Time-series change detection approach for flood modelling

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Abstract: A remote sensing approach for flood mitigation is presented. Landsat TM satellite imagery and digital topographic sheets were the main datasets for mapping a section of the Qu'Appelle River, located in Southern Saskatchewan, Canada. Three time-series change detection images for periods between 1988–1992, 1992–2000 and 1988–2000 demonstrate that Landsat satellite data are efficient multi-temporal and multi-spectral media for the characterisation and analysis of floodplains. Our results allowed for mapping of changes in the Qu'Appelle River floodplain. Remote sensing technologies are effective, fast and economical tools for the mapping and visualisation of the spatial extent for flood mitigation models, especially for this section of the Qu'Appelle River.

Keywords: flood; mitigation; Landsat; change detection.

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1 Introduction

Remote sensing data sources are useful for their accessibility in terms of costs and time of acquisition. Digital capture of these data has an additional advantage in environmental applications that cover large areas of terrain. RS data sources can detect a larger portion of the electromagnetic spectrum than human senses can; such data sources provide a spectral resolution capability that permits comprehensive analysis. Remote sensing data sources are used to measure and monitor physical characteristics and human activities on the earth's surface. RS has become increasingly important in environmental modelling. However, current applications of RS to the planning, design and operation of water resources systems falls far below potential (Schultz, 1997).

Change detection is the process of identifying differences in an object's state by comparing observations at different times (Singh, 1986). Four major aspects of change detection are important when monitoring natural resources:

1 detecting that changes have occurred

2 identifying the nature of the change

3 measuring the aerial extent of the change

4 assessing the spatial pattern of the change (Brothers and Fish, 1978; Malila, 1980; Singh, 1986; Macleod, 1994).

New methods to delineate watershed and extract topographic, topologic and hydrologic information from satellite imageries have been adopted by many researchers for conducting watershed analysis. Wildgen (2001) states that Landsat imageries are reliable media for large scale change detection.

2 Methodology

The present methodology attempts to chart the final floodplain of a section of the Qu'Appelle River in the year 2000 and attempts to identify changes in the stream channel between 1988 and 2000. Figure 1 outlines the RS process, from:

1 image georeferencing or rectification to assign an accurate real world coordinate system followed by

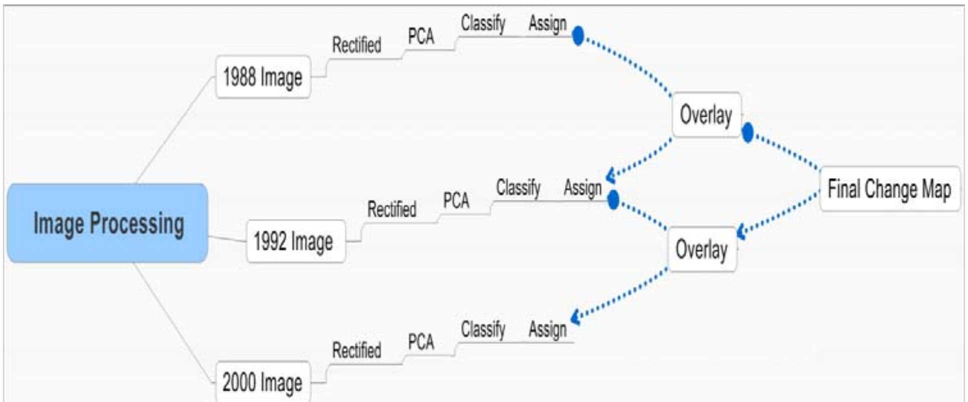
2 the assembling of different satellite bands into a multi-band image

3 classification

4 derivation of the final change-detection image.

The analysis involved image processing, rectification, classification and differencing. The aim was to determine the final shape of the Qu'Appelle River floodplain.

Figure 1 Image processing methodology (see online version for colours)



2.1 Georeferencing

This process consists of two steps: first, image registration where links are established and an affine transformation computed and second image rectification, where the image is further transformed and resampled. During image registration, the software draws links between the reference image or map and the row dataset. Four links can be enough to georeference an image. More links can be created to obtain better alignment. In the present example, Landsat images are georeferenced to an IKONOS image that covers part of the area.

Datasets are georeferenced to the reference image IKONOS-2000 Plate 1, so that the same pixel in one image has a correspondence in the other imagery (Townshend et al., 1992). The registration for each image was performed by nearest neighbourhood resampling algorithms. Nearest neighbourhood-resampling algorithms work better with large scale areas, because they link each corrected pixel to its nearest neighbour in image space. All three datasets were registered and rectified to IKONOS-2000 imagery. Root-mean-square errors of fit were between 0.3 to 0.45 pixels. Subsets of the images were obtained before the classification stage, in order to reduce processing time and to enhance the classification process.

2.2 Image classification

Image classification is the process by which spectral signatures are developed for each category in image space. Spatial features are identified by way of spectral signatures. Water bodies were easy to classify, particularly Qu'Appelle River spectrum signatures, by means of a digital thematic map from satellite imagery.

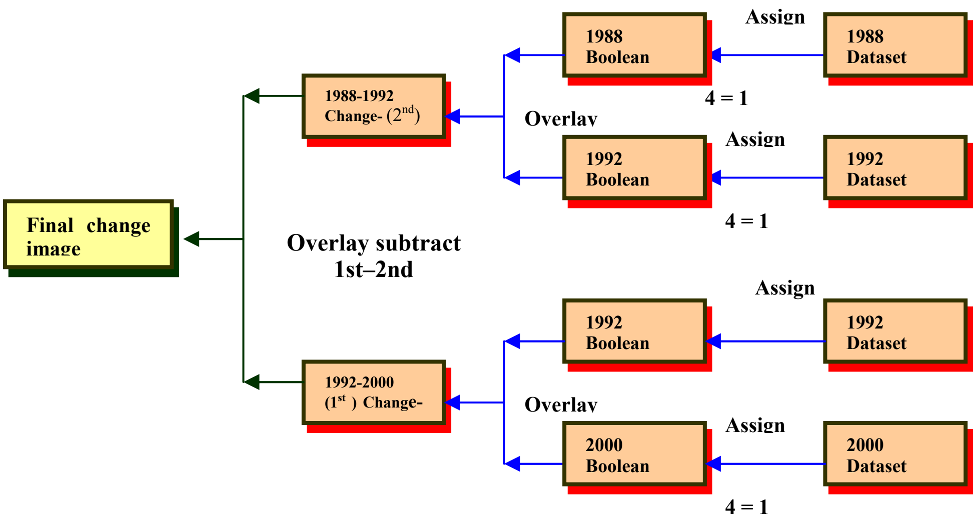
An unsupervised classification step was followed by comparison of the classified image to ground truth. Normally, multi-spectral data is used to perform this classification. The spectral pattern of each pixel is used as the basis for categorisation. Different feature types exhibit different digital numbers (DNs) based on inherent spectral reflectance. Unsupervised classification for the datasets of 1988, 1992 and 2000 was performed after compilation, rectification and the creation of data subsets. The product was an image that is classified by the spectral grouping of each pixel. The Isoclass type of unsupervised classification was selected; Isoclass unsupervised classification is based on the similarity of the digital numbers of each class (Lillesand, 1998). Ten classes of isoclass clustering have been specified, because the land cover of the area is limited. Therefore, ten classes should suit all major classes as well as the feature of interest (the stream channel). Each pixel in the data set is assigned a value between one and ten. Isoclass clustering uses predefined parameters to identify cluster locations in data space. It then determines whether or not individual pixels are in those clusters. This tells the processor to cluster the image data into ten spectral clusters. When the process was complete the output was displayed as a single-band data set.

Supervised classification has two major steps: first training area selection and then a classification step. These two steps categorise all the pixels of an image into land-cover classes or themes (e.g., water bodies, forest types etc.). Image pixels are assigned to particular classes or themes based on statistical characteristics of pixel brightness values (BVs). This supervised classification used maximum likelihood algorithm with a total of five training areas. A maximum likelihood classifier was chosen: this classifier evaluates both the variance and covariance of category spectral responses (Lillesand, 1998). This makes the maximum likelihood classifier suitable for general features, as wanted since the feature of interest is very clear. The process of defining training sites is the most crucial and complicated part of supervised classification procedures. Training sites – vector polygons that define an area of interest – were selected carefully to avoid areas that are of similar spectral signature but which are of different categories. Good representation of the sample area was a factor in selection of the training sites. A minimum number of 25 pixels were used in selecting these categories. Following this, it was verified that each region polygon had a text label before statistical analysis was performed for supervised classification.

2.3 Image differencing

This type of analysis is known as image subtraction. It is performed to identify changes between images collected on different dates. Two georeferenced images are used; the pixel (brightness) values of one image are subtracted from the pixel values of another. The resulting image is scaled by adding a constant to give the output image suitable pixel values. The images were transformed into Boolean images. A value of one was assigned to the floodplain and a value of zero to all other image components. By applying an overlay subtraction between the first image and the second image, changes were detected between 1988 and 1992 and between 1992 and 2000. For a period of the study (as shown by the cartographic model in Figure 1) this image differencing shows the pixels that have changed between time periods. The processes of image differencing are graphically illustrated in Figure 2.

Figure 2 Image differencing (see online version for colours)



2.4 Principal component analysis (PCA)

PCA is a technique that is used to reduce or remove redundancy in multi-spectral data. It is a process of inter-band correlation. Images generated by digital data from various wavelength bands can appear similar, conveying more or less the same information. PCA can be applied before or after classification. The purpose is to compress the information from the original channel into new channels. The new components are used in place of the original data. This could be simply a linear combination of the data values (Lillesand, 1998). PCA can be performed on black and white images, or any three-component image that may be combined in a colour composite. PCA is appropriate where little prior information exists concerning the area. The three bands of the 1988, 1992 and 2000 images were combined to create principal component images. This technique was applied here to remove sensor redundancy and to combine the image bands into one band. Post classification change detection technique, is a technique by which each image was classified separately using both supervised and unsupervised techniques. The three images were then compared to create an image change map.

2.5 Accuracy assessment

It is difficult to derive information about an object using measurements made with a sensor that is not in direct contact. The art of acquiring good remote sensing data for this task depended on the nature and interactions of radiation from a source with object surfaces, with the atmosphere and the sensor itself. Information extraction is central to remote sensing analysis in general. Environmental remote sensing aims to obtain information about properties of objects on the earth's surface and in the atmosphere. The most common approach is to use data from sensors, which record the reflected or emitted electromagnetic radiation. Therefore remote sensing is concerned with monitoring change and with providing clear, easy to use data for spatial models.

3 Study area

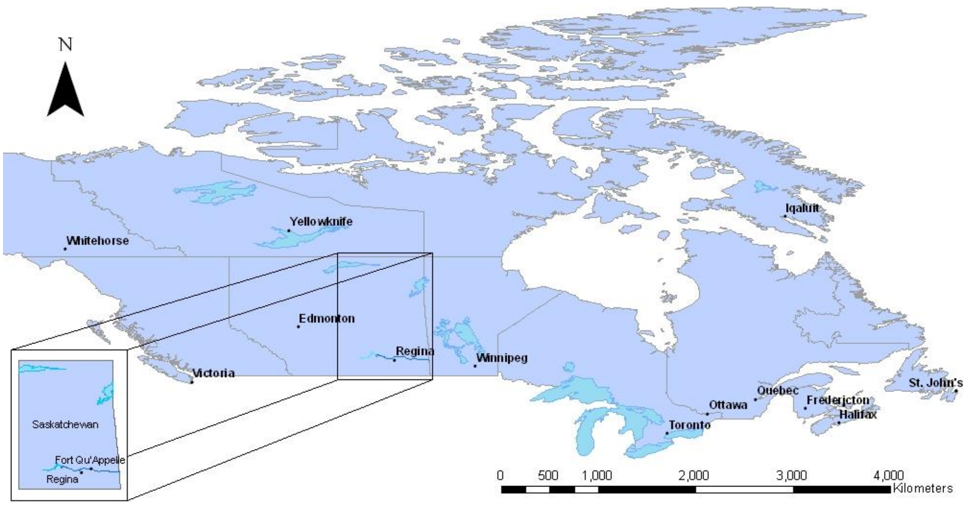
The Qu'Appelle River is of importance, because there are major metropolitan centres located close to the portion represented by the study area. This underlines the importance of monitoring changes in the river and of simulating flooding scenarios. The study area is a 30 km section of the Qu'Appelle River. The Qu'Appelle River is 430 km long, arising northwest of Moose Jaw (South Saskatchewan), flowing east through Buffalo Pound Lake and Fishing Lakes, then past Fort Qu'Appelle to the Assiniboine River (just over the Manitoba border). The section used for this study is part of a huge watershed system. The section is located within NTS 62L11 (as shown in Figure 3, the map of Canada). The Qu'Appelle Valley is deeply entrenched in the Assiniboine River Plains, with an elevation of close to 470 meters. The Indian Head Plain is a subdivision that is an undulating shallow lacustrine area, cut by creeks draining to the Qu'Appelle Valley.

3.1 Datasets

It is crucial to determine which types of data are required for remote sensing models. In most cases, this represents a wish list. For the present research, the first question was the form of the data. Is it enough to use simple vector data for drawing maps, or is a complete dataset needed? It was not an easy task to find the right data for this project, since digital data in Saskatchewan are controlled through a single vendor: Indian Head Research Agricultural Foundation or IHRAF. This makes it difficult to obtain a large variety of data. The format and coverage details are standardised, which bind detailed types of analysis that fall out of the standardised scale ranges.

IHRAF provided the required satellite imagery. Landsat imagery sets were gathered between July and August for the years 1988, 1992 and 2000. IKONOS one-meter resolution imagery of the year 2000 was used as a reference. The three data sets were acquired in July and August, to provide the most realistic floodplain. Reference data for comparison with Landsat TM classification were one-meter resolution IKONOS imagery. IKONOS is a recent commercial satellite. It was launched in the year 2000 to provide commercial products in form of one-meter panchromatic resolution imagery and four-meter multi-spectral. Other reference data were in the form of 1: 50,000 topographic sheets.

Figure 3 Map of Canada showing the study area (see online version for colours)



4 Results and discussion

The results allowed a mapping of changes in the Qu'Appelle River floodplain. One issue related to data selection and collection was the time span required for this project. It was not an easy task to obtain 14 year-old data. The technology applied for gathering such imagery was also relatively primitive; it was not easy to convert this imagery, or to improve its radiometric resolution (the radiometric resolution is the binary capacity of the pixel).

Remote sensing analytical techniques have contributed considerably to the quality and accuracy of these mapping results. The rationale behind the remote sensing analysis was to reach a quantitative understanding of changes in this section of the Qu'Appelle River and to determine if such changes can be attributed to particular environmental factors. The results of the hybrid classification allowed us to verify the accuracy of the unsupervised classification. The overall assessment confirmed the accuracy of the classification of the Qu'Appelle River. This is mainly due to the clarity of the targeted features. Yet the accuracy would have been lower if complex features were targeted, that is, if it were necessary to distinguish between features of similar spectral signatures. The importance of PCA comes from its ability to combine many bands into one and to correct sensor errors between bands.

Plate 1 Indian head town and surroundings in IKONOS one-meter resolution reference imagery (see online version for colours)

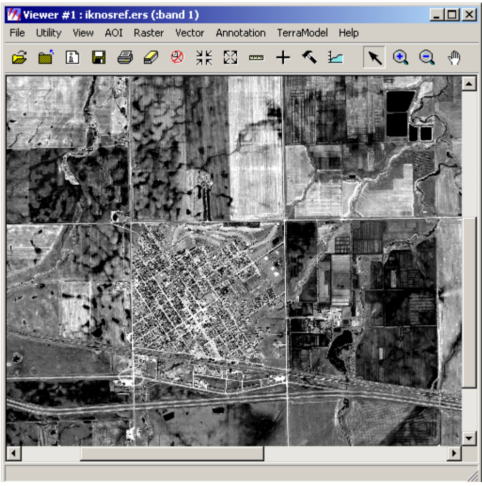


Plate 2 Raw Landsat 7 image of 2000

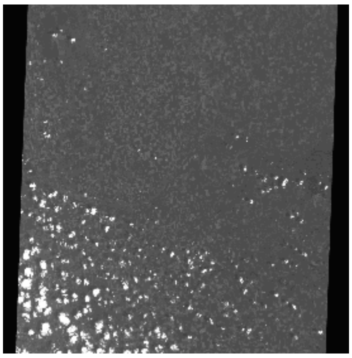
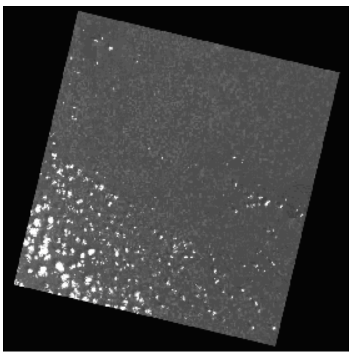


Plate 3 Georefernced Landsat 7 image of 2000



The process of image rectification produced a new image with real-world coordinates (as shown in Plates 2 and 3). This process created an undistorted image, usable as a map in terms of location coordinates. Rectification was performed for Landsat images, which involved identifying real world coordinates for the raster cells of the raw map and filling them with location coordinates. The georeferenced image of Plate 3 was produced from the rectification process of Plate 2.

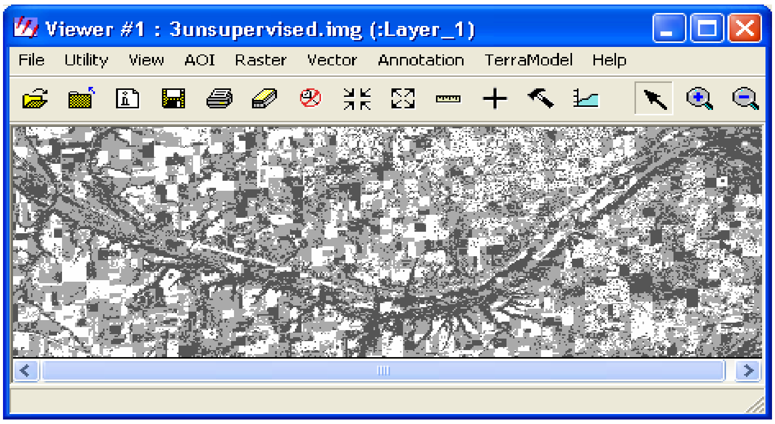
The results of the PCA indicated that the inter-band relation did not muddle image quality. In this effort, PCA was applied as an image enhancement operation. This operation was performed before image classification, to determine if there was obvious sensor redundancy. The results indicate that image quality has not been changed significantly by sensor redundancy. This may be attributed to the clarity of the targeted feature. The process of image classification was continued on the original multi-spectral images. The resulting PCA images are shown in Plates 4 and 5.

Plate 4 PCA of multi-spectral 1992

Plate 5 PCA of multi-spectral 1988

Hybrid classification results produce a better understanding of the Qu'Appelle River floodplain. The results of unsupervised classification (Plate 6) indicate that the software clustering of numbers was close to that of real-world information. However, unsupervised classification results were not important in reaching a quantitative understanding of floodplain characteristics. This is because the floodplain in question has already been mapped. Unsupervised classification is still an effective tool for classification of areas with little or no prior information. Here the objective of performing unsupervised classification was to reach a general idea of clustering, rather than getting detailed results. Ten classes were selected for unsupervised classification.

Plate 6 1988 unsupervised classification image (see online version for colours)



Supervised classification (Plate 7) indicates that the floodplain of the Qu'Appelle River is an easy classification target. Bodies of water are easy to interpret and classify, especially since supervised classification requires prior information about the target area. The other classes of the classification revealed vegetation, bare soil, moisturised soil and bodies of water (Plate 8). It showed that the result of the classification is in agreement with the topographic reference data.

Plate 7 1988 supervised classifications image (see online version for colours)

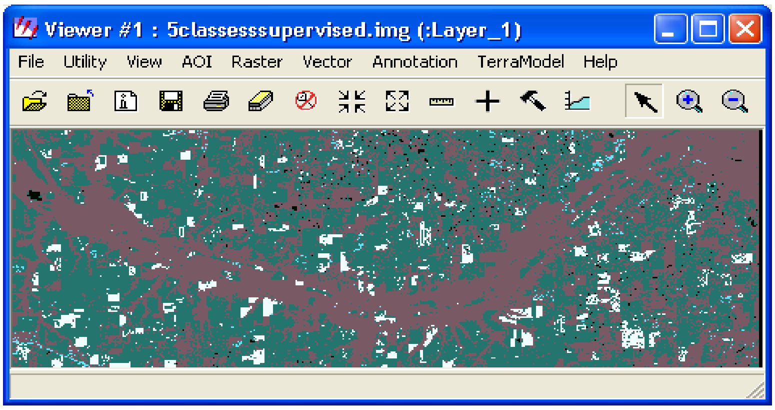


Plate 8 Initially classified Landsat TM of 2000 (see online version for colours)

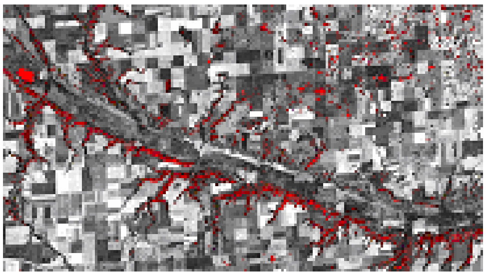


Plate 9 Initially classified Landsat TM of 1992 (see online version for colours)

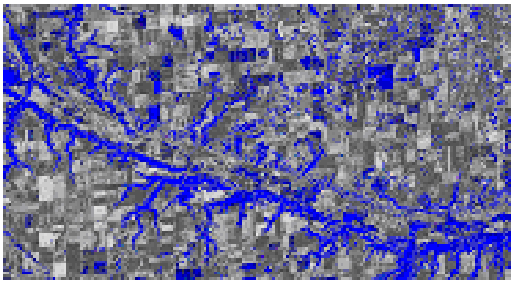
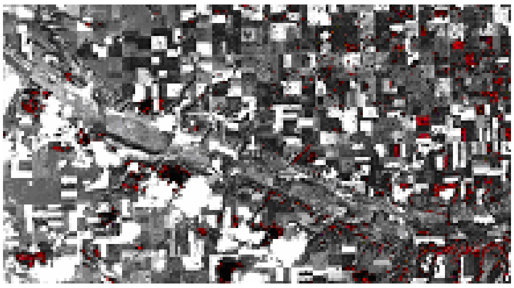


Plate 10 Initially classified Landsat TM of 1988 (see online version for colours)



Change detection analysis showed that there was no change in the Qu'Appelle River channel for the period between 1988 and 2000. The results were obtained directly from the image differencing process for the classified images.

Change detection analysis performed through image differencing showed that this section of the Qu'Appelle River has not changed in the 12-year period covered by the research. The objective of performing classification accuracy assessment was to compare two sources of information: the remote sensing derived map and the test reference information. An error matrix expresses several characteristics of classification performance. The training set pixels are classified into the proper land cover categories, and are located along the major diagonal of the matrix. The accuracy of change detection technique using multi-temporal satellite imageries is mostly provided by means of change detection of sum of errors accumulated from the classification. More importantly, standard accuracy assessment techniques may verify the procedures that have been applied in this study. Classification accuracy was calculated through the statistical analysis of the error matrix and found to be 85%.

Change detection techniques generally depend on classification procedures. However, accuracy might be poor if classification is poor. Then the combination of accuracy assessment procedures can seriously influence outcome. Classification accuracy for all three data sets was obtained using standard, single data and quantitative accuracy. Accuracy assessment techniques for a single date remotely sensed data are reviewed by Congalton (1991). Some issues do remain: How do datasets enable the best representation of change detection?; Can the pattern of change be statistically represented? and, Which change detection techniques are best for particular environmental application? (Macleod, 1994).

5 Conclusions

In summary, this approach described a way of using remote sensing data for floodplain mapping and change detection, specifically to Qu'Appelle River. Floodplain extent was visualised for the geographic section studied. By image processing and rectification, we showed that projecting satellite imagery to real world coordinates can add visual prospectus to imagery. Although the results of change detection analysis showed no significant change in the stream channel between 1992 and 2000, these techniques can still be used for future monitoring studies. These results can also be used in assessment and prediction of flooding scenarios. The present change detection technique can support environmental risk assessment studies of channel alteration, as well as advanced spatial modelling. Such modelling is of special importance in the fields of environmental protection and planning, agriculture, emergency response and preparedness. Results of this research differ from traditional techniques for floodplain characterisation: notably, traditional techniques fail to represent spatial extent fully.

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