to natural processes.

**Water:** waterbodies including oil-sands-related (e.g., tailing pond, artificial lake), as well as natural waterbodies (e.g., lakes and rivers).

**Cloud/Shadow:** land covered by clouds and shadows from the satellite imagery.

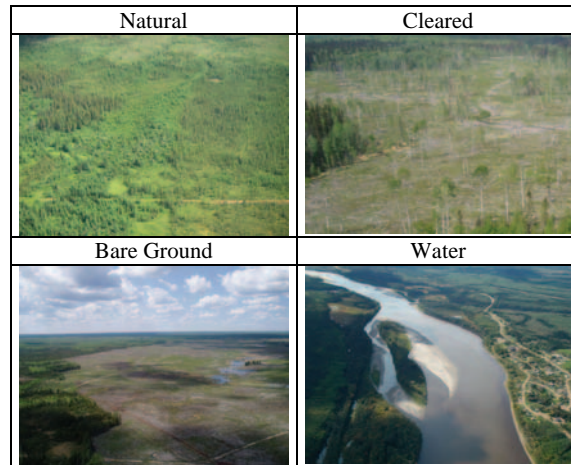


Figure 2. Photographic examples of the landcover classes

**2.4.2 Class Allocation:** Class allocation involved reassigning the 50 ISODATA classes to the five aggregated landcover classes defined by the classification scheme described above. This manual process was based on the analyst's assessment of the clusters that result from the ISODATA process, and was often completed with the aid of field survey data, photographs and local knowledge. Alberta Environment provided Alberta-Pacific Forest Industries Inc. (ALPAC) Enhanced Wetland Classification, Alberta Vegetation Inventory, and Phase 3 Forest Inventory supporting data that were used to verify classes during the allocation process.

**2.4.3 Manual Editing and Masking:** Due to the often distinct differences in landcover spectral signatures, most classes were easy to define and class allocation was a straightforward process. However, some landcover types, such as 'bare ground' and 'cleared', can be related to oil sands activities and others to natural or non-oil sands industries (e.g., forestry cut blocks). Some of the natural vegetated areas along river and lake shorelines had similar spectral signatures to 'bare ground' or 'cleared'. To separate these classes and refine the classification, manual editing and 'masking' techniques were applied based on image interpretation, local knowledge and review comments provided by Alberta Environment.

This **initial landcover** classification dataset forms the first part of the landcover/land use classification (see Section 2.8)

### 2.5 Orthorectify and Mosaic Air Photos

Black and white 1:60,000 air photos (1982 to 1984) scanned from paper prints were orthorectified and mosaicked to use in ArcGIS for this project. The raw, scanned air photos were at a spatial resolution of approximately 3 m. A total of 65 air photos were used to create orthophoto mosaics.

Ground control for the aerial triangulation process was captured from the cut-lines dataset. 1:250,000 scale Digital Elevation Models (DEMs) with a 25 m pixel size were used in the orthophoto production. The images were orthorectified to the 10TM projection and re-sampled to a 1 m pixel size using the cubic convolution re-sampling kernel.

### 2.6 Georeference Conservation and Reclamation Maps

CnR maps from each active oil sands project in both 2007 and 1998 containing detailed disturbance and reclamation features were georeferenced in preparation for oil sands project footprints feature extraction.

### 2.7 Extract Oil Sands Project Footprints and Capture Attributes

An oil sands ‘footprint’ was manually digitized for each oil sands project, based on the observations made from a combination of sources, including orthophotos, CnR report maps, supporting GIS data supplied by Alberta Environment, and satellite imagery. A footprint was defined as oil sands disturbance or reclamation features of interest. Examples of ‘footprint’ features include ‘plant site’, ‘well pad’, ‘borrow pit’, and ‘pipeline’. For easier comparison among oil sands projects, Alberta Environment standardized these feature names.

In the 2007 and 1998 datasets, features were primarily captured from CnR report maps while in the 1985 dataset, features were captured with on-screen digitizing at full resolution (at a scale less than 1:4,000) using the orthophoto mosaics as the primary source of information.

Once each project’s ‘footprint’ was defined, features with overlapping polygons were removed using a GIS “Union” process. Overlapping features occurred when features digitized from different sources were coincident. Topology, including slivers, multipart polygons, and gaps were checked and corrected. Where appropriate, polygons smaller than 0.25 hectares were examined and eliminated by joining with adjacent polygons.

The following footprint features were captured:

- airport
- borrow pit
- camp housing
- cutblock
- disposal well pad
- disturbed other industry
- disturbed unclassified
- drainage system
- external tailings pond
- geophysical exploration
- in pit tailings pond

- mine pit
- observation well
- oil sands cleared
- operations
- overburden dump
- pipeline
- plant site
- reclaimed
- RMS (reclamation material stockpile)
- road
- sedimentation pond
- sump
- utilities
- waste water
- water source well
- well pad

This **oil sands footprint** dataset forms the second part of the landcover/land use classification (see Section 2.8).

### 2.8 GIS Integration

GIS integration of the **initial landcover classification** and the **oil sands footprint** produced the **final landcover/land use classification** based on the following definition of Level 1 and Level 2 classification schemes:

**Level 1 classification:** consists of landcover (natural, cleared, bare ground, water and cloud/shadow) and broad land use (reclaimed and disturbed) classes; and

**Level 2 classification:** consists of landcover (natural, cleared, bare ground, water, and cloud/shadow), reclaimed, detailed cleared, and detailed disturbance classes (oil sands project ‘footprint’ features).

The following broad land use classes are defined and shown in Figure 3:

**Disturbed:** land areas that have been excavated (where the soil is removed) for oil sands operation. Examples include tailings pond, plant site, borrow pit, well pad, road, and pipeline.

**Reclaimed:** land areas that were previously disturbed that have been recovered.



Figure 3. Photographic examples of disturbed and reclaimed land use classes

To create the Level 2 classification, the ‘disturbed’ and ‘cleared’ classes were sub-divided based on the oil sands ‘footprint’ feature types identified from the assessment of the 2007, 1998 and 1985 imagery and supporting data. Natural, bare ground, water, and cloud/shadow landcover classes defined under the Level 1 classification scheme remained the same for

the Level 2 classification scheme. Figure 4 provides a graphic example of the process.

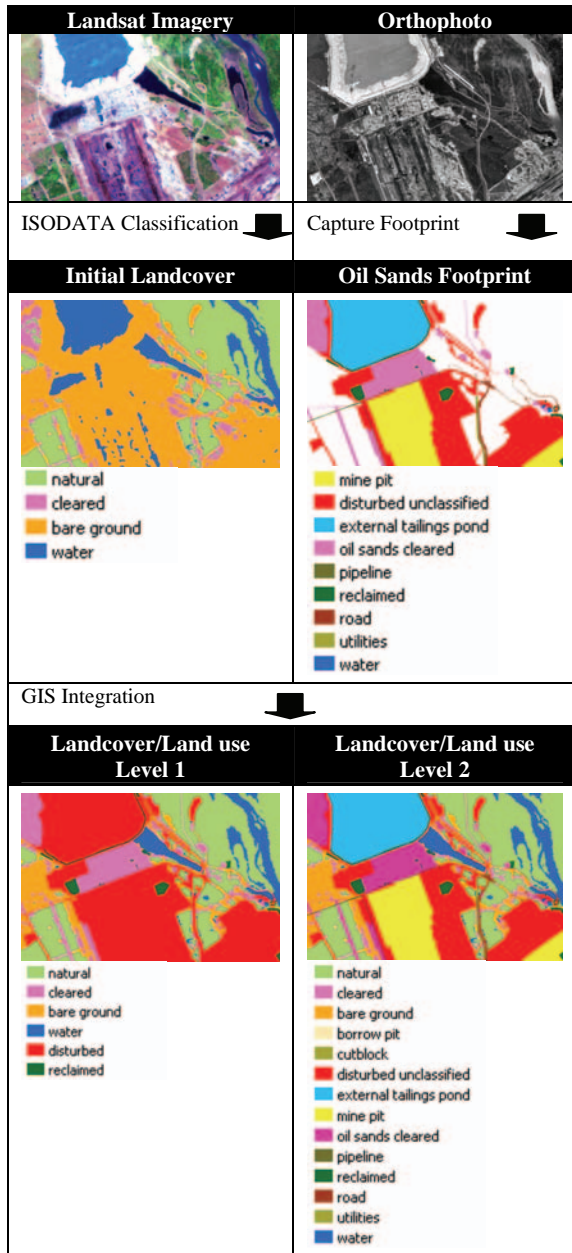


Figure 4. Graphic showing steps leading to Landcover/Land use Level 1 and Level 2 classifications

### 2.9 Design and Populate the Geodatabase

The geodatabase was populated with the raster and vector datasets from all years studied and was built to accommodate additional spatial and attribute datasets.

The geodatabase contains the following datasets:

- Oil sands project boundaries
- Landcover/Land use Level 1 and Level 2 Classification

- Orthophoto mosaic (raster)
- SPOT image mosaic (raster)
- Landsat image mosaics (raster)

Fields in the database include:

- Oil Sands Project Name and Number
- Alberta Oil Sands Area
- Mine Type
- Year of Classification
- Data Source
- Oil Sands Feature Type (Footprint)
- ISODATA Classification
- Landcover/Land use Level 1
- Landcover/Land use Level 2

Topology rules of “Must Not Overlap” and “Must Not Have Gaps” were applied and validated for each feature dataset. Multipart polygons were converted to single-part polygons and small polygons were merged with adjacent polygons. Also, Coded Value Domains were applied to certain fields to ensure consistency and validate feature attributes and ensure data integrity, e.g., “well pad”, “wellpad”, and “wellpads” were standardized to “well pad”.

Methodology documents were produced with details describing the input data, the processes undertaken, and the output product delivered.

For quality control, the Geographic Information Office of Alberta Environment will conduct an accuracy assessment of the landcover/land use classification.

Also, Alberta Environment’s Geographic Information Office will create FGDC-compliant metadata for each of the datasets in the file geodatabase with input from Hatfield Consultants as required.

### 3. RESULTS AND FUTURE WORK

#### Results:

The geodatabase produced for this project contains digital georeferenced landcover/land use datasets suitable for land change analysis over multiple years. The geodatabase structure is designed to support additional datasets.

#### Future work:

As a result of this data capture project, Alberta Environment has developed templates and a prescribed methodology for digital submission of geospatial data relating to annual conservation and reclamation activities as well as life of mine closure plans. These submissions will enable operational and policy staff to conduct regional analyses and understand the historical and future disturbance in the oil sands areas. This data will also be made available to the public on an information portal containing environmental information on the impacts of the oil sands development. These data will populate the geodatabase. High resolution satellite imagery will also be considered to generate additional disturbance and reclamation datasets outside the project areas and for validation of operator submissions.