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Detecting Wetland Change through Supervised Classification of Landsat Satellite Imagery within the Tunkwa Watershed of British Columbia, Canada

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Abstract

Wetlands are considered to be one of the most valuable natural occurring forms of land cover in the world. Hydrologic regulation, carbon sequestration, and habitat provision for a wide assortment of flora and fauna are just a few of the benefits associated with wetlands. The implementation of satellite remote sensing has been demonstrated to be a reliable approach to monitoring wetlands over time. Unfortunately, a national wetland inventory does not exist for Canada at this time. This study employs a supervised classification method of Landsat satellite imagery between 1976 and 2008 within the Tunkwa watershed, southwest of Kamloops, British Columbia, Canada. Images from 2005 and 2008 were repaired using a gap-filling technique due to do the failure of the scan-line corrector on the Landsat 7 satellite in 2003. Percentage pixel counts for wetlands were compared, and a diminishing trend was identified; approximately 4.8% of wetland coverage loss was recognized. The influence of the expansion of Highland Valley Copper and the forestry industry in the area may be the leading causes of wetland desiccation. This study expresses the feasibility of wetland monitoring using remote sensing and emphasizes the need for future work to compile a Canadian wetland inventory.

Keywords**:** wetlands, remote sensing, Landsat, Tunkwa watershed, land use, supervised classification

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1. Introduction

1.1 Background

Although wetlands only cover roughly 6% of the Earth's land surface, they are considered an immensely important part of the global ecosystem (Töyrä & Pietroniro, 2005; Kashaigili, Mbilinyi, McCartney & Mwanuzi, 2006). Wetlands are often described as land that shares a boundary between bodies of water and terrestrial zones (Sader, Ahl, & Liou, 1995). A number of different sub-classes of wetlands exist, but each can be defined as an area saturated with water for a duration that is sufficient to sustain various types of hydrologic and biological activities (National Wetlands Working Group, 1997). Wetlands are commonly attributed to high levels of biodiversity, they help regulate watershed hydrology, and they are source of carbon sequestration (Wright & Gallant, 2007). However, environmental researchers in recent decades have detected a trend of diminishment regarding the extent and health of wetland areas. Wetlands have been considered to be one of the most threatened environments in the world (Huang, Wang, Liu & Niu, 2010; World Wildlife Fun, 2000). Western Canadian wetlands have been predicted to potentially suffer between 7 and 47% decrease in future years (Withey & Cornelis van Kooten, 2011). This trend has been linked primarily to direct anthropogenic interaction, such as use for irrigation, or indirect forces, namely climate change (Eppink, van den Bergh & Rietveld, 2004; Hartig, Gornitz, Kolker, Mushacke & Fallon, 2002). Ecological fragmentation is often linked to human development in wetlands, generating a desire for management to establish a reasonable degree of land use that will generate a state of sustainability in these areas (Eppink et al., 2004). Researchers have concluded that land use changes and agricultural expansion are of the main driving factors in the decrease of the extent of riparian zones in wetland areas (Dimitriou & Zacharias, 2009; Jogo & Hassan, 2010). Adjacency to urban centers has proven to be problematic, as these zones are frequently altered for agricultural or urban development purposes.

Depending on the climatic and human impact on some watersheds, wetlands may be at risk of rapid area loss, especially in cases of synergistic interactions from both causes.

As the impacts of climate change and land use practices in the environment have become more abundantly apparent, remote sensing becomes more of a vital tool for the assessment of the well-being of wetlands (Cook, Bolstad, Næsset, Garrigues, Morisette, Nickeson, Davis, 2009). The creation of satellite missions, such as the Landsat program established in 1972 by NASA and the U.S. Geological survey (Wulder, White, Goward, Masek, Irons, Herold, Cohen, Loveland, Woodcock, 2008), have become an essential source of remotely sensed data for decades. Maintaining accurate records of the state of wetlands is crucial in their preservation, and remote sensing technology has proven to be effective in doing so; systematically conducting field studies can be an arduous task. One of the main aspects that can be closely monitored remotely is the overall behaviour of wetlands over time. GIS tools are commonly implemented to measure the certain hydrologic parameters, such as water level, through comparison of remotely sensed data from different dates (Weiss & Crabtree, 2011; Williams & Lyon, 1997). Fairly accurate water levels can be measured using high resolution images as a means of monitoring wetland desiccation. Generation of a number of maps of the same area on a regular basis allows analysts to identify relationships between changes in the terrain over time (Töyrä & Pietroniro, 2005). A wealthy amount of information can be extracted through the comparison of multiple images, and this data can sometimes be extrapolated to predict future changes. Using images from a single date is an ineffective method in highlighting the fluctuations in wetland extent over time; the dynamic nature of wetlands is best monitored using a series of images from different years (Wright & Gallant, 2007). The flexibility of GIS allows the analyst to control the scale of their research, depending on the data available. Remote sensing is complemented by ground analyses in wetland mapping from local to global scales, allowing for wetland inventories to be compiled (Poulin, Davranche, Lefebvre, 2010; Rebelo, Finlayson, Nahabhatla, 2009). The quality and reliability of these inventories expands as the awareness of wetland importance rises, and scientists skilled with GIS software are able to capitalize on the availability of remotely sensed data to maintain comprehensive and dynamic data regarding wetland health.

Unfortunately, a national wetland inventory does not exist for Canada. The availability of wetland data is staggered throughout the provinces and biomes of the country from multiple sources. One of the forerunners in wetland investigation is Sweden. An extensive survey over 25 years resulted in the Swedish national wetland inventory (VMI) (Gunnarsson & Löfroth, 2009). The survey's intent is to educate people on the value of wetlands, so future planning considers the potential impacts on them. Similarly, the U.S. Fish & Wildlife Service, a branch of the United States government, provides their own National Wetlands Inventory (NWI) to the public (U.S. Fish & Wildlife Service). Development of the NWI began in 1975 using single-date colour-infrared aerial photography as well as grayscale photography (Wright & Gallant, 2007). Use of Landsat data was not implemented at this time due to the inability to accurately classify land cover. A similar collective effort and single database has not been accumulated for Canada, likely due to the implausibility of gathering data for a country so immense with such a large amount of wetlands. Canada is estimated to be home to one quarter of the world's wetland ecosystems (Natural Resources Canada; Environment Canada).

However, government branches including Environment Canada and Natural Resources Canada provide some information to the public on a regional scale, most of which are broad facts about Canadian wetlands in general, or monitoring and maintenance efforts for specific wetland programs (Natural Resources Canada; Environment Canada). Third party organizations are often a good source of wetland data; GIS and remotely sensed data and maps that may not be readily available from government sources is gathered and shared by organizations or researchers independent of Environment Canada or Natural Resources Canada. An international organization with a major outlet in Canada is Ducks Unlimited Canada (DUC). This organization is a collaboration of individuals whose primary goal is to preserve waterfowl habitat and implement wetland conservation and restoration programs (Ducks Unlimited Canada). Ducks Unlimited's U.S. branch began using Landsat imagery for wetland mapping in 1979, and a recent initiative outlining steps towards creating a Canadian Wetland Inventory (CWI) using similar methods is described in an article published by DUC entitled "The Need for a Canadian Wetland Inventory" (Reimer, 2009). The development of a CWI is an ongoing operation established in 2002 by DUC, Environment Canada, Canadian Space Agency, and North American Wetlands Council. Wetland mapping has begun using primarily Landsat and RADARSAT imagery, which is considered to be the most cost-effective imagery. A progress map highlighting the status of the wetland inventory is shown in Figure 1. The current lack of wetland information for British Columbia is quite clear. A comprehensive case study performed by DUC and the Nature Conservancy of Canada suggests that the protection of wetlands is beneficial to the overall wealth and well-being of society (Olewiler, 2004). Some examples of the value of wetlands provided in the study are: improving surface and subsurface water quality, decreasing greenhouse gas emissions, improving air quality, and decreasing water treatment costs. Wetlands are also habitats to a wide variety of wildlife, and their diminishment is a threat to these species (Symmetree Consulting Group, 2009). These are just a few of the reasons why the creation of a wetland inventory for preservation purposes would be beneficial to the country.

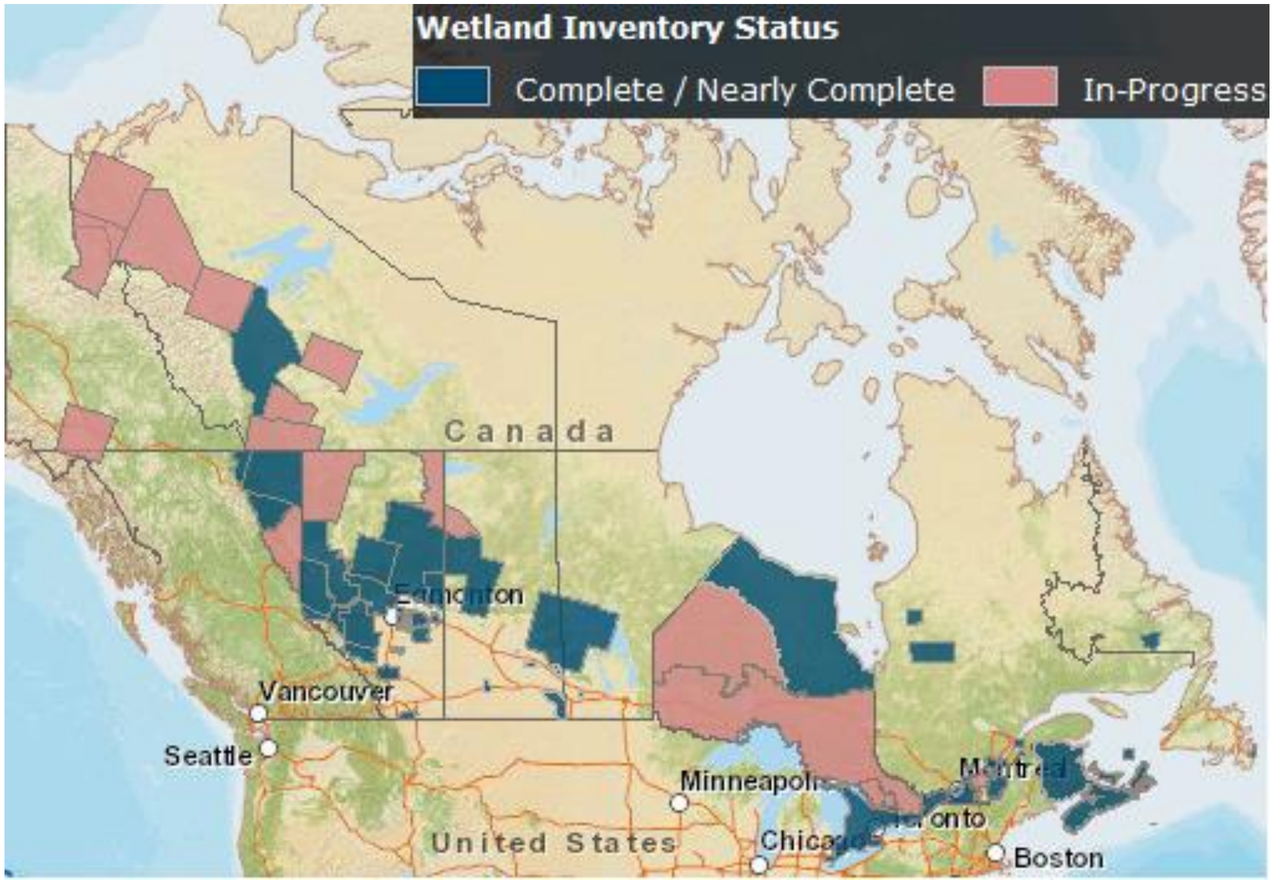

Figure 1: Wetland inventory progress in Canada
Source: http://www.ducks.ca/cwi/

1.2 Study area

Part of the motive in selecting an area for this study stemmed from the lack of progress in mapping wetlands in western Canada. The chosen area is based on findings of Ducks Unlimited's Intermountain Wetland Conservation Project; wetlands within the Tunkwa watershed, southwest of Kamloops, British Columbia, have been identified as degrading environments. This watershed is a portion of the interior of British Columbia, in the Thompson/Okanagan region. The selected area considered in this study includes the watershed's two largest reservoirs, Tunkwa and Leighton Lakes. The extent reaches from northeast of these lakes, to southwest of Highland Valley Copper Mine (Figure 2). All satellite images of the area used in this study were taken during the late spring or summer season.

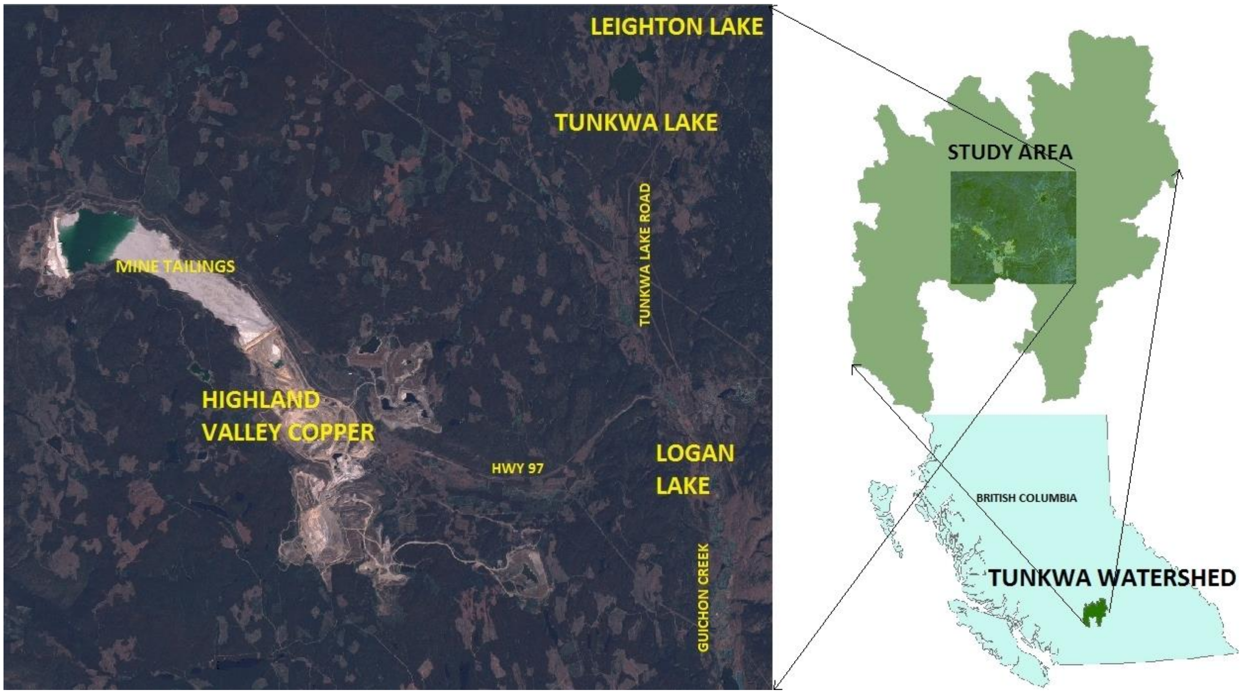

Figure 2: Study area including major landmarks within it

1.3 General scope and aims of study

Using the information available on Canadian wetlands, as well as the literature regarding wetlands and remote sensing as a basis, this study aims to accomplish the following:

- Identify wetlands for a number of different years in the Tunkwa watershed using remote sensing and detect any changes in their extent or existence.
- Correlate changes with nearby land use practices or climate fluctuations over time. The growth of Highland Valley Copper Mine and influence of the forestry sector in the area will be major considerations on the impact of wetland degradation.
- Assess the feasibility and practicality of using remote sensing for this study, determine if gap-filled imagery is useable, and compare Landsat imagery with other data types or methods.
- Suggest potential improvements to similar studies based on the apparent limitations in this one.

Due to the lack of a provincial or national wetland inventory, remotely sensed images become a valuable source for monitoring wetlands, and image classification allows the measurement of changes to be quantified. Studies concerning the recession or loss of different types of wetlands are often based on the analysis of remotely sensed data (Melendez-Pastor, Navarro-Pedreño, Gómez, Koch, 2010). Comparison of multiple images typically yields better results, as evaluation of wetland condition using a single image is not as reliable due to the dynamic nature of wetland environments (Nielsen, Prince, Koeln, 2008). Implementation of remote sensing technology in case studies of land cover change proves to be a rapid and advantageous alternative to the more labour-intensive and time-consuming method of field investigation (Lee, Yeh, 2009; Zomer, Trabucco, Ustin, 2009). Field observations or the use of previously classified land cover data as corroboration for the classification of the study area is common practice in ensuring that classes are being accurately represented (Nielsen et al., 2008; Kashaigili et al., 2006). This study will attempt to showcase the methods employed in the generation of a Canadian wetland inventory for British Columbia. Due to British Columbia's unique terrain, it's possible that the imagery and methodology used for wetland classification in other parts of Canada may not be as suitable.

A major factor in wetland analysis is attempting to determine whether or not degradation of is stemmed from anthropogenic sources, or if it is a result of climate change. It's important to consider criteria that could lead to both scenarios, such as abnormalities in weather patterns or accelerated use of the wetland's groundwater. One indicator that might suggest reduction in wetland size is attributed to land use is the growth in agricultural area over several years (Dimitriou & Zacharias, 2009). Remote sensing and land use classification can be a useful tool for correlating these factors with wetland recession by simply comparing climate data or land use change over time with the extent of wetlands. However, it may be dangerous to associate correlation with causation; remote sensing may be able to link these phenomena to each other, but may not be the best method in identification of the driving force behind wetland degradation.

2. Methodology

2.1 Materials

The software used for this study existed as two programs: ArcMap 10 and PANCROMA. The latter was employed in this study as a tool for pan-sharpening and gap filling images taken by the Landsat Program. Each image was acquired from the United States Geological Survey's Landsat database from Landsat missions 1, 5, and 7 (U.S. Geological Survey, n.d.). Examples of all raw images retrieved from the Landsat archive can be found in Appendix A. Image processing in PANCROMA was preparatory, and processed maps were subsequently imported into ArcMap for final analyses. All processes were performed in a raster environment with the exception of vector data used for defining the study area. ArcMap's Image Classification toolbar was used for classification purposes.

2.2 Defining an Image Classification

Image classification is the process of automatically categorizing every pixel in a raster environment based on their individual spectral reflectance. There are two approaches to the classification process: supervised and unsupervised. The latter automatically groups cells into clusters based on the statistics of their digital numbers (DNs), which are representative of each pixels intensity value (Lillesand, Kiefer, Chipman, 2004, p. 551). This process requires minimal user input; aside from selection of preferred number of classes, the unsupervised classification method is entirely automated. In a supervised classification, the user manually controls the inputs, allowing the user's knowledge to influence the results.

A supervised classification process was selected for this study. It was executed by digitizing individual training sites for each year's satellite image. Determination of appropriate classes for the area was extrapolated from a year 2000 land use layer provided by GeoBase. This layer acted as a surrogate for on-site investigation. This method allows for monitoring of wetland characteristics without experiencing the difficulties associated with attempting to reach wetlands in the field; encounters with dangerous wildlife and areas with unfavourable navigability prove difficult for the researcher (Zomer et al., 2009). The ability to classify wetlands and the vegetation within them remotely over several years eliminates these drawbacks by providing a practical alternative. Running each classification generates pixel counts for each class, which allows for comparison between each year.

2.3 PANCROMA

PANCROMA is a valuable software application for the manipulation of Landsat satellite imagery. One of the software's main features is its ability to sharpen lower resolution bands by adding the panchromatic high-resolution band (Childs, 2011a). Pan-sharpening is a technique that employs the fusion of data from the lower resolution multispectral bands and the higher resolution panchromatic band (Garzelli, Nencini, 2007). PANCROMA allows for the creation of higher resolution images with this process. Images provided by Landsat for some years include these appropriate bands that allow images to be reduced to 15 m resolution from 30 m resolution.

A second use of PANCROMA that was essential for this study was the gap filling function. A permanent failure of the scan-line corrector (SLC) on the Landsat 7 satellite on May 31st of 2003 rendered all subsequent images taken by the satellite void of approximately 20% of the pixels in the entire coverage (Pringle, Schmidt, Muir, 2009). Figure 3 illustrates the difference in scanning before and after the fault. Due to the significant data loss in each SLC-off scene, gap filling techniques have emerged to mend the images. The gap filling process used in this study combines the data from an image taken in 2001 by the Landsat 7 satellite with interpolated values derived from pixel brightness in both the 2001 image and the gapped image. These gap-filled images were subsequently pan-sharpened and the resulting rasters of the study area appeared quite seamless.

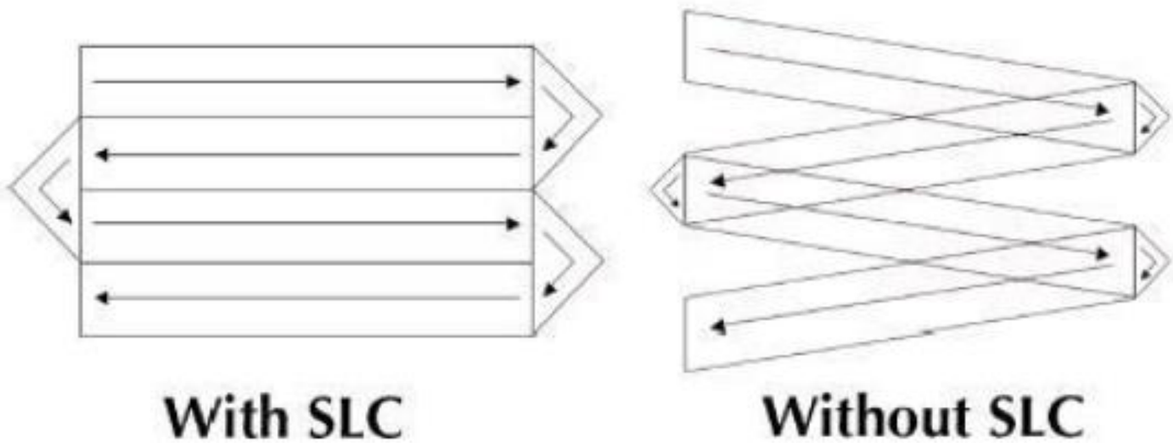

Figure 3: Diagram explaining the different scan pattern after the SLC failure
Source: PANCROMA user's manual (Childs, 2011a).

2.3.1 Gap Filling

The procedure to fill the gaps in the SLC-off images requires both a reference and an adjust image. The reference image refers to a SLC-off image with gaps, while the adjust image is a SLC-on image taken before May 31st, 2003. The 2001 adjust image is shown in Figure 4, and an example of one of the two reference images used is shown in Figure 5. Each image is zoomed to the study area for clarity; the extent of each Landsat image in its entirety can be seen in Appendix A.

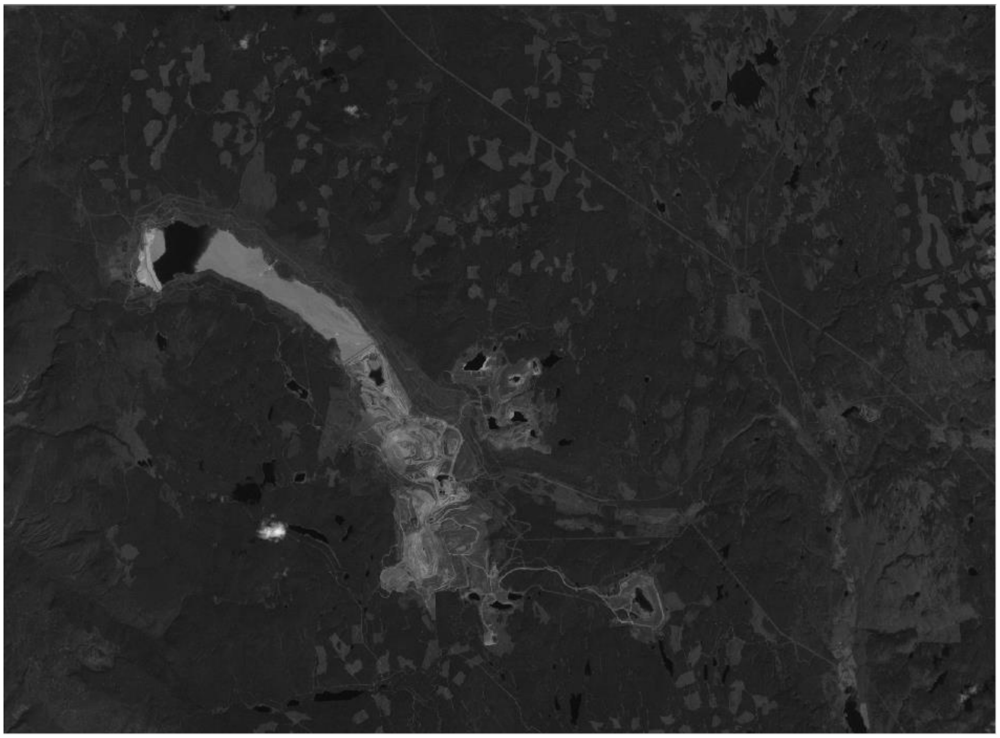

Figure 4: 2001 panchromatic band, one of many individual bands used to repair the gapped images

Figure 5: 2008 panchromatic band, showing the gaps present in all Landsat 7 images after May 31st, 2003

PANCROMA requires only the blue, green, and red multispectral bands for gap-filling, but the process employed in this study utilizes the near infrared (NIR) and panchromatic bands in order to pan-sharpen the image after being filled. Each of the five images for each band of the reference image was subset into smaller images, effectively eliminating the area beyond the extent of the study area. The same process was then implemented for each band of the adjust image. For the gap-filling procedure to perform correctly, the software demands that each pair of matching bands from the two images have identical corner coordinates and row and column sizes. Each of the red, blue, green, and NIR pairs was resized to 1515 x 1236 columns and rows, respectively. The pair of panchromatic bands was then resized to 3030 x 2472 columns and rows; these bands require twice as many rows and columns and must perfectly match the other four bands in order for the process to generate a useable product (Childs, 2011a).

With five matching pairs of grayscale images prepared, the gaps in the Landsat 7 images were then filled. This study followed the Hayes Method for filling gaps, which is a preferable to a simple transfer method. The Hayes method considers both the pixel values in the adjust image and the reference image, and estimates appropriate new values based on an interpolation of the raster's cells. Gaps were filled in each image individually by selecting matching bands from the reference and adjust images and running the algorithm. Interpolation parameters were fixed for each set of bands as any differences would result in problems when creating an RGB image. Parameters were tweaked slightly from the default settings based on a number of trial runs. Adjustments were made based on the degree of visual congruence the gap-filled image had with the adjust image, as well as the lack of visibility of the gap residue.

2.3.2 Pan-sharpening

Once the references images for each band were repaired, all five bands were simultaneously pan-sharpened and combined to produce a true colour image at 15 m resolution. This entire process was executed for the 2005 (Figure 6) and 2008 (Figure 7) SLC-off images. Pan sharpening was also applied to the 2001 SLC-on image.

Figure 6: True colour pan-sharpened and gap-filled satellite image of the study area for 2005

Figure 7: True colour pan-sharpened and gap-filled satellite image of the study area for 2008

An example highlighting the difference between a gapped and gap-filled image is shown at a zoomed-in scale in Figure 8. A larger scale image highlighting the difference between a sharpened an unsharpened image is shown in Figure 9. The boundaries between land cover types, such as Tunkwa Lake's shoreline, are more clearly defined in the pan-sharpened image.

Figure 8: 2008 gapped image (top) vs. 2008 gap-filled and pan-sharpened image (bottom)

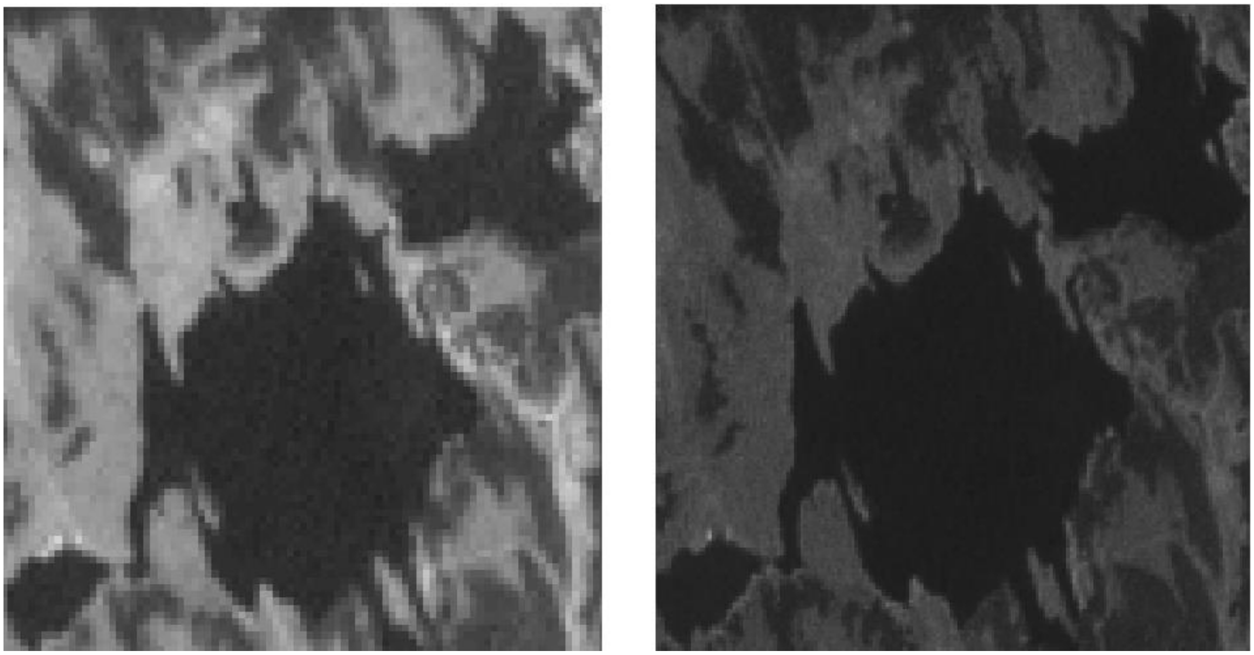

Figure 9: Close shot of Tunkwa lake in grayscale displaying the clarity difference between an unsharpened (left) and pan-sharpened (right) satellite image of 30 m and 15 m resolution, respectively

2.4 Image Classification

2.4.1 Training stage

The image classification process was carried out using ArcMap 10's Image Classification tool. Although the clumping of pixels is performed automatically by the software, the procedure followed in this study required manual input. The quality of these inputs is instrumental in generating an accurate classified image. These inputs existed in the form of training sites, which were polygons digitized within the boundary of several different feature classes. The placement of these polygons was based primarily on the spectral reflectance of pixels as seen in different wavelength band combinations. Some useful combinations of the red, green, and blue bands used during the training stage were 4, 3, 2 (Figure 10) and 4, 1, 4 (Figure 11) for the purposes of visualization and better object determination. The latter was effective in identifying wetlands, while the former was good for digitizing training sites for most of the other features. In addition, the pre-classified land cover layer from 2000 was used to help identify what each feature was in reality. This layer helped differentiate between some pixels of similar reflectance. It also proved useful for comparing land use changes in different years.

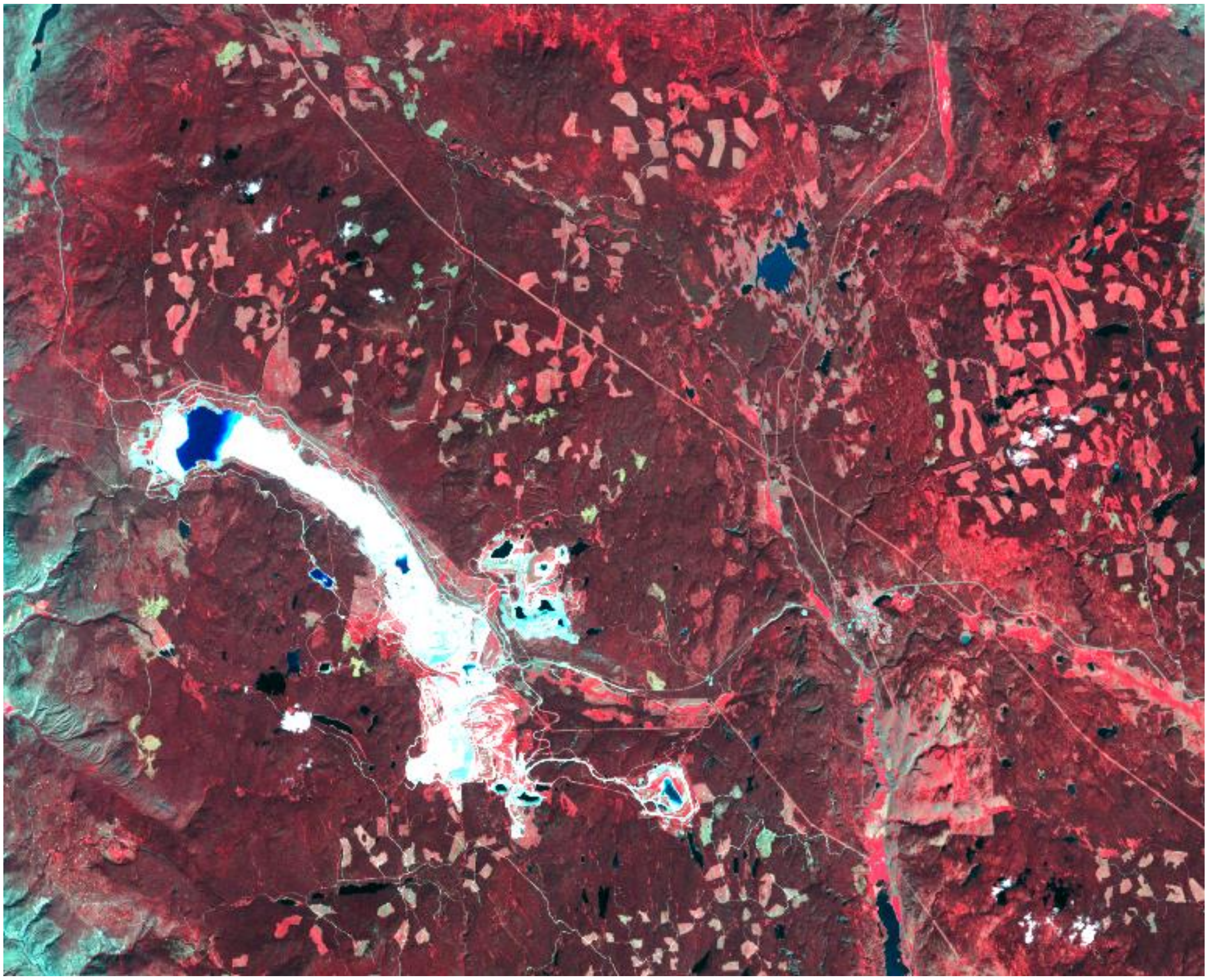

Figure 10: False colour image of 2001 using the Near-infrared band

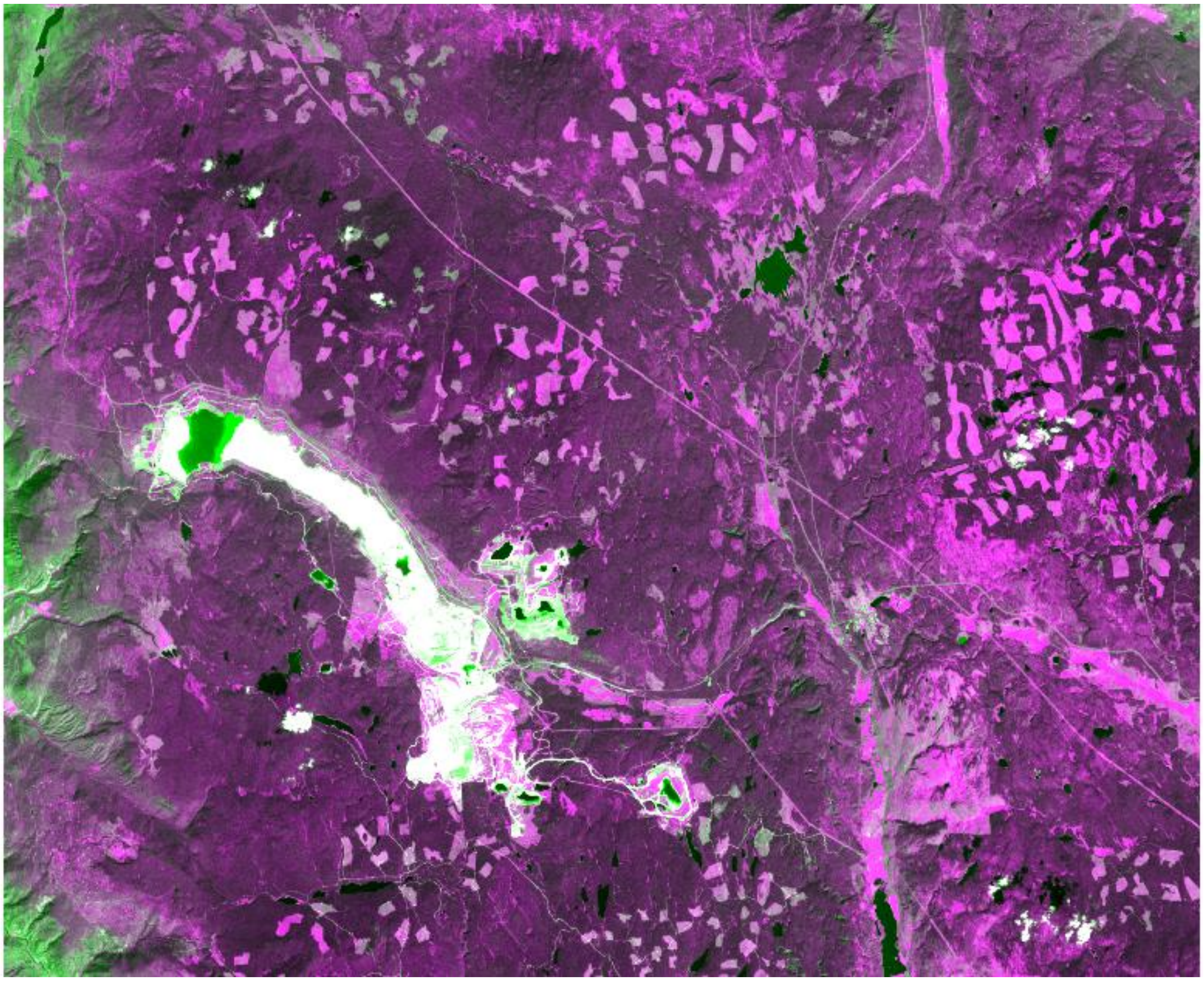

Figure 11: False colour image using a 4, 1, 4 band combination for red, green and blue, respectively. This combination was useful for identifying wetlands.

Although the focus of this study is on the wetlands and associated vegetation, accurate classification of all other features must be separated into their own distinct categories to reduce error in the final pixel counts. An example of the training sites digitized for each feature class is shown in Figure 12. The training process was repeated for each year's image and the training sites digitized for each image was kept relatively consistent in regards to polygon sizing and placement. Several features considered similar were clumped together into the same class.

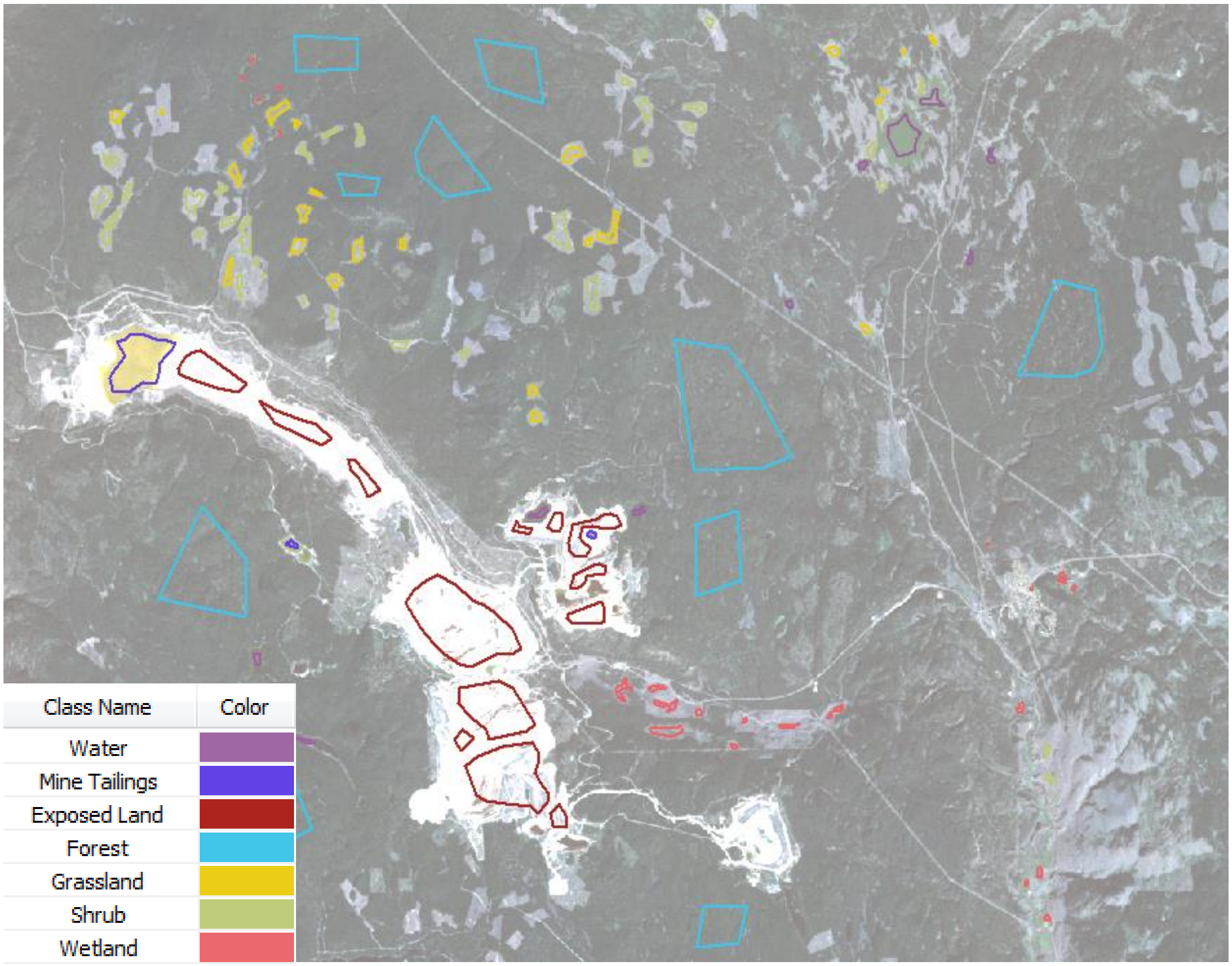

Figure 12: Example of digitized training sites shown atop a transparent 2001 image

2.4.2 Supervised Classification

A Maximum Likelihood classification was executed for each image. This method assumes a normal distribution of DN values, allowing the function to determine the probability of a pixel belonging to a certain feature class and assign each pixel to the highest probability class (Lillesand et al., 2004, p. 552). Classifications were often repeated numerous times after additional training sites were added to achieve satisfactory results. Wetland areas were occasionally classified as grassland, requiring additional polygons to be digitized to properly classify the image.

2.4.3 Post Classification Processing

The classification process often misclassifies pixels in outlying areas that are not an accurate representation of reality; individual or small clusters of pixels that are apparently segregated from other groups of the same class are often misclassified. Cells with DN values that fall midway between two distinct classes may be misclassified, creating a generous amount of noise within the image. Two filters were used to manage these problems. Isolated cells whose class did not match adjacent cells were changed to match the class of the majority of neighbouring cells. This filter adjusted cells with four orthogonal neighbours of another class. The pixels along the boundaries of the resulting layer's classes were then smoothed by expanding and shrinking the pixels, reducing clutter along the boundaries shared by two classes. These post-processing tools were useful for eliminating misclassified pixels regardless of the image's resolution. With filtering complete, each classified image was clipped to the same extent.

2.5 Accuracy Assessment

The accuracy of each classified image was tested by randomly generating a series of points within ArcMap 10, manually identifying the land cover type at each location, and subsequently comparing the land cover with the classified image. 100 points were generated for each image. The resulting accuracies are shown in Table 1.

Table 1: Accuracy assessment results

Year	1976	1990	1995	2001	2005	2008
% accurate	91	85	85	86	82	84

3. Results

The wetlands within the portion of Tunkwa watershed located southwest of Kamloops, British Columbia were identified as receding through comparison of each classification. Each classified, filtered and clipped layer is shown in Figures 13 - 18.

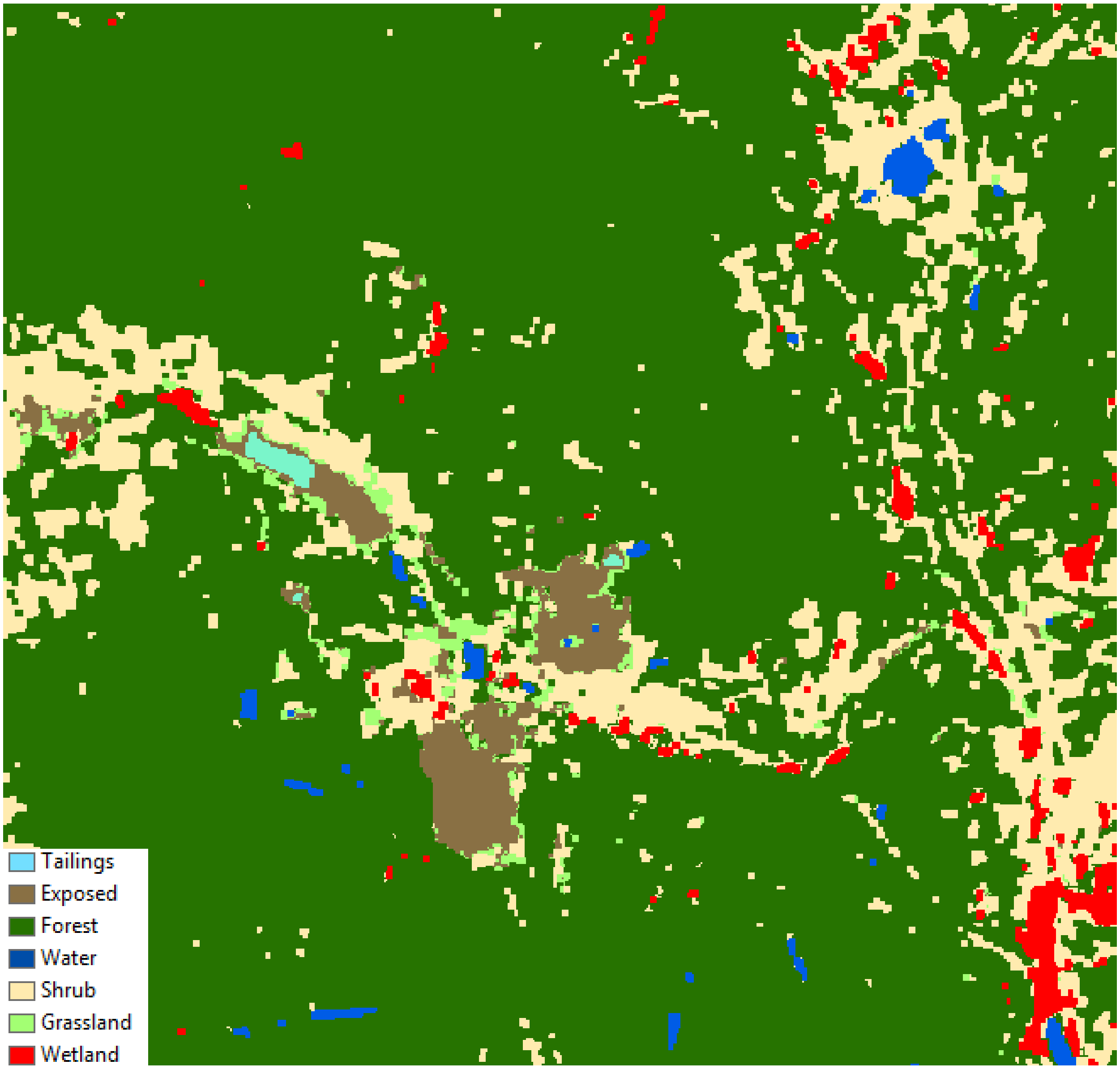

Figure 13: Supervised classification result for 1976

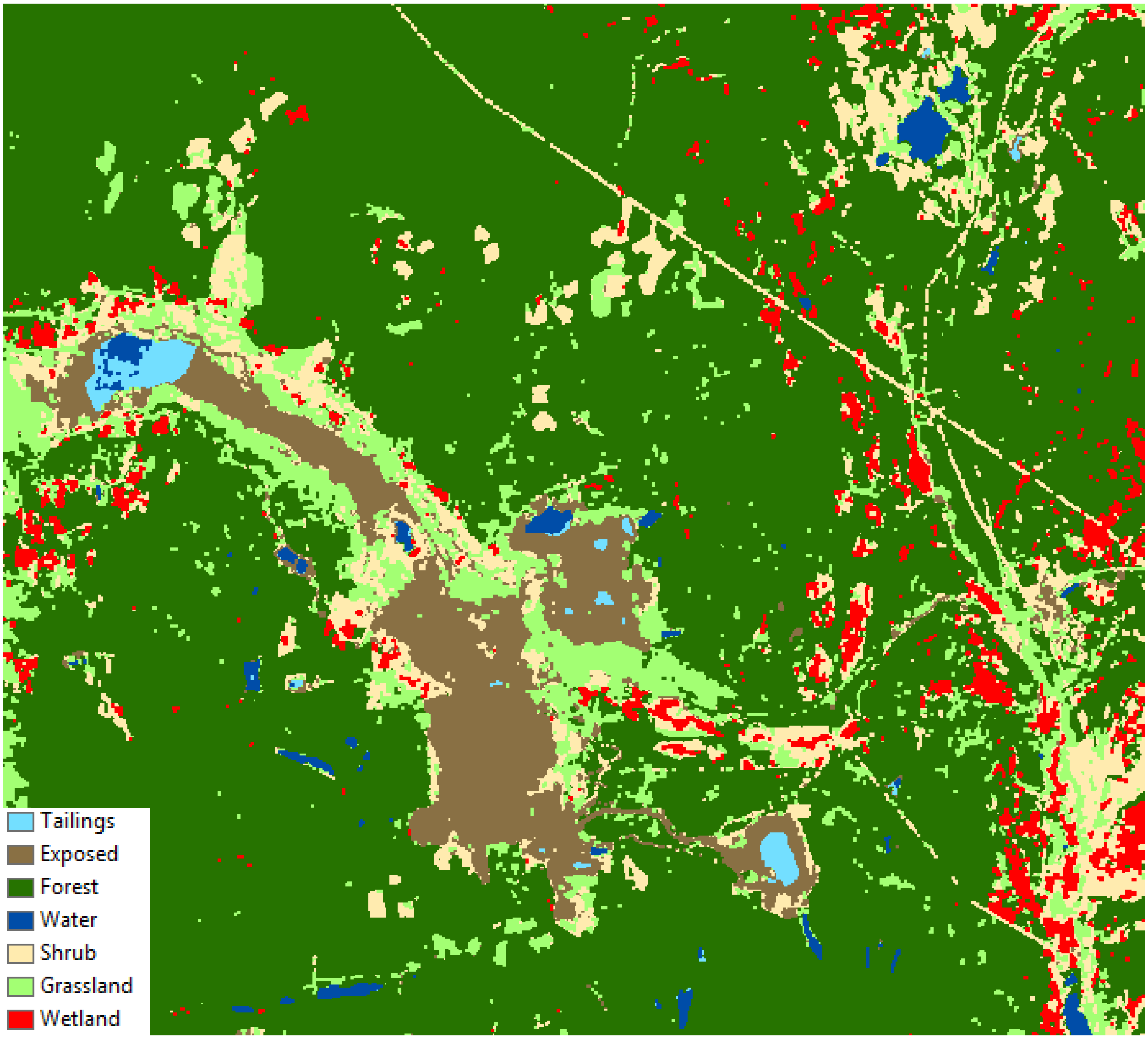

Figure 14: Supervised classification result for 1990

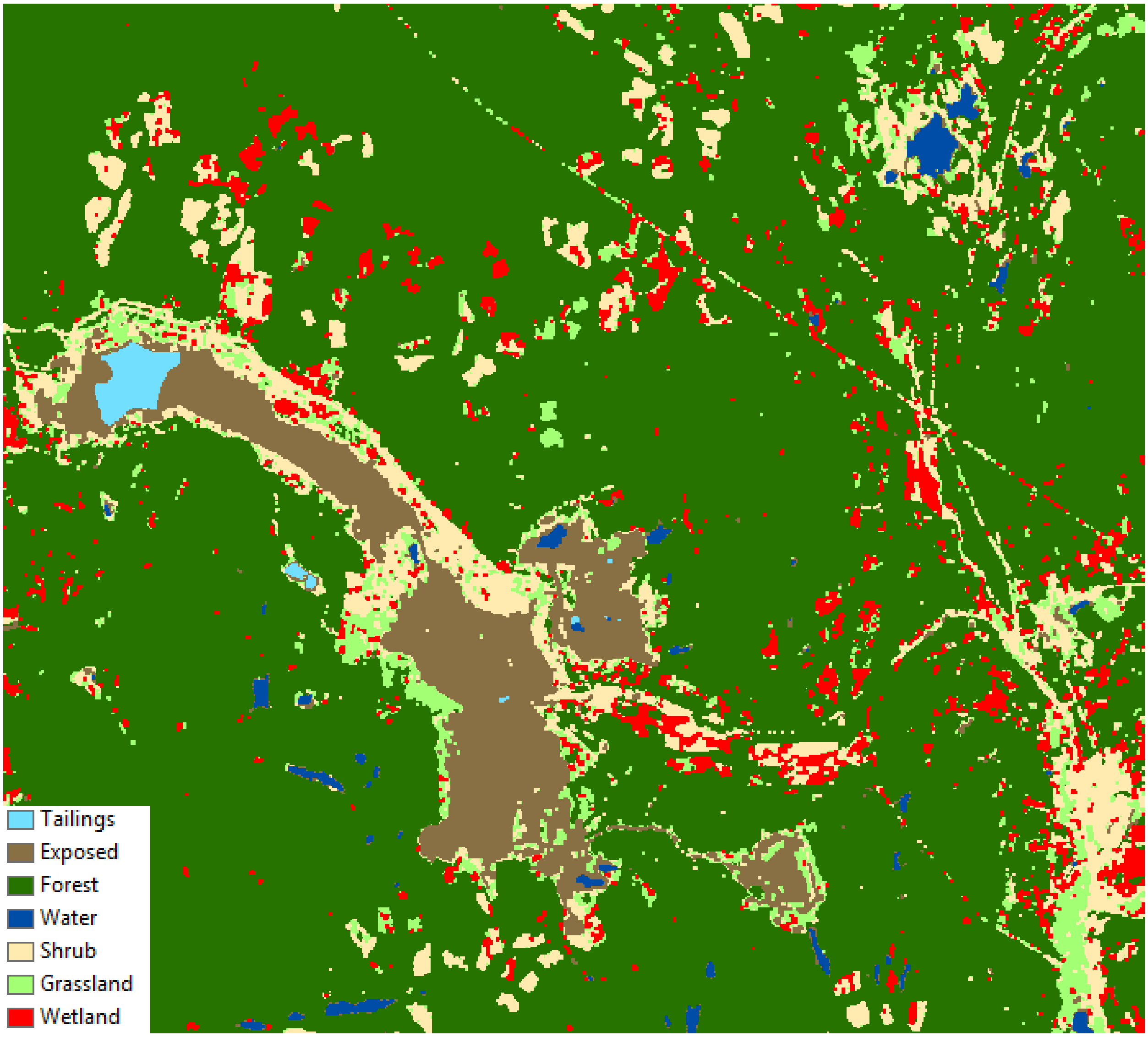

Figure 15: Supervised classification result for 1995

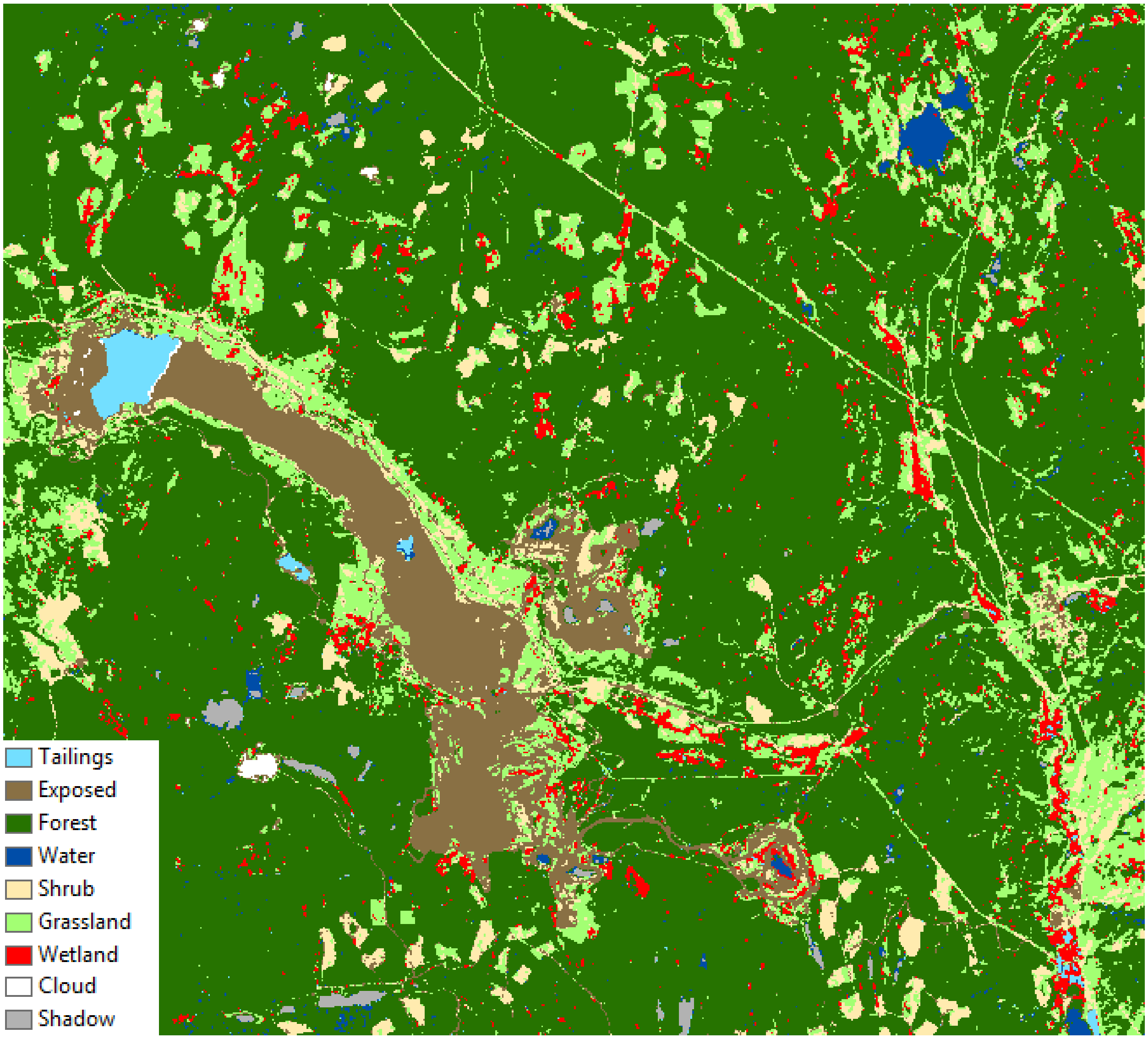

Figure 16: Supervised classification result for 2001

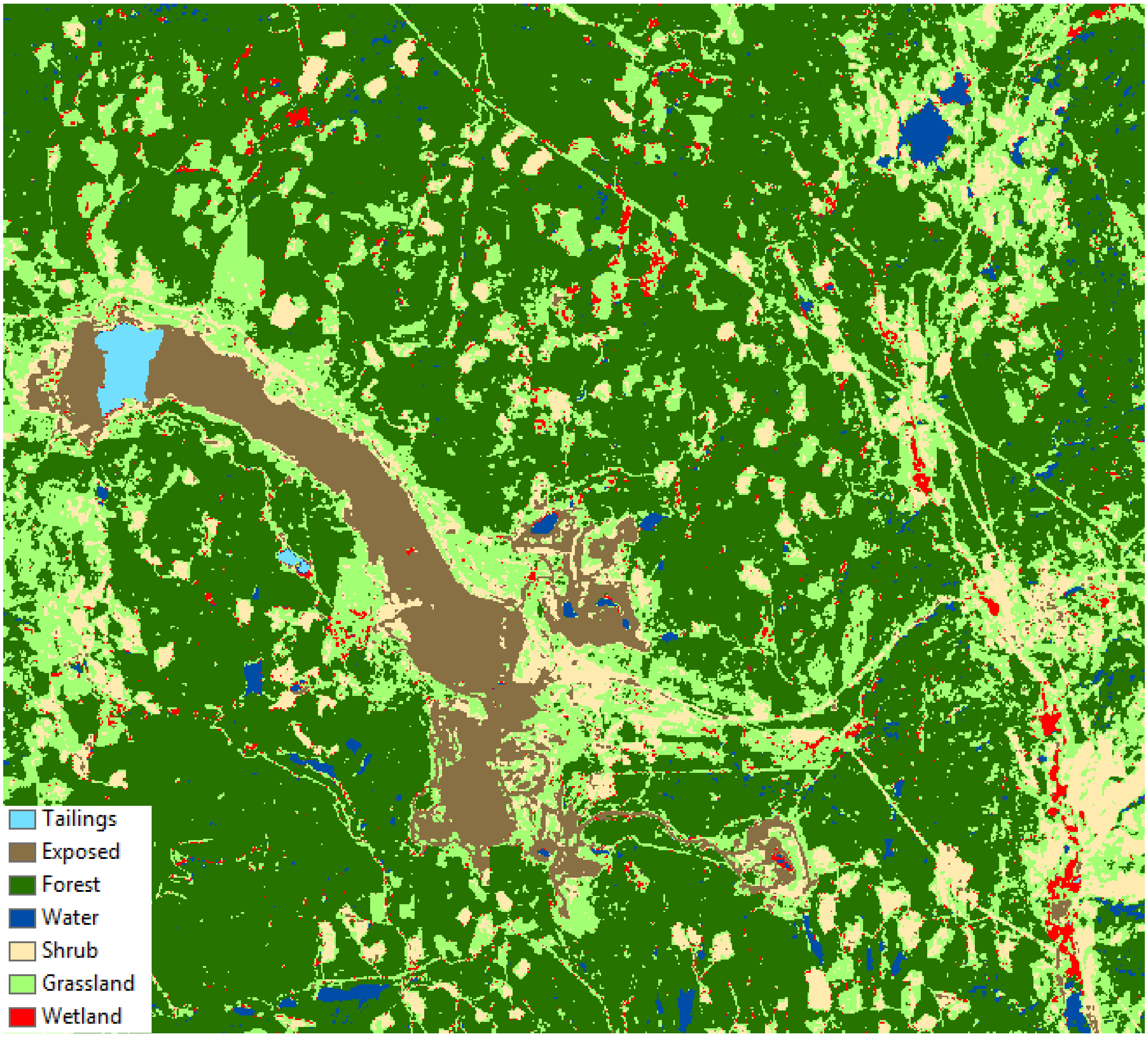

Figure 17: Supervised classification result for 2005

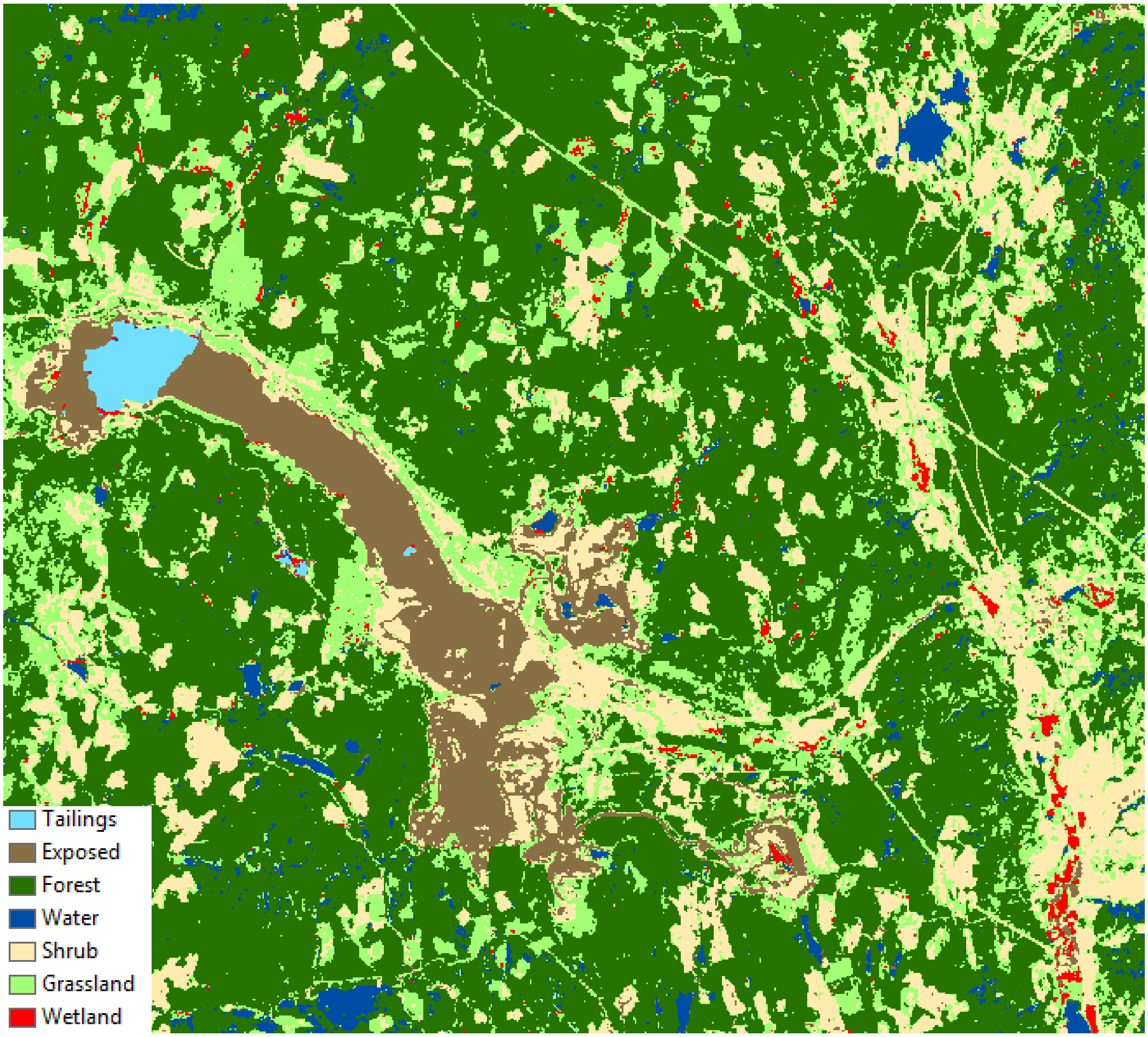

Figure 18: Supervised classification result for 2008

The amount of pixels present for each class was then compared for each year. Due to incongruent pixel sizes for each year, land cover changes for each feature are expressed as a percentage of the total coverage, as opposed to an exact pixel count. Percent coverage values for wetlands for each year are shown in Table 2. Values from 1976 were excluded as the pixel counts were a poor representation of the actual wetlands in the Tunkwa watershed due to their poor resolution. However, the image is a good visual representation of the land cover changes since the image was taken.

Table 2: Wetland coverage percent for each considered year from 1990 to 2008.

Year	1990	1995	2001	2005	2008
Wetland coverage (%)	5.7509	5.0700	3.1798	1.9329	0.9250

A diminishing trend in the extent of the wetlands was identified through comparison of each image. Approximately 4.8% cover loss was recognized in the area. The changes based on the supervised classifications for 1990 and 2008 are shown Figure 19**.** The wetland cells for 2008 are displayed atop the 1990 pixels, highlighting the approximate change over the 18 year period.

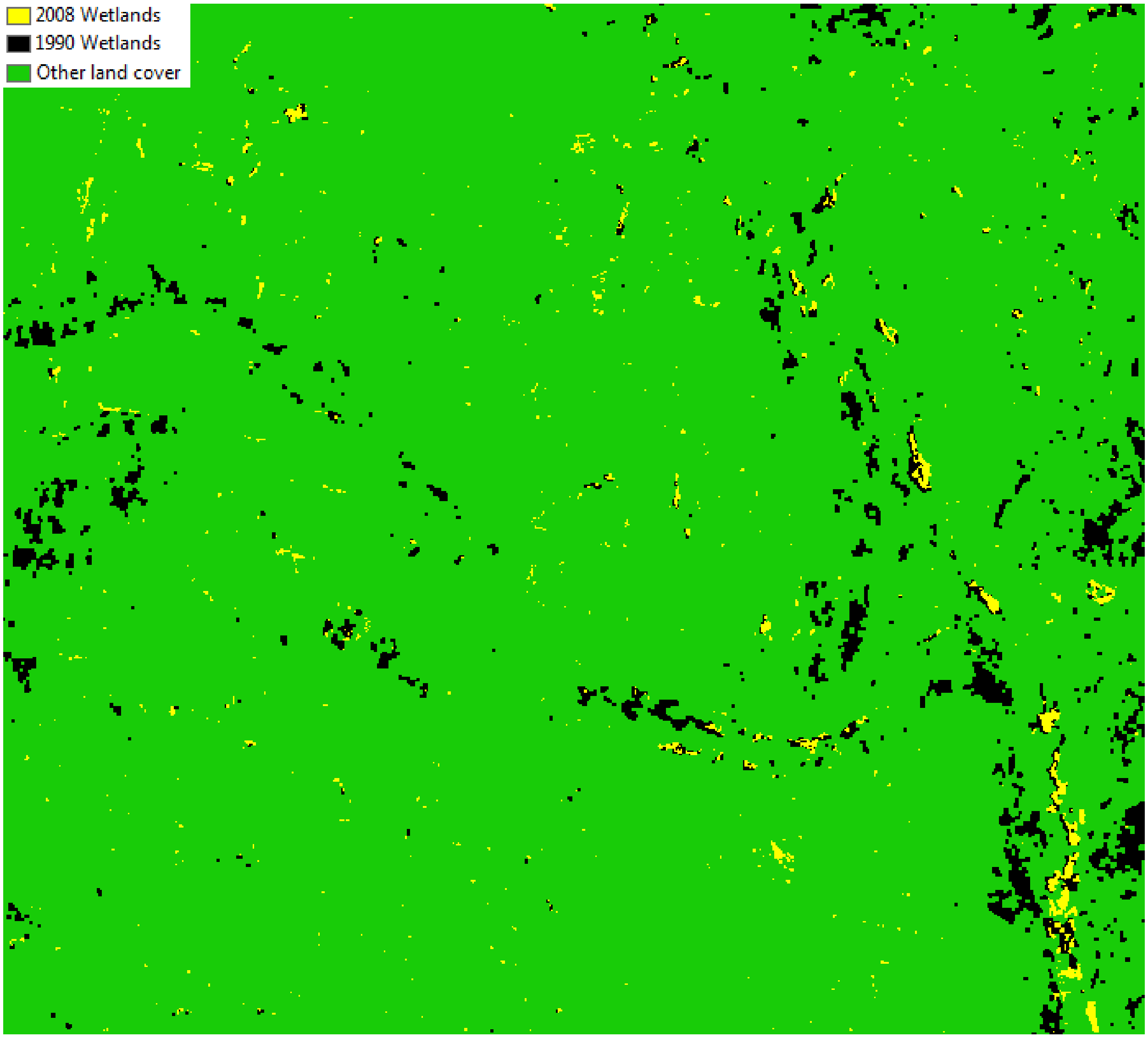

Figure 19: Comparison of change in wetland coverage based on the 1990 and 2008 supervised classifications.

Wetlands present in 1990 appear to have suffered the most near Highland Valley Copper, along Highway 97, and adjacent to the Guichon Creek tributary (Fig 2). In some cases, isolated wetland cells for 2008 that do not appear in 1990 may be due to the difference in cell sizes; small clusters of cells classified as wetlands may have been filtered from the 1990 image, but not the 2008 image.

4. Discussion

The results of comparison of remotely sensed images in this study proved to be a good method in determining the changes in wetlands over time. The ability to monitor wetlands without direct contact is a relatively simple and time effective task. Studying wetlands in direct contact can be a difficult task given their inaccessibility and unforgiving terrain to the field researcher. The use of inexpensive or free satellite imagery is a good approach to monitoring wetland conditions. However, limitations associated with coarser resolution images prevent from high accuracy classification of wetlands. The inconvenience of gap-filling SLC-off images is another downside to using Landsat images. Gap-filling is a demanding procedure does not guarantee totally accurate results.

4.1 Defining classes

Despite the high level of detail in the classified land use map used as a reference, many features were combined into a single class during the training stages. The spatial resolution of an image is a major influence on the quality of classified images; land cover features that dominate an area, such as forested land in this study, have a tendency to mask features of lesser cover, such as wetlands (Moody, 1998). Individually classifying each feature to the same degree of precision as the reference layer was unfeasible. Landsat data is frequently used for identifying general classes, while higher resolution sensors are better for much more detailed classification (Töyrä & Pietroniro, 2005). Aggregating similar classes together is often necessary for the sake of accurate classification; allocation of similar features to individual classes in a relatively low resolution image may generate unwanted complexity in the results that could ultimately result in accuracy loss (Wright & Gallant, 2007; Baker, Lawrence, Montagne, Patten, 2006). Although a wetland can be considered a label for a number of different sub-classes, such as marsh, bog, or fen, attempts to isolate each type into its own individual class is unrealistic without good quality data or on-site corroboration. Landsat imagery is often unable to distinguish between a feature's different sub-classes (May, Pinder III & Kroh, 1997).

4.2 Use of Landsat data

Landsat data was an appropriate source for the purposes of this study. Many researchers, including those associated with Ducks Unlimited Canada, have often opted to use Landsat imagery due to its cost-effectiveness and appropriate quality for the project (Konrad & Rempel, 1990). While aerial photography and field studies are often sufficient approaches to mapping land cover in smaller countries, they prove to be arduous methods for Canadian researchers (Wulder, 2003). Imagery from the Landsat 5 and Landsat 7 missions has been instrumental in the generation of the land cover maps provided by GeoBase. The land cover map for Tunkwa was crucial for labelling each classified feature correctly; without physical interaction with the site, determining land cover classes based solely on spectral reflectance may be unreliable and implausible. Budget-limited studies, such as this one, will find the free data from the Landsat missions and the GeoBase database to be a blessing. Even without the addition of the panchromatic band from Landsat 7 images, the lower resolution Landsat 5 images have been successfully used for wetland mapping in the past (Wakelyn, 1990). Data retrieved from the MODIS (Moderate Resolution Imaging Spectroradiometer) satellite may have been a reasonable alternative for this study's purposes as well. This imagery has been shown to be useful for the measurement of water surface levels (Weiss & Crabtree, 2011).

4.3 Limitations

A number of limitations and obstacles associated with the data and methodology used in this study impacted the accuracy of the results. Although the processes executed using PANCROMA successfully generated useful gap-filled images, these images are still of slightly lower quality than Landsat's SLC-on images. The gap-filled images are not an exact representation of reality, suggesting that misclassification of pixels is possible, and accuracy may be reduced. Studies have been performed comparing the results of supervised classifications for an SLC-on image, and an SLC-off image that has been repaired using similar interpolations methods to this study, and it was found that loss of accuracy in the gap-filled image was very minimal (Chen, Zhu, Vogelmann, Gao, Jin, 2011). Interpolating pixel values for SLC-off images is considered the best approach to gap-filling, despite is slow processing speed (Pringle et al., 2009). Fortunately, the gaps corresponding with the study area are near the center of each Landsat image and the gaps are much smaller than areas nearer to the image's borders. Figure 20 shows two locations from the gapped 2008 image, highlighting the difference between pixel loss due to the failure of the scan-line corrector. Each area is shown at the same scale. Estimation of pixel values for a study area with larger gaps may have deteriorated the accuracy of the results to the point where they wouldn't be considered usable.

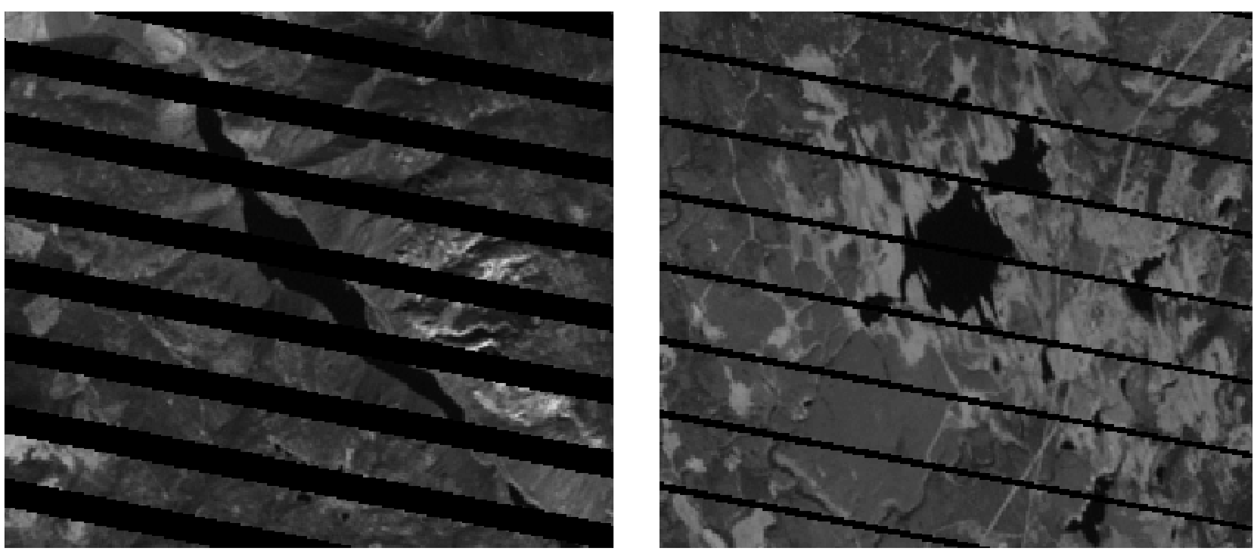

Figure 20: The left figure show a lake outside of the study area but found on the same, unclipped Landsat 7 satellite image from 2008. The right figure is Tunkwa Lake from the same image. Significantly more data loss is apparent in areas further from the center of satellite image.

Misclassification of pixels also proved to be somewhat problematic throughout the study. The combination of atmospheric noise, such as the presence of aerosol particles and water droplets, and mixed pixel information are two contributors to pixel misclassification (Elmahboub). It is sometimes difficult to measure changes in wetlands using images with a high degree of variability in land cover (Nielsen et al, 2008). The pixels representative of wetlands in some images were very similar to some pixels that belonged to the grassland feature type. Band manipulation and re-digitizing of training sites was often necessary to produce a good result for some years. For this reason, supervised classification was the preferable method; unsupervised classifications were tested, but the images this method produced were filled with a generous amount of noise or had apparent misclassification issues. The use of the land cover map from GeoBase as a reference for digitizing wetland training sites helped prevent subjectivity during the process. Some of the water bodies in the 2001 image were misclassified as cloud shadow as well, but this was a negligible shortcoming as the cloud clover was minimal and they didn't coincide with any of the major wetlands. Post-classification processes have been found to be useful for improving supervised classification accuracy (Wang & Howarth, 1993). The filters used in this study produced cleaner looking images with visibly reduce noise, as shown in Figure 21. A large amalgamation of misclassified pixels can compound into a significant difference regarding the accuracy of the final product. These processes are valuable for eliminating this potential for error.

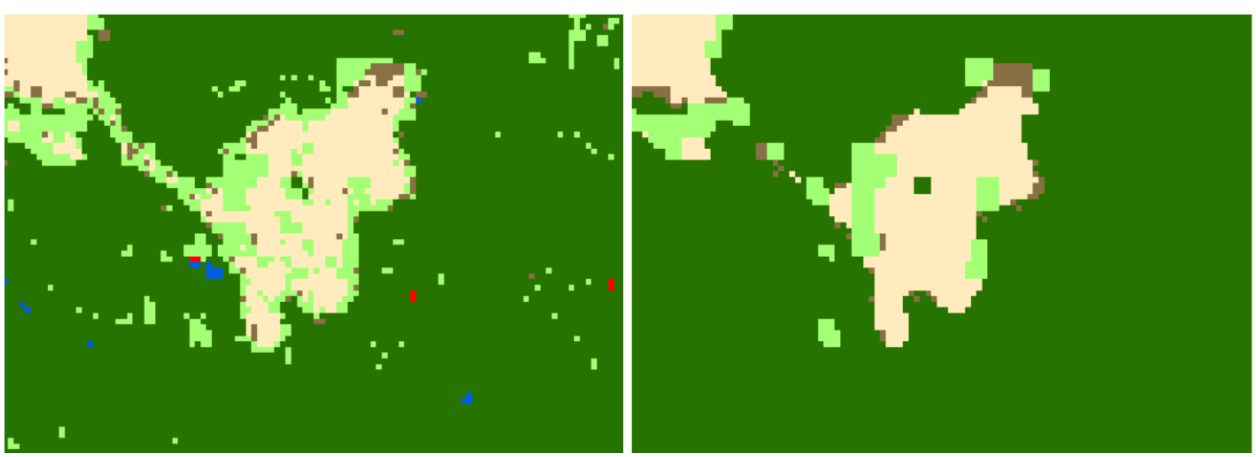

Figure 21: Difference between an unprocessed supervised classification (left) and a filtered and smoothed classification (right). Post-processing is shown to be useful for removing excess pixel noise.

Retrieval of imagery was another difficulty throughout the study. Despite the abundance of available Landsat imagery, cloud presence was a major inhibitor in image selection. Minimal cloud cover is acceptable; the presence of clouds in the 2001 image was not a problem, but 0% cloud cover is optimal for image classification. However, finding images taken during the summer season on a clear day is not always possible. Imagery for 2010 or 2011 was either too cloudy or there was too much snow cover for classifications to be considered consistent and accurate enough for comparison. The limitations associated with both availability and cost of data is a major inhibitor to performing similar studies (Zomer et al, 2009).

4.4 Inclusion of 1976 image

Although the image taken in 1976 is of a significantly lower resolution, it is still valuable for this study's purposes. The wetlands are easily identifiable in the image, and the cell size is an even ratio to the Landsat 5 and Landsat 7 images. This allows the user to assume cells that have been accurately classified with a high degree of confidence can be associated with the same cluster of cells in each other year's image. For example, a 60 m cell from 1976 could be matched with four 30 m cells from 1990 or 1995. Unfortunately, there is bound to be some degree of inaccuracy in this classification; more than one land cover feature can exist within a cell of 60 m resolution. It's possible that cells found along the boundary of each feature type may be misclassified. For this reason, the cell values for each classified feature in the 1976 image were not considered to be directly proportionate to the features in the later years. It's possible that digitizing the wetlands for this year may have been a marginally more accurate method, but without a reference that indicates where each wetland's boundaries are, the process would be too subjective to be considered accurate.

However, based solely on the aesthetics of the 1976 image, a number of correlations can be made between the more recent wetland loss and the apparent land cover changes from 28 years prior. Figure 22 shows two false colour images using the NIR band that exemplify the major changes in land cover between 1976 and 2008.

Figure 22: 1976 (top) and 2008 (bottom) false colour images. Major land use changes are apparent between the two, specifically the expansion of the copper mine, and the impact of deforestation.

4.5 Land use in the study area

Perhaps the most apparent difference is the expansion of Highland Valley Copper Mine. The body of water with the bright blue appearance is the mine's tailings, which are the waste effluents produced during the mine's processing (Engels & Dixon-Hardy, 2010). The construction of the dam used to contain the tailings seems to have been situated so the reservoir would cover a wetland; the land classified as wetland in the northwest section of the study area in the 1976 image from Figure 22 has vanished and been replaced by the tailings. The wetlands along Highway 97 are also in close proximity to the expanding copper mine. The desiccation of these wetlands may be a result of the ongoing operations at the mine. The presence of contaminated water contained within the tailings can be a potential hazard to the nearby environment (Fourie, 2009).

Another major change seen in the study area is the rapid deforestation. The growth in number of cut blocks in the area is clearly apparent, and the trend in loss of forest cover is shown in Table 3**.**

Table 3: Forest coverage for each considered year from 1990 to 2008.

Year	1990	1995	2001	2005	2008
Forest coverage (%)	75.8666	80.3453	75.2468	62.0844	60.0318

Cut blocks in British Columbia are replanted within two years after harvest (Pypker & Fredeen, 2003). They were classified in this study as grassland or shrub based on their DNs. The increased coverage of both shrub and grassland is shown in Figure 23 in relation to the loss of forested areas.

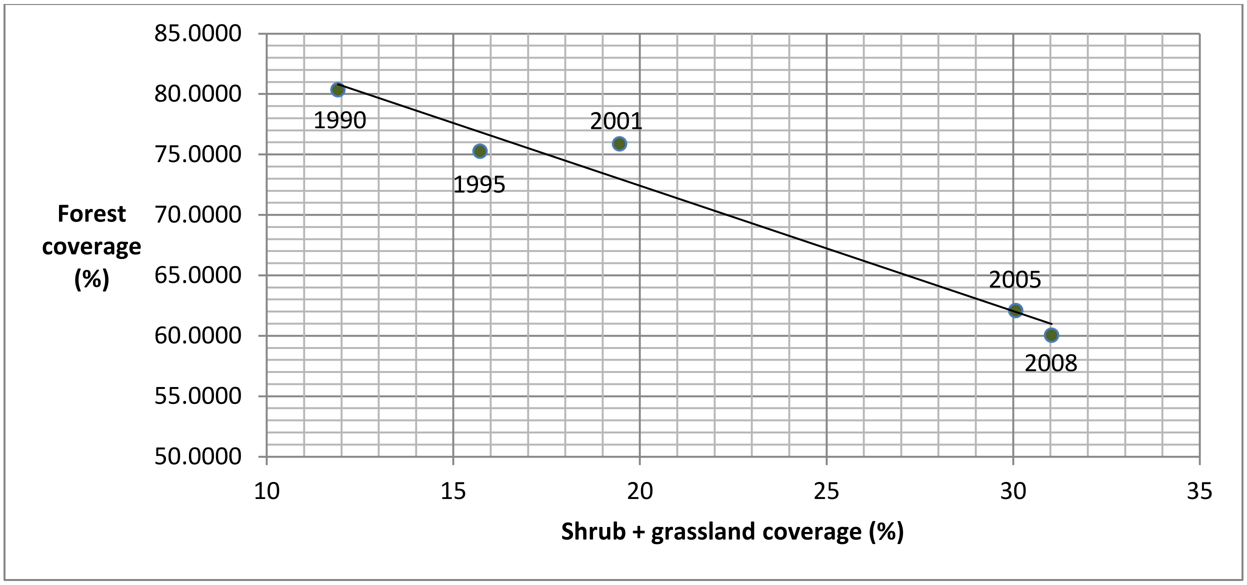

Figure 23: Increase in coverage classified as grass and shrub is a direct result of forest loss within the study area.

Changes in land use has been attributed to approximately 50% of the rise in CO_2 levels in the atmosphere, and timber harvests in the boreal/sub-boreal regions of British Columbia have been associated with these trends (Pypker & Fredeen, 2003). Considering wetlands are a major contributor to carbon sequestration, the combination of their desiccation with frequent deforestation is likely to generate negative trends regarding the concentration of greenhouse gases in the atmosphere.

4.6 Correlation vs. causation

Despite that correlating change in land cover with the recession of wetlands is relatively easy through comparison of satellite images, this method does not necessarily allow the researcher to draw conclusions regarding causation. British Columbia's Ministry of Environment's guidelines on urban and rural development emphasize the importance of on-site environmental monitoring (British Columbia Ministry of Environment, 2006). The Riparian Areas Regulation outlines methodology to determine where development is having an impact on riparian habitats, which include wetlands (British Columbia Ministry of Environment). Remote sensing technology may be a major contributor to studies observing the link between land use and wetland degradation, but consideration of the specific operations that contribute to changes in land use is beyond the realm of remote sensing.

Skeetchestn Indian Band conducted a field study including Tunkwa Lake and other surrounding lakes with the intent of developing methods specializing in low impact timber harvesting in riparian zones (Karakatsoulis, Paul, Osborne, Ortner & Anderson, 2005). The study found a decline of up to 25% in a number of plant species coverage near Tunkwa Lake as a direct result of timber harvesting. These finding suggest that the wetland loss near Tunkwa may be partially due to the widespread deforestation in the area.

4.7 Impact of climate change

The threat of climate change is also a concerning factor that may attribute to wetland loss (Hartig et al., 2002). Current trends suggest that a future lack of winter snow for groundwater recharge and extended summer droughts are a potential threat to wetlands (Symmetree Consulting Group, 2009). Temperature trends during the 20th century in British Columbia appear to be mostly increases in daily minimum temperatures, rather than increases in maximum temperatures, resulting in a 1.1℃ rise in the interior for this century (Taylor, 2004). However, the impact of climate change on wetlands in British Columbia is reported to be potentially more problematic for the future than it has in recent decades (Bunnell, Kremsater, Moy & Wells, 2011). Environment Canada stresses that the future impacts of climate change will be much more apparent than the current impacts if measures aren't taken to help reduce greenhouse gas emissions (Environment Canada, 2007). This suggests that the wetlands of Tunkwa watershed may be affected more by anthropogenic interaction than any temperature or precipitation fluctuations.

4.8 Value of remote sensing

Although using remote sensing may not be the most appropriate technique in identifying the need to implement wetland management programs, it has proven to be a useful tool in conjunction with GIS initiatives to suggest locations for wetland restoration projects. A study in northeast China combined assessment of farmland productivity with hydrologic modeling in order to identify farmland sites that were suitable for conversion to wetlands (Huang et al., 2010). In cases where wetland conservation or restoration is too late, similar methods could be followed to suggest conversion projects.

Depending on the aims of a study, alternative sources of satellite imagery may be preferable. Studies have been performed that test the accuracy of using and classifying satellite images using different methods (Sader et al., 1995). Monitoring a wetland using a poorly classified or very low resolution image isn't an advisable approach to wetland management. If the data is unfit for use, it would not be worthwhile to attempt to perform any sort of analysis through comparison. It has been noted that it can be difficult to obtain data for wetlands that do not interfere with land use practices in some areas; wetlands that are more isolated from anthropogenic interaction tend to receive less attention than those closer in proximity (Rebelo et al, 2009). The value of high resolution satellite imagery becomes apparent in these scenarios. Wetland vegetation has been successfully modeled using LiDAR (Light Detection and Ranging) and Quickbird multispectral data (Cook et al, 2009). Land cover uncertainties associated with the use of coarse resolution data can be evaluated with fine resolution multispectral imagery from the Quickbird or IKONOS missions (Morisette, Nickeson, David, Wang, Tian, Woodcock, Shabanov, Hansen, Cohen, Oetter, Kennedy, 2003). Although the use of this imagery may be more costly, the data has been successfully implemented in validation of studies using lower resolution images. Another parameter that should be considered by researchers is the scale of the study area. Depending on the cell resolution of a satellite image, different scales may be more appropriate for wetland studies. Images with fine resolutions are often useful for performing studies at a local scale (Sawaya, Olmanson, Heinert, Brezonik, Bauer, 2003). The Landsat images used in this study would be appropriate for a more localized scale study of a wetland; a smaller study area reduces the likelihood of pixel misclassification. Wetland mapping for the purpose of generating a land cover map or a wetland inventory may be appropriate at smaller scales, but monitoring wetland change over time may be preferable at more localized scales. Figure 24 shows the changes identified in an individual wetland between 1990 and 2008.

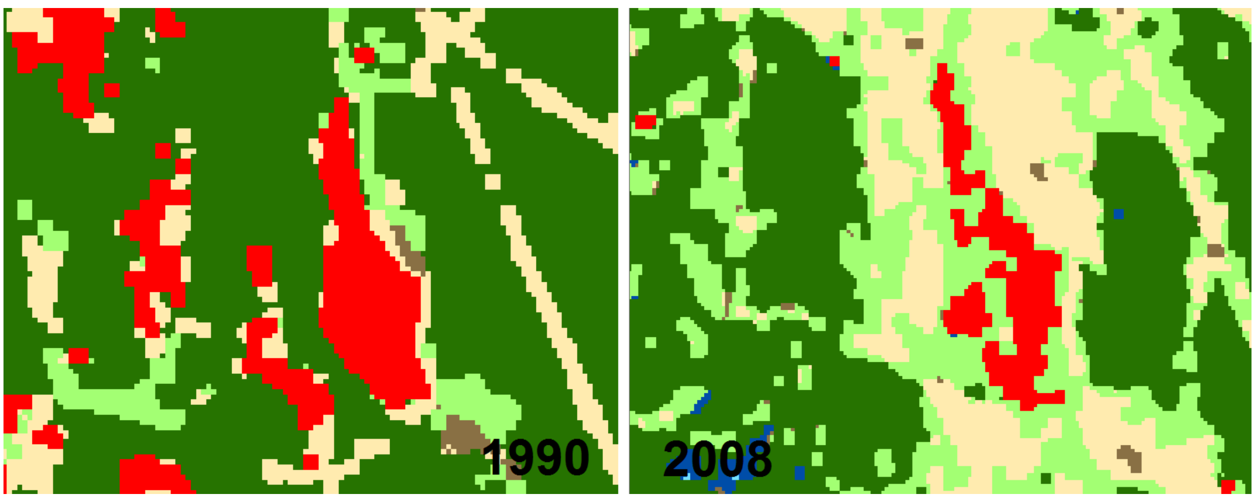

Figure 24: Clear changes in land cover can be identified at a more localized scale using Landsat imagery.

The methods used in this study can be implemented by any organization that is considering starting a wetland preservation initiative. The ability to easily monitor wetland health allows the user to decide at what point a wetland is beyond the point of conservation, and restoration becomes the solution. Unfortunately, some wetland policies favour restoring or creating wetlands over protecting them (Whigham, 1999). This has proven to be an undesirable approach in many cases, as restored or created wetlands may not function in the same manner as natural wetlands. However, remote sensing techniques remain useful for monitoring wetlands irrespective of these policies.

4.9 The need for wetland monitoring

This study, among many others, has emphasized the need for wetland monitoring, and future collaboration and effort is necessary for their survival. Further measurement of the wetlands in the Tunkwa watershed is suggested using any moderate or fine resolution imagery. Data collected from the next Landsat mission, named the Landsat Data Continuity Mission or Landsat 8, which is scheduled to launch in December of 2012, may be a great source of imagery for this purpose (NASA, 2011). However, considering this study area is a relatively small portion of the Thompson/Okanagan region is British Columbia, the generation of a wetland inventory for other watersheds around Kamloops would be a significant contribution to organizations such as DUC that strive to preserve these wetlands. Results from this study should not be extrapolated to other nearby wetland areas and assumed to be comparable; the unique land use practices in this region, primarily the growth of the copper mine, may produce different classification results than in other watersheds. In order to identify appropriate wetlands for restoration, the health and rate of desiccation of other wetlands in the region should be considered as well. Due to the abundance of land use practices in the Tunkwa area, including the expansion of the Highland Valley Copper Mine and the forestry operations, wetlands may be more valuable in other areas, such as regions where agriculture is abundant.

The combination of field studies with remote sensing for wetland management and monitoring purposes is a good approach to generating accurate descriptions of these sites. Knowledge of the hydrologic processes, vegetative cover, and land use impacts associated with wetlands would be useful for determining their health and suggesting preservation initiatives (Zomer et al., 2009; Nielsen et al., 2008). Similarly, the availability of wetland inventories are a supportive of these studies, and the creation of a Canadian wetland inventory would be largely beneficial to those willing to invest the time and money to conservation efforts. The collaborative efforts of both approaches to wetland monitoring would be an important step towards managing them for the future. With readily available inventory data, management can assess the degree to which any sort of land use can be implemented before significant impacts to wetlands become apparent (Melendez-Pastor et al., 2010).

5. Conclusion and future recommendations

This study exemplifies an approach to monitoring wetlands using a time-series analysis technique of comparing remotely sensed images from Landsat missions. The link between human development and wetland recession can be measured through image classification, given that data is available and affordable for researches. Although image quality is an important factor in classification accuracy, moderate resolution imagery has been proven to be appropriate for measuring wetland health. Considering wetlands are so valuable to both humans and wildlife, the need for a comprehensive wetland database for Canada should be apparent. Fortunately, optimism is expressed that compilation of a Canadian wetland inventory, much like the aforementioned VMI in Sweden, will be completed in future years. With frequently updated inventories for wetlands, monitoring their well-being becomes much more feasible, and wetland health can be considered before the implementation of any land use practices.

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Appendix A

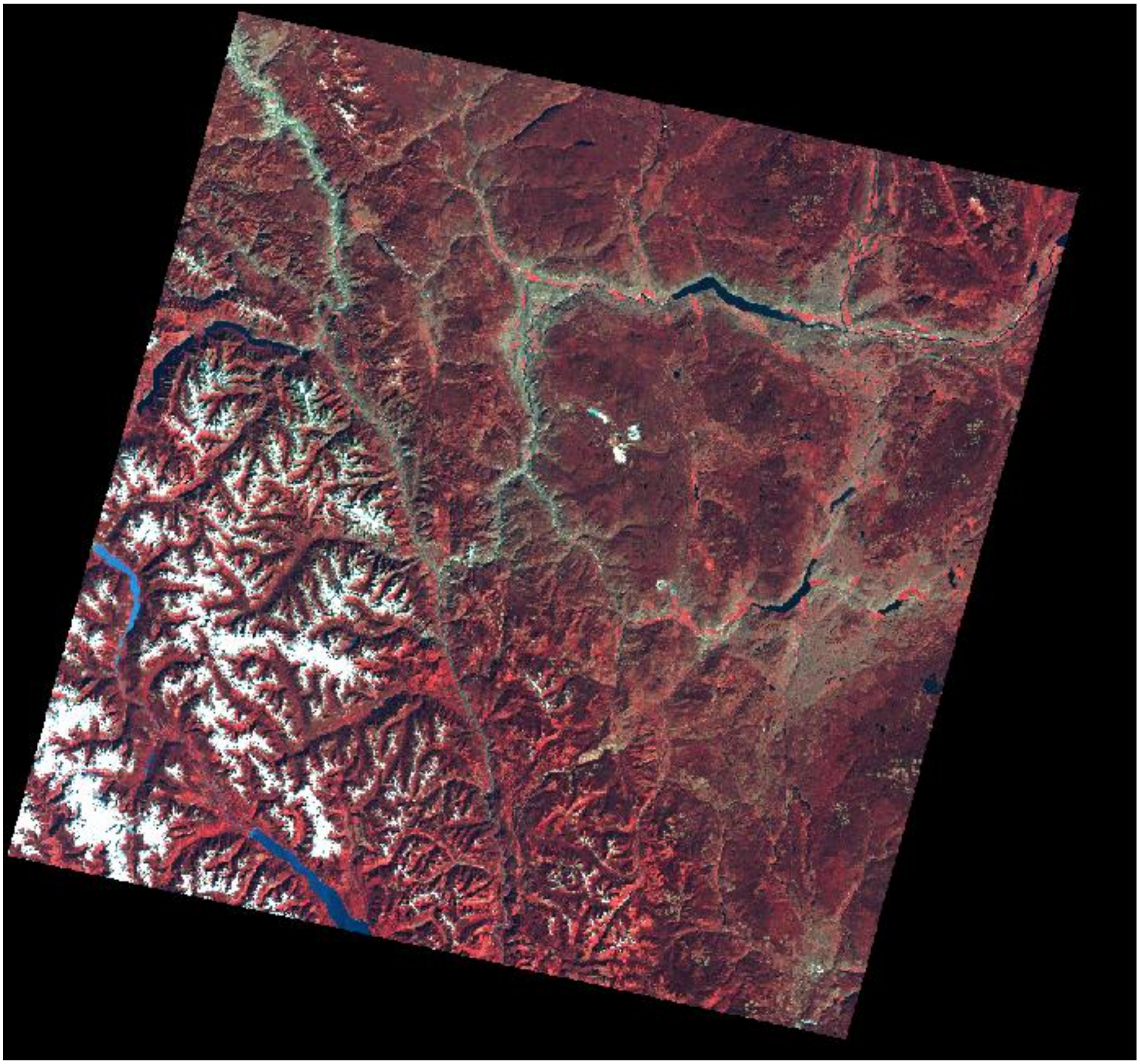

Figure 1: False colour Landsat image (1976)

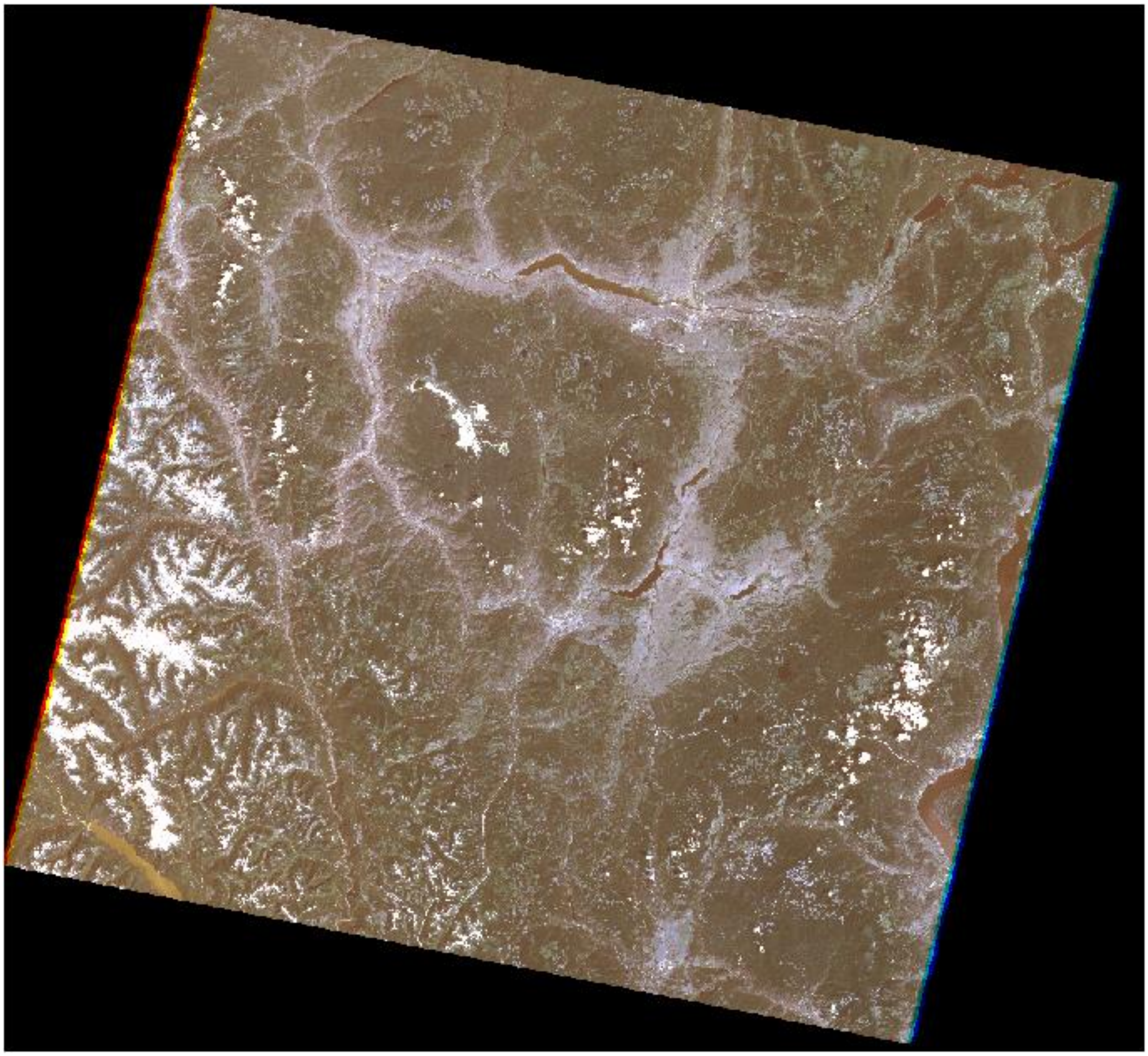

Figure 2: Landsat image (1990)

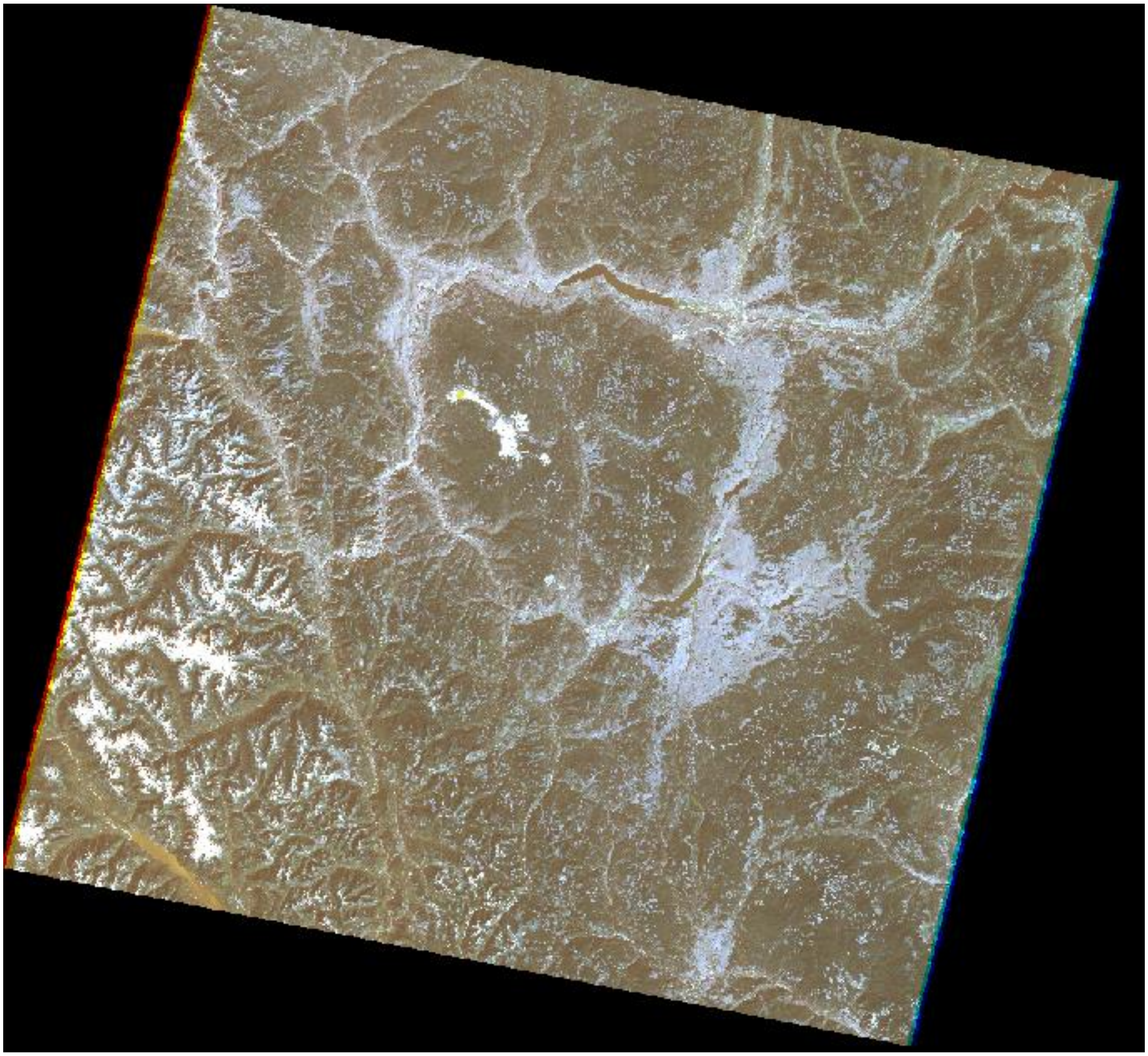

Figure 3: Landsat image (1995)

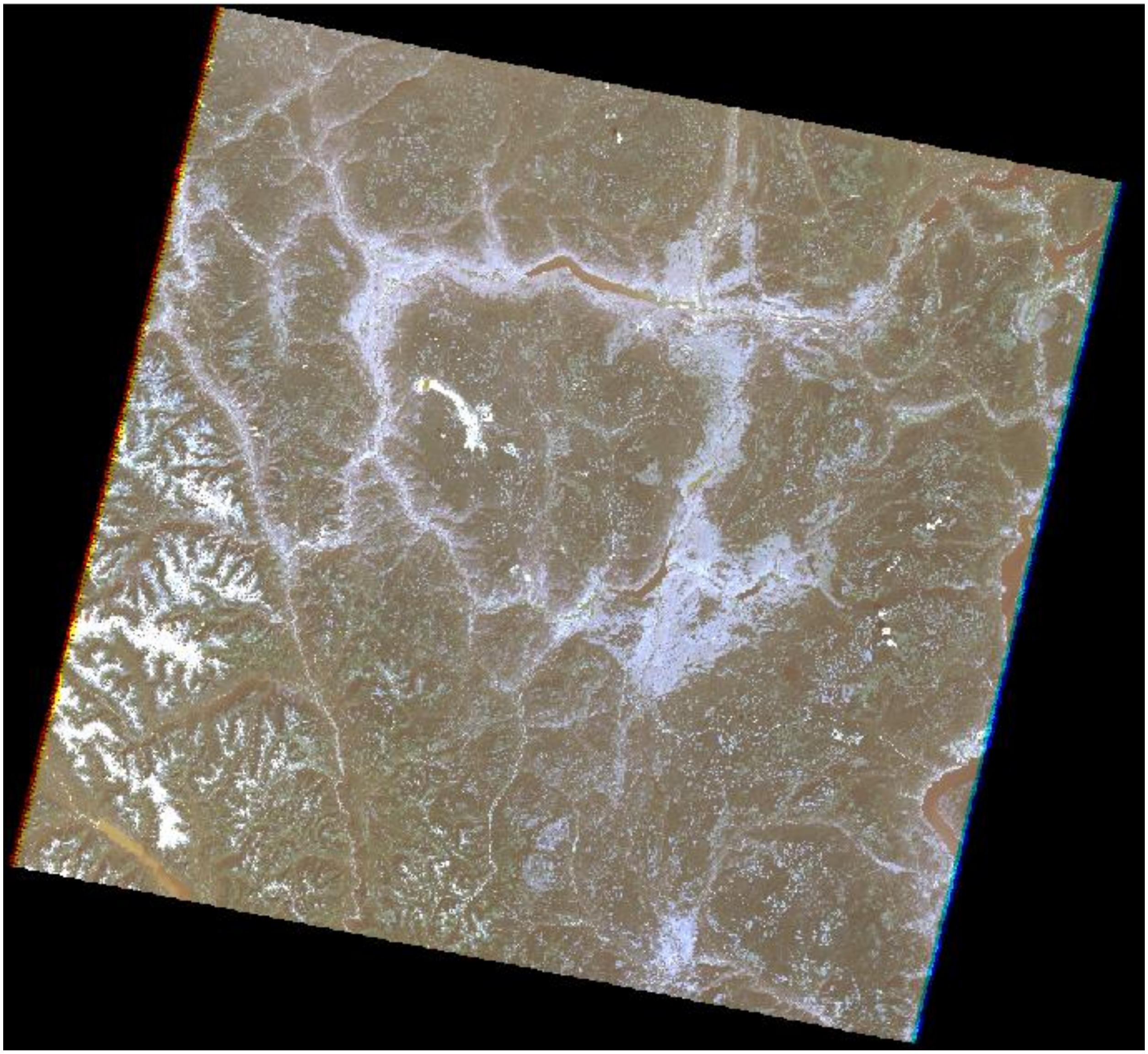

Figure 4: Landsat image (2001)

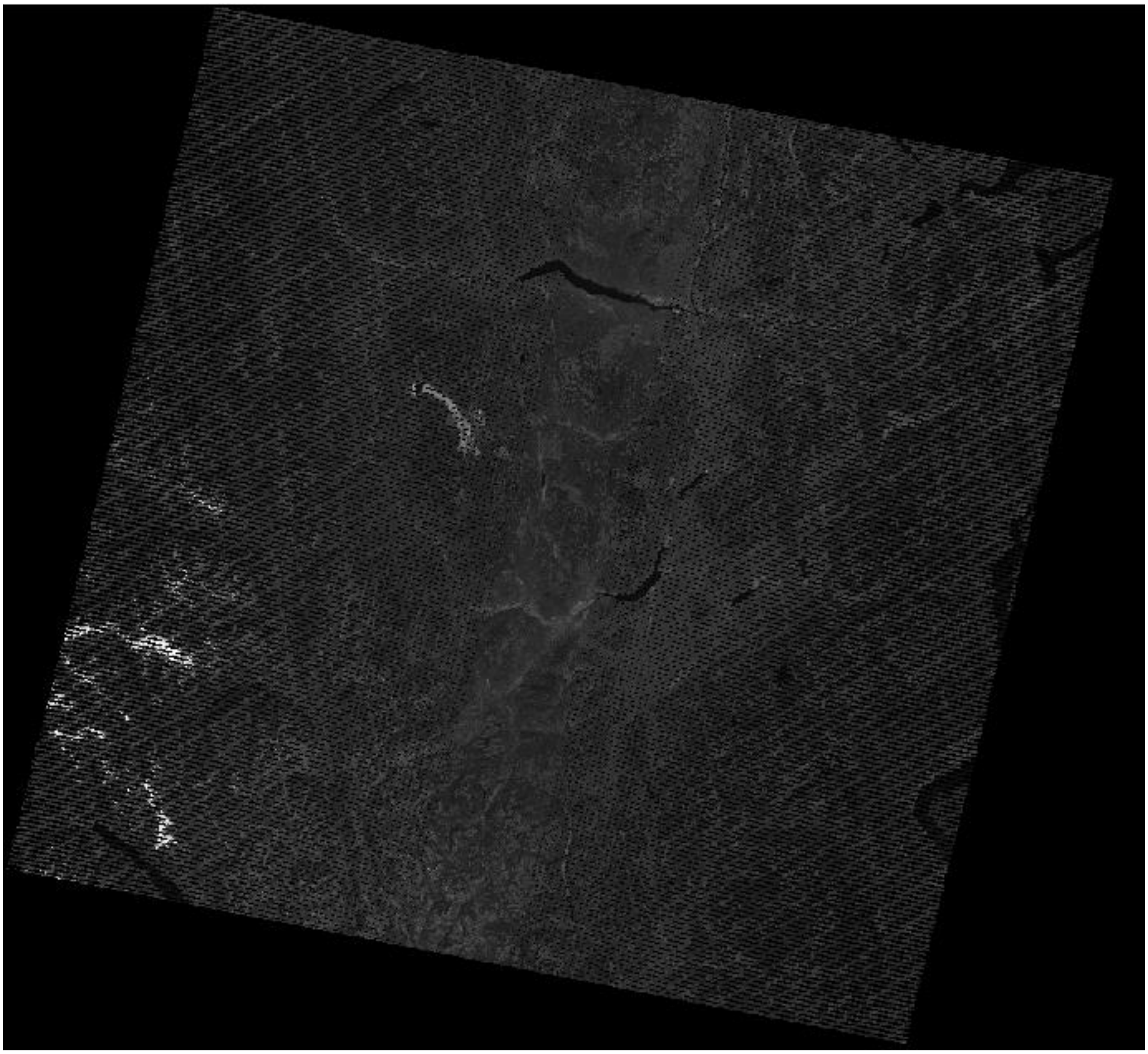

Figure 5: Landsat image (2005 panchromatic band)

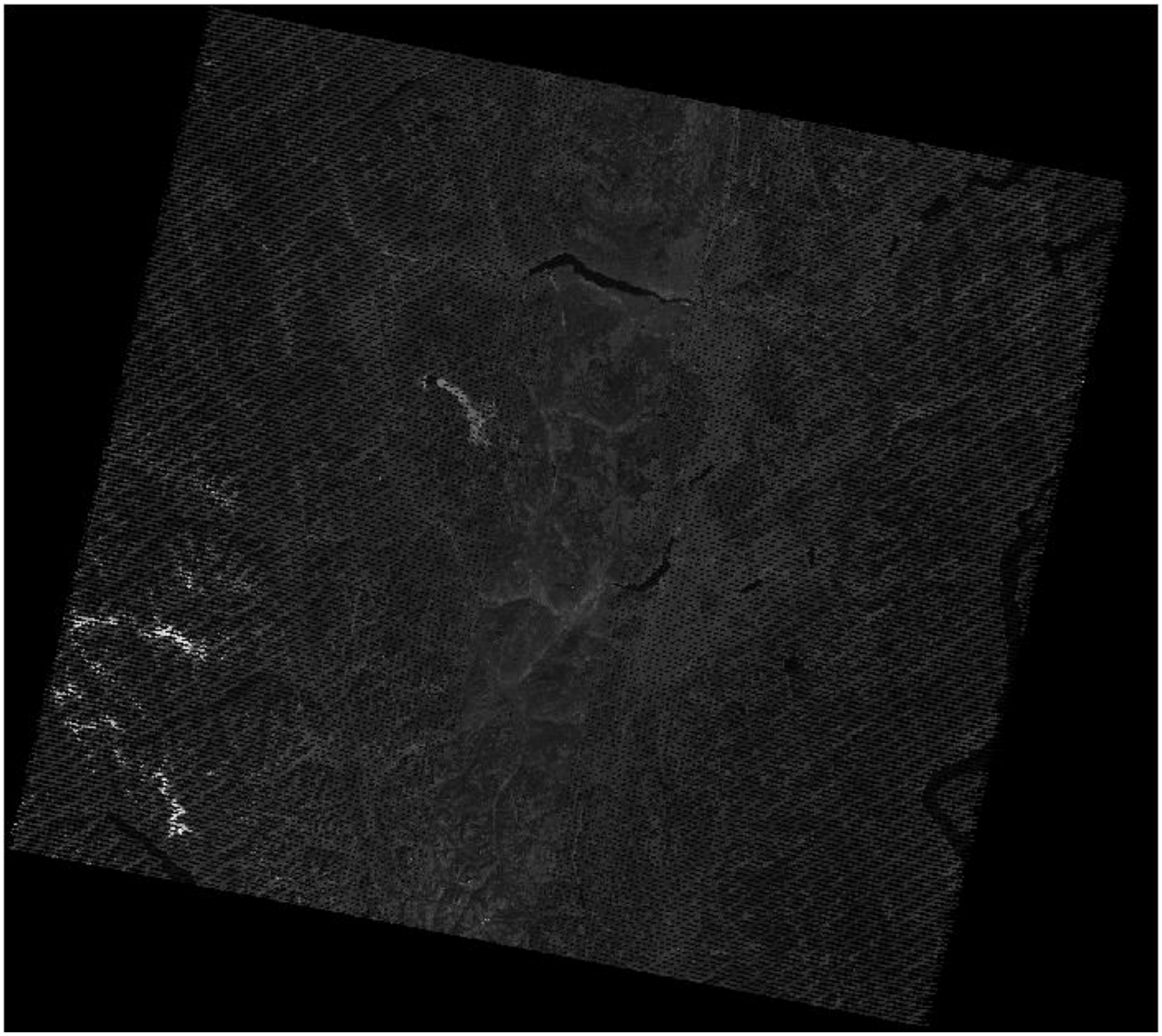

Figure 6: Landsat image (2008 panchromatic band)