USING LANDSAT-7 IMAGES TO UPDATE CANADIAN NATIONAL TOPOGRAPHIC DATA

M.-E. Martin, E. Loubier

Natural Resources Canada, Centre for Topographic information
010-2144 King Street West, Sherbrooke J1J 2E8, Québec Canada
www.ctis.nrcan.gc.ca
eloubier@RNCan.gc.ca

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ABSTRACT:

Natural Resources Canada's Centre for Topographic Information has a significant collection of topographic data at the 1:50 000 scale. The extent of the Canadian landmass makes it very difficult to update these data on a continuing basis. Following production of national Landsat-7 orthoimages coverage produced in partnership with more than 20 Canadian organisations, a project for updating topographic data using these orthoimages was initiated in June 2001. This article presents the operational constraints related to implementing an updating project of this magnitude (nature of topographic entities, image heterogeneity, size of the territory, production rate, absence of recent ground truth, etc.). Moreover, it describes why production could not be completely automated and why some visual interpretation had to be used.

RÉSUMÉ:

Le Centre d'information topographique de Ressources naturelles Canada possède une importante collection de données topographiques à l'échelle de 1/ 50 000. L'étendue du territoire canadien rend la mise à jour continue de ces données très difficile. Suite à la mise en production d'une couverture nationale d'orthoimages Landsat-7 via un partenariat de plus de 20 organisations canadiennes, un projet de mise à jour des données topographiques utilisant ces orthoimages a débuté en juin 2001. Cet article présente les contraintes opérationnelles liées à la mise en production d'un projet de mise à jour d'une telle ampleur : nature des entités à cartographier, hétérogénéité des images, étendue du territoire, rythme de production, absence de vérité-terrain récente, etc. Il explique pourquoi la mise en production n'a pu être totalement automatisée et pourquoi l'interprétation visuelle a dû être en partie utilisée.

1. TOPOGRAPHIC DATA OF CANADA

The Centre for Topographic Information (CTI), part of Natural Resources Canada, is responsible for providing the digital representation of the Canadian landmass required by users of geographical information in support of the protection and development of the country, which includes its resources and their use. The main type of information managed by the CTI is topographic data at the 1:50 000 scale. These data yield more than 14 000 maps based on the National Topographic System (NTS). They cover nearly the entire Canadian landmass, with the exception of certain more northern regions that haven't been mapped at this scale. The data are available in vector form (National Topographic DataBase or NTDB) or on paper (Canadian Topographic Maps).

The vector data contain many topographic features divided into 14 themes: hydrography, vegetation, manmade features, hypsography, designated areas, road network, power network, rail network, relief and landform, water saturated soils, roads, general, and toponymy. These data were originally acquired by photogrammetry and ground survey, and constitute a unique resource of topographic data for all of Canada.

2. CONTEXT

Canadian topographic data were acquired over the last 50 years. Many focused update projects have been completed in recent years, such as updating the road network, major towns, and more densely populated regions. Yet no updating project of national scope has been carried out, since the costs and time involved are too great. The validity of some maps can be as old as 1948.

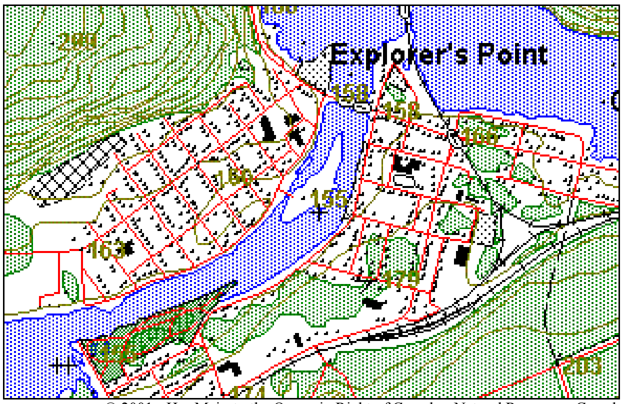


Figure 1: Extract of a 1:50 000 topographic data file

The current context for developing new technologies and the increasing use of topographic data in many sectors ranging from Web-based cartography to precision agriculture has led to a growing need for accurate, current, and integrated data for the entire landmass. While the need to update topographic data continued to grow, the costs related to the photogrammetric process and high-resolution satellite imagery were simply prohibitive.

The flexible distribution rights policy and the lower acquisition costs of imagery of the Landsat-7 satellite launched in 1999 opened the door to new possibilities for data providers and users. As such, a project funded by GeoConnections with more than 20 Canadian federal, provincial, and territorial organisations working in partnership focused on creating national Landsat-7 orthoimage coverage.

Although the Landsat-7 images do not have optimal spatial resolution for working with data at the 1:50 000 scale, they are adequate for producing a partial update. Moreover, being able to produce national orthoimage coverage brings a Canada-wide update into the realm of possibility.

3. OBJECTIVES

CTI initiated a national program to update topographic data at the 1:50 000 scale using Landsat-7 orthoimages.

The objectives of this project are:
- Enhance the planimetric accuracy of existing data;
- Update topographic data;
- Restructure the data in a format that complies with international standards in a new database: the Geospatial Database (GDB).

This article deals mainly with the first two project objectives. Interested individuals can find additional information about the Geospatial Database and its standards by consulting CTI website at www.cits.rncan.gc.ca.

This project is an audacious production project both in scope and the number of operational constraints involved. Indeed, thousands of topographic data must be updated homogeneously while the terrain's conditions vary greatly.

4. METHODOLOGY

4.1. Landsat-7 Orthoimages

The orthoimages used for the project were produced from Landsat-7 images. The objective is to produce orthoimages with an accuracy of 50 m or better with most of them under 30m. To date the accuracy of the orthoimages produced varies from 11 m to 26 m. To cover the entire Canadian landmass, more than 700 Landsat-7 images will be acquired over a period of 5 years. The images, usually collected from early May to mid-October, are selected in order to minimize cloud cover and maximize vegetation activity. For more details about Landsat-7 orthoimages characteristics and production methods, see Bélanger & Benoit 2002.

The resulting orthoimages (15m for the panchromatic band and 30m for the multispectral bands) were fused using ©PCI's PANFUSE tool. They were then subdivided according to the National Topographic System for correspondence with NTS maps. The orthoimages were not mosaicked even when two orthoimages were necessary to cover a mapsheet.

4.2. Planimetric Enhancement

The planimetric accuracy of Canadian topographic data varies from 10 m to more than 100 m. When the orthoimage accuracy is better than the accuracy of the topographic data, the topographic data are corrected planimetrically. Altought the data shown on map could be out of date, amelioration of its accuracy is a great improvement for customers.

The planimetric correction is outsourced to private companies. Although we recommend that contractors use a method based on local linear correction to carry out this task, no specific method is imposed. CTI quality control ensures that the quality of the work complies with our accuracy requirements.

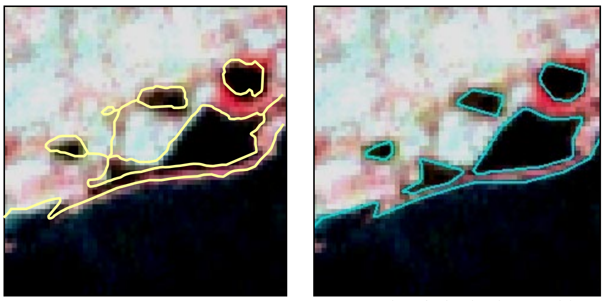
The maximal relative accuracy allowed between orthoimages and vector data is 20 m with a degree of confidence of 90%. The relative accuracy is calculated by measuring the displacement between the orthoimage and a representative sampling of the resulting planimetrically corrected vector data. The absolute accuracy obtained from the resulting vector data is computed based on relative accuracy and orthoimage accuracy. To date, more than 350 mapsheets have been planimetrically improved.

4.3. Other available datasets

Orthoimages and topographic data are not the solely data available for this project. Aerial photographs used to originally produce the topographic data are still available. Although they are as old as the data to update, they can be very useful to understand the environmental context in some regions. Canadian updated national road network and Canadian digital elevation data are under completion and can also help interpreting the orthoimages when they are available.

4.4. Selection of a update method

Different approaches can be use to update topographic information at scale 1:50 000. On one hand, it would have been possible to use the Landsat-7 orthoimage to create a totally new map coverage of Canada. However, this option would have meant quality deterioration, or even loss, of many entities that did not change over time. Data like the hydrographic network would have been difficult to recreate with Landsat-7 imagery. (Figure 2) For this reason, this approach was not selected.



Original hydrography network — Example of the hydrographic network extracted from Landsat-7 imagery

Figure 2: Comparison of quality difference between original data and data capture on Landsat-7 orthoimages.

On the other hand, a change detection approach was deemed more appropriate. The change detection process makes it possible to validate the existence, the geometry, and the description of features visible in the image, whether they have been modified or not. New features are captured as seen on the image and features that are not visible are preserved and transferred if there is no proof that they should be eliminated.

The main advantage of a change detection approach is to combine, both in terms of resolution and content, the currency of Landsat-7 data with the heritage data provided by years of photogrammetric data capture and ground surveys. Moreover, this approach leaves the door open for future updates with better tools or imagery.

A number of avenues are open for detecting change and updating data using satellite imagery. They include methods based on classification, texture recognition, snakes, and so on. Nevertheless, the operational constraints in this project significantly limited the choices available. The main constraints encountered in implementing production are provided below.

Constraint 1 - Entities not suitable to the Landsat-7 context: Entities to update are very heterogeneous and their definition does not always suit to Landsat-7 images. For example, topographic mapping normally distinguish different types of mining operations and indicate whether it is a pit, quarry, or mine. Landsat-7 orthoimages may show the extent of the mining area but can hardly shows its type.

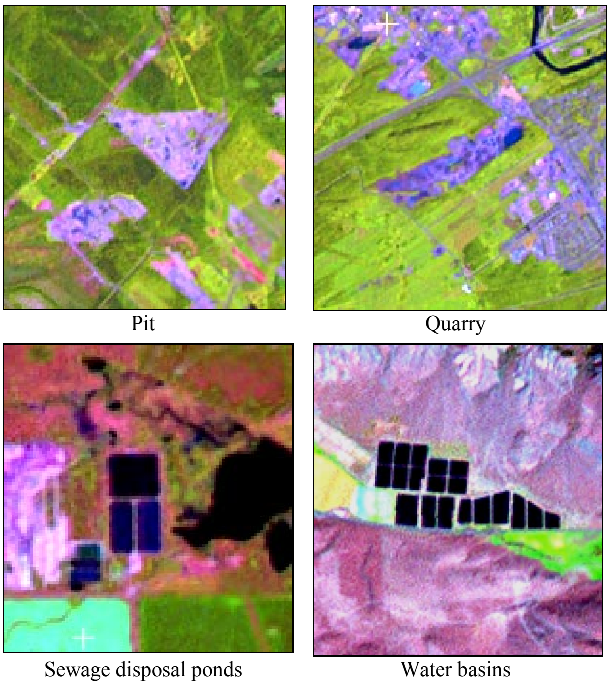


Figure 3: Examples of entity definition not suitable to the Landsat-7 image

Moreover, due to the spatial resolution of Landsat-7 images, certain entities, such as hydroelectric lines and buildings, cannot be updated at all. It was therefore decided to limit the entities to be updated to major themes generally visible in the images such as vegetation, hydrography, water-saturated soils, built-up areas, and certain designated areas. As much as possible, the definition of entities was adjusted to comply with the orthoimages possibilities. For example, the entity ''mining operation: type unknown'' was added to the existing entities set. Other entities, like the roads, are acquired through other projects or are obtained through partnerships with specialised partners.

As it will be explained later, the adjustments made were not sufficient to allow the implementation of a completely automated change detection method.

Constraint 2 – Image heterogeneity and size of the territory: More than 700 images are required to cover the entire country. The coverage should be completed within five years. In order to do so, images from various seasons will be used. Despite this constraint, the objective is to conduct the map updating process as homogeneously as possible. As such, interpretation rules, entity definition and output format characteristics are the same all over the Canadian territory. An entity that should be fairly easy to interpret, such as vegetation, can be a problem when the quantity of variables involved is taken into consideration: variation of the type of vegetation, variation of the images acquisition date, lack of ground truth and so on.

Constraint 3 – Production rate: CTI is committed to provide the most up-to-date data possible. In doing so, it is extremely important to have a production rate that prevents the data offered from becoming obsolete. This problem takes critical proportions when the ongoing updating process must be carried out for a territory as large as Canada. The required production rate limits the amount of time that can be spent on a single image. For example images preparation is conducted using fully automated methods, such as main component analysis and unsupervised classification.

4.5. Description of the updating process

Updating data through change detection process is done by studying the evolution of a given entity. This study leads to important questions and decisions that can not easily be undertaken by automated systems. The main questions set by the change detection concerns visibility, entity identification, importance of the change, minimal dimensions, generalisation and identification of the change detected. Figure 4 summarises the change detection decision tree through which every entity has to go. Some negatives branches (no capture, entity destruction) have been omitted to simplify the figure.

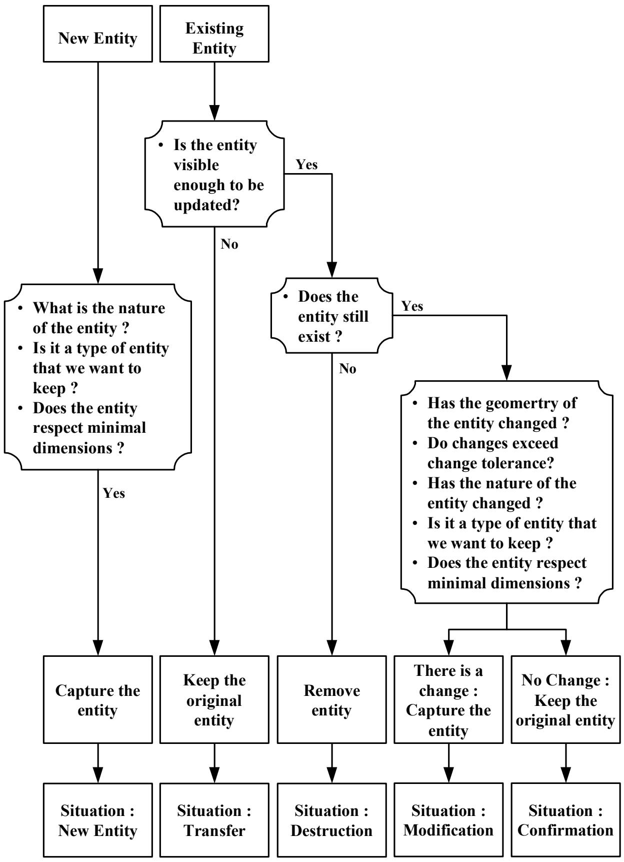
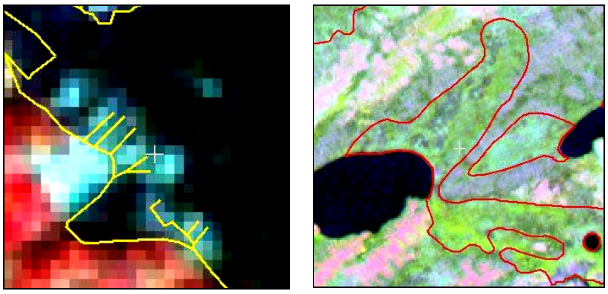


Figure 4: Change detection decision tree.

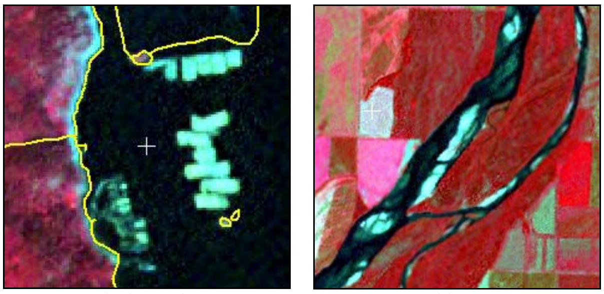
Entity visibility: The evaluation of the visibility of an entity may seem easy but the difference between an entity that has disappeared and an entity that is not visible can be difficult, specially for entities like wetlands. An entity may not be visible and still continue to exist. The first decision to make is therefore to decide if the entity is visible enough to be updated. Non-visible entities are preserved as they were in the old data set and information indicating that they were not updated is registered (Transfer situation).



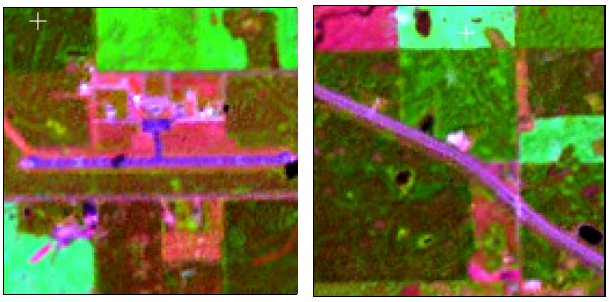
Wharfs Wetlands

Figure 5: Example of non-visible entities. Entities are too small or do not contrast enough with the surroundings to be updated

Entity nature: Entity nature, or identification, determines if a visible entity should or should not be mapped. Identification of an entity does not rely uniquely on its composition but also on its utilisation. Some entities, like roads, should not be mapped although similar entities like runways should. Sometimes, entity nature can only be deducted for the surrounding context.



Timber rafts Sand in water



Runway Road

Figure 6: Examples where the surrounding context is necessary to identify an entity

Change versus entity nature: If the entity visible on the image has been geometrically modified compared to the original data set, a decision has to be taken whether or not the change should be mapped. For example, lakes are shown on topographic maps with their normal water level. Half-drained lakes or inundation should not be mapped if those water levels are only temporary. The normal water level may not have changed.

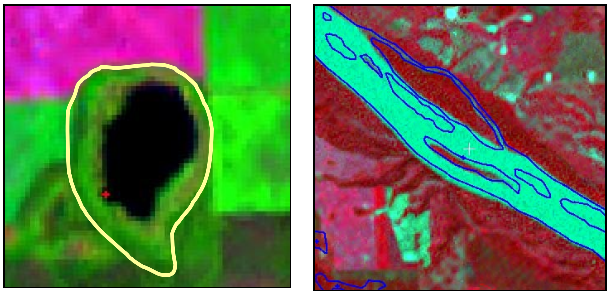
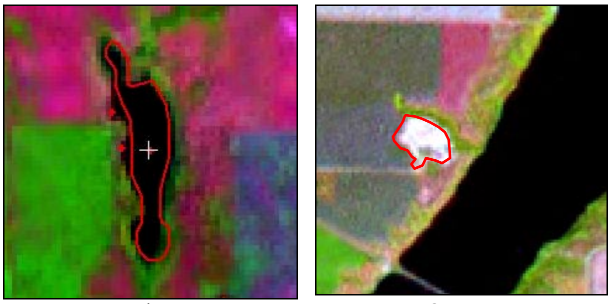


Figure 7: Temporary draining and inundation

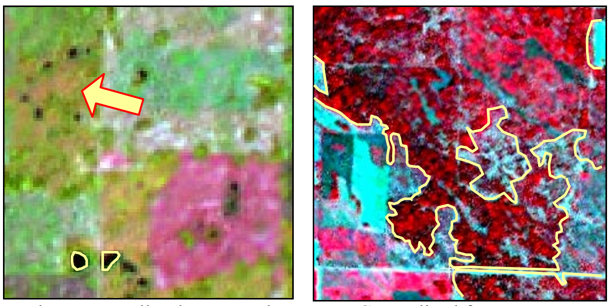
Change versus change tolerances: The extents of the visible change also need to be evaluated against change tolerances. A change that is under the change tolerances is not considered significant and should not be mapped. The use of change tolerances gives more control on the change detection process, as only significant changes are mapped. The change tolerances have been defined to fit the Landsat-7 resolution and vary according to entity visibility.



Lake Quarry

Figure 8: Are those changes significant enough to be mapped?

Minimal dimensions: The extent of the entities should also be evaluated according to the 1:50000 scale needs. Some small entities will not be mapped and others will be generalised. A river too narrow to be represented as a surface should for example be mapped as a line. Sparse forest entities could be represented as one big forest if the clearings between them are too small.



Lakes too small to be mapped Generalised forest area

Figure 9: Examples where minimal dimensions affect mapping

Metadata: The change detection process leads to different situations: destruction of entities, confirmation, modification, transfer or new mapping. Each of those situations comes from decisions taken while going over the decision tree. They lead to different information on the entity: its precision, its validity, or its historic evolution. All this information should be registered as metadata. Therefore, for every entity, the right metadata have to be identified and saved.

5. PRODUCTION

The objective of the updating process is to obtain an up-to-date mapping coverage. In order to do so, a change detection approach based on existing topographic data sets was chosen over creating a completely new cartography. The chosen change detection process implies that the evolution of every entity is studied and preserved. This evolution is deducted from decisions taken while going through a decision tree.

There are different ways to update data. Traditional methods like classification, filtering, vectoring, are some of those methods. Used with GIS systems, they could give interesting automated results for specific usage. However, given the constraints of a national coverage using existing data, it was shown that it is very difficult to automate the topographic map updating process. The nature of the entities to map was too difficult to discriminate by an automated method. Given the various constraints listed above (image heterogeneity, territory size, production rate, and definition of entities) and the complexity of the decision process, visual inspection had to be partly maintained as it is the only method that enables us to update the data adequately. As the process could no be completely automated, the updating work was given to private companies. Companies are free to use the method they prefer to conduct the map updating.

CIT responsibility is brought down to inspection of the results. The inspection process is faster and simpler but implies that the same decision tree is used for quality control. Some decisions can be automated, like those referring to minimal dimensions and generalisation. The rest of the decisions could not be automated with satisfactory results. For instance identifying the nature of an entity depends on the image but also on the context. As for today, minimal dimension, generalisation and image preparation process have been automated. Work is still done to automate other inspection process like the automatic identification of the metadata.

5.1. Resulting data

The production process for correcting and updating began in June 2001; 200 maps were updated during fiscal 2001-2002. These maps represent 17 Landsat-7 images. In the years to come, the production rate should accelerate to attain an objective of more than 1000 maps per year. Planimetric correction of the data is also proceeding; 350 were corrected during fiscal 2001-2002 and nearly 1500 maps will be during the next fiscal year.

Canadian topographic data with enhanced accuracy will be distributed to users as accurate data and correction matrices. The updated maps will be used and distributed as a new product.

6. CONCLUSIONS

The purpose of this article was to present a production project using Landsat-7 images and the operational constraints involved in implementing practical applications on a large scale.

Updating data for territory covering more than 9 900 000 km^2 involves interpreting more than 700 images and represents a colossal challenge. The change detection process and the project's operational constraints, such as production rate, image heterogeneity, absence of recent ground truth, and territory size, obliged us to use methods partly based on visual interpretation. The change detection process of topographic data is too complicated to be totally automated. Existing automated process and remote sensing tools may help human operators but still can't replace them on a functional basis.

As for today, the results are satisfactory. Nevertheless, the objective is still to replace visual interpretation to the degree possible by automated methods, subject to the operational constraints mentioned above, which would reduce or eliminate the use of human interpretation and enhance the quality and homogeneity of the results.

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