MAPPING MINING WASTE

AN INVESTIGATION OF THE IMPACT OF MINING ACTIVITIES ON SETTLEMENT PATTERNS

by

Mohammad Ariful Alam

Bachelor of Architecture, Bangladesh University of Engineering and Technology, 2003
Master of Urban Design, the University of Melbourne, 2009

A Major Research Paper
presented to Ryerson University

in partial fulfillment of the requirements for the degree of

Master of Planning
in
Urban Development

Toronto, Ontario, Canada, 2014

AUTHOR'S DECLARATION

I hereby declare that I am the sole author of this major research paper. This is a true copy of the major research paper, including any required final revisions, as accepted by my examiners.

I authorize Ryerson University to lend this major research paper to other institutions or individuals for the purpose of scholarly research

I further authorize Ryerson University to reproduce this major research paper by photocopying or by other means, in total or in part, at the request of other institutions or individuals for the purpose of scholarly research.

I understand that my major research paper may be made electronically available to the public.

MAPPING MINING WASTE

AN INVESTIGATION OF THE IMPACT OF MINING ACTIVITIES ON SETTLEMENT PATTERNS

Master of Planning
in
Urban Development
Ryerson University

ABSTRACT

This research focuses on the waste and environmental damage caused by mining activities and the impact that this has on settlement pattern of adjacent areas. This research identifies that mining cities are unique in their land use dynamics due to the physical attributes of mining sites and there impacts on human and nature. Using a method of three sequential approaches to understand the land use dynamics of mining cities the first study examines the physical attributes of mining sites, through the creation of a new data set that combines existing and abandoned sites from existing separate datasets, outlining production, proximity to settlement areas and water bodies to identify their degree of threat to human and nature. Secondly, a single case study of Copper Cliff, ON is used to investigate how mining activities and its changes interact with surrounding land uses through a Land mosaic-function-land change feedback model adapted from Richard T.T. Forman's theory of land mosaic. The analysis then investigates the policy responses that are enacted to mitigate the mining activities with other land uses. The analysis identifies that the potential impact of mining activities is more prominent where mining waste production is higher and located at close proximity to settlement areas. However, although the growth pattern of settlement areas are often guided by the physical characteristics of mining sites, effective response of land use policies may stimulate positive changes of land use pattern.

Key words: mining wastes; settlement patterns; land change; land use policy; Northern Ontario.

ACKNOWLEDGEMENT

This research paper is made possible through the help and support from everyone: my teachers, family and friends. Especially, please allow me to dedicate my acknowledgment of gratitude toward the following significant advisors and contributors:

First and foremost, I would like to acknowledge the inspirational instruction and guidance of my research supervisor Dr. Shelagh McCartney. This research paper is made possible through her continuous help and invaluable detailed advice on grammar, organization, and the theme of the paper.

Second, I would like to thank my second reader Mr. Victor Doyle for his useful feedback and encouragement. His thoughtful comments pushed me further to bring positive outcome.

Third, I would like to thank Samira Behrooz, Mark Romeril and Brennan Finely for their meaningful comments and advices during our weekly meetings. It was truly a great learning experience and helped me to understand a wide spectrum of critical planning issues.

Finally, I would like to thank my wife, Sharmeen, for her continuous support and encouragement. I could not have completed this effort without her assistance, tolerance, and enthusiasm.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES:

LIST OF APPENDICES:

1.0 INTRODUCTION

Ontario has been a leader in mining for nearly a century (Ontario Nature, 2012). Between 2000 and 2010, the value of total mineral production in Ontario was higher than that of any other province in Canada (Stothart, 2011). Mining has long been one of the major contributors to Ontario's economy and the industry continues to grow in terms of production and revenue generation. Ontario produced approximately $7 billion worth of minerals in 2006; this amount increased to $10 billion in 2011. The majority of mining revenue is derived from metals (Ontario Mining Association, 2013). Recent findings such as the "Ring of Fire" create tremendous opportunities for regional development as well as socio-economic benefits for many Northern communities. Most mining cities in Ontario are located in the northern part of the province. Because many mining cities initially flourish with the development of mining sites, physical growth, economic progress, and the lifestyles of residents are all highly influenced by the decline or growth of mining activities. One critical consequence of mining activities, though, is the production of mining wastes that have the potential to cause significant ecological damage to adjacent areas. In some cases, environmental contamination—emission of air pollutants, erosion of waste rocks, or leaching of toxic wastes into waterways—can spread across thousands of acres. The contamination that results from mining activity has received significant attention in scholarly research, given the broad spectrum of possible social, environmental, and economic impacts. However, the extent to which mining activities physically change adjacent settlement areas has received little attention both in the existing literature and in planning policies.

This study identifies mining activities as a means by which to understand the unique characteristics of land use patterns in mining cities. In particular, it examines how mining activities, including the expansion of facilities and discharged wastes, influence both city growth and land use patterns. This phenomenon is explored in two parts. The first part investigates, through a priority ranking system, the process of base metal mining in Ontario by focusing on its potential environmental impact and the degree of threat of all mining sites. Base metal mines are an ideal point of inquiry as they are known to produce a high level of contamination both in Ontario and in other parts of the world (Mudd, 2009). The analysis of all base metal mining sites in Ontario, with attention to waste production and proximity to their settlement area, informs the identification a region where major mining-related contaminations have occurred and are still occurring, and where there remains a significant threat to the natural landscape. This study takes up that region as the focus of a case study. The second part of the analysis engages a case study of the Sudbury region to understand the physical changes in adjacent settlement areas and the role of mining activities in this process. Overall, this research demonstrates that there is an interaction between mining activities and the growth pattern of settlement areas but that this process is both complex and entangled with several other issues such as mining regulations, changes to waste management processes, land use planning responses, demographic changes, and even the common perception of mining cities as a contaminated terrain. This research recommends an integrated, preventive approach to dealing with mining waste, in contrast with the dominant, prescriptive approach. The findings of this study also indicate that resource extraction, as a unique characteristic of mining cities, should receive more attention in planning research to identify innovative approaches for sustainable development.

1.1 A CHANGING CONTEXT: In the 1880s, massive deposits of copper-nickel ores were uncovered near what is now the city of Sudbury, Ontario. Large-scale mineral extraction began in the early 20th century after major discoveries of gold and silver on the local Precambrian Shield (Republic of Mining, 2010). Since then, exploration has expanded and discoveries have been made throughout Ontario. Despite this long history of mining activities, environmental issues did not receive the attention of mining companies or legislative authorities until the end of the 20th century. The Mining Act, first issued in 1906, was primarily created to provide a simple means by which to secure interests in mining claims (Republic of Mining, 2010). In 2009, the Mining Act included, for the first time, a requirement for the remediation of exploration sites alongside secured financial liability (Hart & Hoogeveen, 2012). Similarly, the Fisheries Act is one of the oldest acts that regulate the allowable amount of industrial metal effluent in natural waterways (Hart & Hoogeveen, 2012). Until recently, the toxic contents of waste rock dumping areas, smelters, and other processing plants “poisoned aquatic life, polluted fisheries, and harmed the livelihoods and food supply of thousands of people” (Mining Watch, 2012, p. 7). Legal action taken under the Fisheries Act was not evident before the 1970s (Fisheries and Oceans Canada, 2014).

In most cases, the actual cost of these impacts is not possible to determine, specifically because the true cost goes mostly unnoticed and is burdened by local communities with damaged ecosystems (Ontario Nature, 2012). The negligence caused by a century of mining activity in Ontario has resulted in 4000 abandoned mining sites which are considered hazardous to public health and safety (Ontario Nature, 2012). Of these 4000 abandoned sites, 250 pose an environmental risk due to the possibility of leaching of minerals and other contaminants from mine tailings areas (Ontario Nature, 2012).

Figure1. Nickel tailings in Sudbury, Ontario (Burtynsky, 1996).

1.2 IMPACT OF MINING ACTIVITIES ON LAND USE: According to the conservation group Ontario Nature (2012), **"**[i]t is important to understand what mining means in the long-term for northern ecosystems, and community health and prosperity. While the life of a mine can last a few years, the footprint it leaves on the land can be permanent" (p. 2). Mining regulations ensure that potential mining activities are prioritized over other land uses, which can thus compromise local agriculture and residential development across a large area. For this reason, the economies of many mining cities remain dependent on mining. Moreover, there are numerous cases in which communities are adversely affected by environmental degradation (Mining Watch, 2009). Most of the large-scale mining activities in Canada plan to operate for 20 to 50 years; however, after closing, care to the area may extend for hundreds of years (Kuyek, 2011). Reviews of the literature on the health impacts of mining have found that "[i]n addition to causing pollution of resources, mining uses large quantities of water and destroys land that might have been otherwise used for other purposes such as agriculture or housing" (CCSG, 2004, p. ii). The Sudbury Soil Study, which is considered one of the largest and most comprehensive studies of its kind in North America, reveals severe surface soil contamination as well as damage to the vegetation and biodiversity of a significantly large part of the area (Wren, 2012). Although this study did not find a significant health impact in existing local communities, other research has shown that soil contamination in Sudbury covers 10,000 hectares of blighted area adjacent to mining sites (Mitchell, 2002). Researchers have also determined that, during the course of expansion of mining activities, land use patterns in adjacent areas are transformed because of expanded mining and processing, and the consequent ecological impact (Wu, Yao, & Kang, 2008). This change in land use also affects adjacent settlement areas in terms of loss of agricultural lands, decline in housing markets, low population growth, and the migration of residents to other places. Considering the limited amount of research on mining activity and how its discharged wastes influence land use patterns in Ontario, the present study aims to investigate base metal mining sites in Northern Ontario to understand the changing dynamics of land use patterns in adjacent areas.

1.3 HYPOTHESIS: MINING WASTE AFFECTS SETTLEMENT PATTERNS. The present research aims to identify a direct relationship between decades of mining activities and the changing patterns of settlement in adjacent areas. The research suggests that the expansion of mining activities and the long-term ecological impact of mining activities affect the land use patterns in adjacent regions. The impact often results in loss of agricultural lands, loss of wetlands, deforestation, shift or stagnation in settlement areas, and many other externalities such as lack of population growth and decline of housing market.

1.4 METHOD OF STUDY: This project identifies an area where mining activities have had a significant impact on human activities and nature in order to investigate the relationship between mining activities and changes in settlement patterns. This impact may take, for example, the form of loss of agricultural land due to soil and water contamination. Mining activities in urban areas can also restrict other land uses in adjacent areas and create barriers to growth. To select an ideal case study, this project compiles and considers various data such as mining production and amount of discharged wastes of all base metal mining sites of Northern Ontario, and subsequently analyzes them to understand the degree of threat posed to adjacent communities. This process allows for the identification of the concentration of mining activities in a regional context, which is important to understand the potential collective impacts on both the ecosystem and human settlements. Based on the most potentially intimidating mining activities, this project conducts a case study to further explore how mining production, associated wastes, and consequent ecological damages affect the growth pattern of adjacent land use. The research follows a sequential approach by starting with a thorough exploration of mining activities and degree of threat based on their location, and follows with a case study in order to understand the impact of mining activity on settlement patterns.

1. The first part of this study aims to understand the base metal mining process and its potential impacts on nature. To this end, it assembles data from semi-structured interviews with mining-related professionals in the public and private sectors, in addition to pollution data and

geographic information system (GIS) data from various provincial data inventories. These data sets are utilized to create a new, combined data set of all abandoned base metal mines in Ontario.

A priority ranking system has been prepared for both active and abandoned mines by adapting a ranking method developed by the Ministry of Northern Development and Mines (AMEC, 2008). Two parameters are used to identify the degree of threat of all mining sites: waste production and contamination-related parameters (such as tailing area, volume of waste rock, acid rain drainage potential, etc.); second, the distance between mining sites and water/settlement areas. The outcome of this analysis is the preparation of a new data inventory of all active and abandoned base metal mines of Northern Ontario.

The GIS data for the priority list of all base metal mines help to recognize a case study to further investigate how mining activities affect adjacent settlement areas. This step in the investigation produces a set of GIS maps that assist in the selection of a case for further study of mining-related impacts on land use patterns.

2. The second part of this project involves an in-depth case study (based on the priority ranking system) of mining activities to understand their impacts on land use patterns. In particular, this research aims to identify whether mining activities and their impacts influence changes in settlement patterns. The research utilizes two methods of analysis to investigate the changes:

    a. **Study of Land Mosaic Function Land Change:** This first approach is adapted from the concept of “land mosaic and landscape change” (Forman, 2008), which identifies various land classifications and traces their changes over time. The purpose of this mapping analysis is to identify how various land uses transfer to other uses. Satellite sensing images of different periods of time are used to analyse land use changes. This method identifies various land classifications including mining areas, vegetation, agriculture, settlement areas, and bodies of water (Forman, 2008). Based on the GIS data, a land use transfer matrix is prepared, which identifies the transfer of various land classifications over the last 40 years. The land transfer matrix provides an opportunity to identify how one particular land use interacts with other uses as well as any changes over time, by showing their functions and influences on other uses. For example, the increase in waste dumping of mining sites may reduce the quality of adjacent vegetated lands, which are graphically represented in the matrix. In this way, the matrix provides information on all land uses and illustrates how any changes affect other land uses.

b. **Study of Policy Responses:** After analyzing the "land mosaic function land change" model, the final segment of this research examines the changes in planning policies and development strategies that catalyze or restrict changes in the landscape. The research identifies various forces, such as mining activities that influence land use change, and then identifies various policy responses. The analyses of development policies and other city initiatives inform the extent to which an institutional framework addresses the impact of mining activities in their development strategies.

   Finally, the research attempts to create a link between planning policies, land transfers, and other externalities (such as population changes) to understand the unique characteristics of mining cities. It is expected that a detailed understanding of their interactions may reveal the relationship between mining activities and settlement patterns.

1.5 SIGNIFICANCE, SCOPE AND CONTRIBUTION: Since the beginning of 20^{th} century, mining activities have played a significant role in continuous changes in the physical characteristics of mining cities in Northern Ontario (Ontario Nature, 2012). Decades of dumping wastes such as tailings—a form of waste in the process of mining—and slag produced from smelters influenced the changing pattern of vegetation, biodiversity, water quality, agriculture and settlement patterns of many mining cities such as Sudbury and Timmins. Despite extensive research on the environmental and health impacts of mining activities, the influence of mining activities on overall land use patterns in cities in Northern Ontario has received little attention from researchers. Taking a land use planning perspective, this study aims to provide insight into changes in the dynamics of land use caused by mining activities.

This research collected a comprehensive list of existing and abandoned mining sites with tailings waste and selected a single case study for further study of land use changes in the affected areas. The findings of this study can be utilized to investigate other mining sites and adjacent areas to identify the patterns of land use change.

The study will contribute to the field of land use planning particularly in the context of mining cities by providing a data inventory of a prioritized list of existing and abandoned base metal mines based on the possibility of ecological damage. This research will also raise awareness about the influence of mining activities on development patterns and its impact on land use planning.

2.0 STUDY OF MINING PROCESS (BASE METAL), IMPACTS AND PRIORITISED MINING SITES OF NORTHERN ONTARIO

2.1 REVIEW OF BASE METAL MINING PROCESSES: This review outlines the base metal mining process, regulatory framework, and potential impact to natural ecosystems and human settlements. This study focuses on base metal mines producing copper, zinc, lead, and nickel because these metal extractions are considered unsustainable in that they create millions of tons of waste rocks and other forms of waste during processing. The profitable concentration of minerals extracted from base metal ore is only about 5% (Ontario Nature, 2012). This figure reveals that, despite minor recycling in some cases, 95% of the processed ore becomes waste that is then received by nature. The base metal mining trends, particularly in copper and nickel, show that, in Canada, production has continued to remain at the same level since the 1970s (Mudd, 2009). Between 1976 and 2000, cumulative use of land by mining was about 37,000 square kilometres, which amounts to 0 2% of world land (Dudka, 1997). In the U.S., about 60% of land disturbed by mining is used for dumping mining wastes. In Sudbury, between 1969 and 1979, nickel and copper smelters produced more sulphur dioxide than all of the volcanoes throughout the Earth's history (Dobrin & Potvin, as cited in Dudka, 1997). Although mining in Canada has been regulated by a more stringent regulatory framework since the beginning of 21st century, the legacy of environmental degradation has left significant and lasting environmental impacts (Jewiss, 1983). Most of the existing research on mining wastes has focused on environmental and human health issues. The present study focuses on the relationship between mining wastes and physical patterns of mining cities which may be significant from a land use planning perspective. According to the CCSG (2004), "[m]ining is an industry of extraction that intensively uses resources, both human and environmental, at the expense of communities. In addition to causing pollution of resources, mining uses large quantities of water and destroys land that might have been otherwise used for other purposes such as agriculture or housing." (p. 22).

This section reviews the sequence of events in the base metal mining development and extraction process to understand how land use planning plays an important role in mining development and vice versa. Similar to other mining enterprises, the development of base metal mining in Ontario has to adhere to five basic stages, in accordance with the Mining Act of 2009. The process of development requires conformation to regulations and different levels of interaction with communities and the environment. Figure 2 illustrates the basic sequence of a mining development.

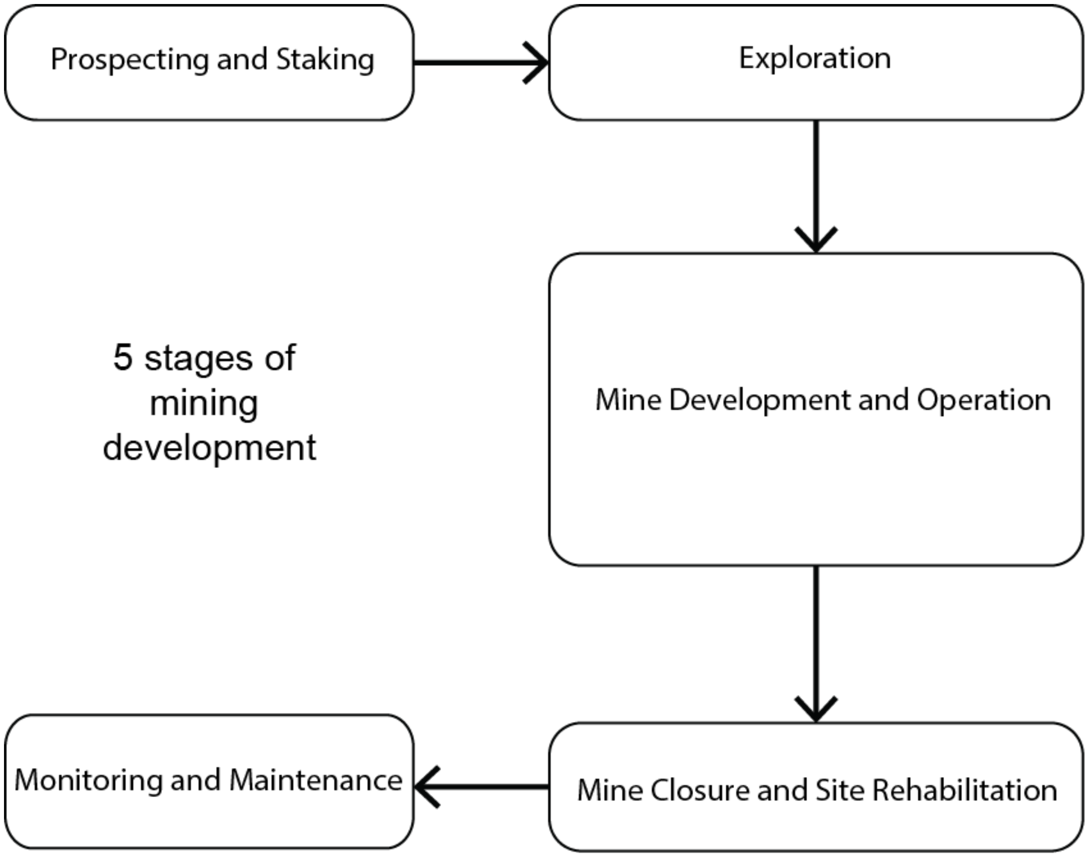


Figure 2. Five stages of mining development adapted from Ontario Nature (2012).

2.1.1 Prospecting and Staking: Prospecting is the process through which potential mining sites are discovered. If prospectors believe that any site has potential for mining extraction (often based on exploring rock formations and an analysis of geological data), they can stake a claim that confers the legal right to further explore the area and conduct a feasibility study for mining development. Prospecting and staking are based on a “free entry system,” which gives the prospector the legal right to explore an area for mining even if the surface land is privately owned or traditionally reserved for Aboriginal communities (Ontario Nature, 2012). Historically, the concept of a “free entry system” provided priority for mining over other land uses. Provincial policies take an economic perspective to strategic land use decisions related to mining activities. Current provincial policy states that “[e]xtraction of minerals and petroleum resources is permitted in prime agricultural areas, provided that the site is rehabilitated” (MMAH, 2014, p. 27). The “free entry system” caused significant conflict between agricultural and mining activities in many municipalities in Ontario. Despite a recommendation that companies consult with local neighbourhoods and Aboriginal communities (Mining Act, 1990), there are numerous cases of dissatisfaction and legal conflicts between mining companies and local communities due to a lack of regulation regarding how to establish consensus among stakeholders (Hart, 2012). However, the recent amendment to the Mining Act (2009) requires that all mining companies consult with Aboriginal communities (but not other land owners) and reach a consensus-based Impact and Benefit Agreement (IBA) before proceeding with extraction. The "modernization" of the Ontario Mining Act also restricts future staking on all private lands in the southern part of the province and provides an option for private landowners to request that their property be "withdrawn" from the lands available for staking (MNDM, 2009). However, most crown and private lands, which are not presently under restriction, can still be claimed and used for mining, as mining is given priority over other uses that may have other economic, cultural, or environmental value.

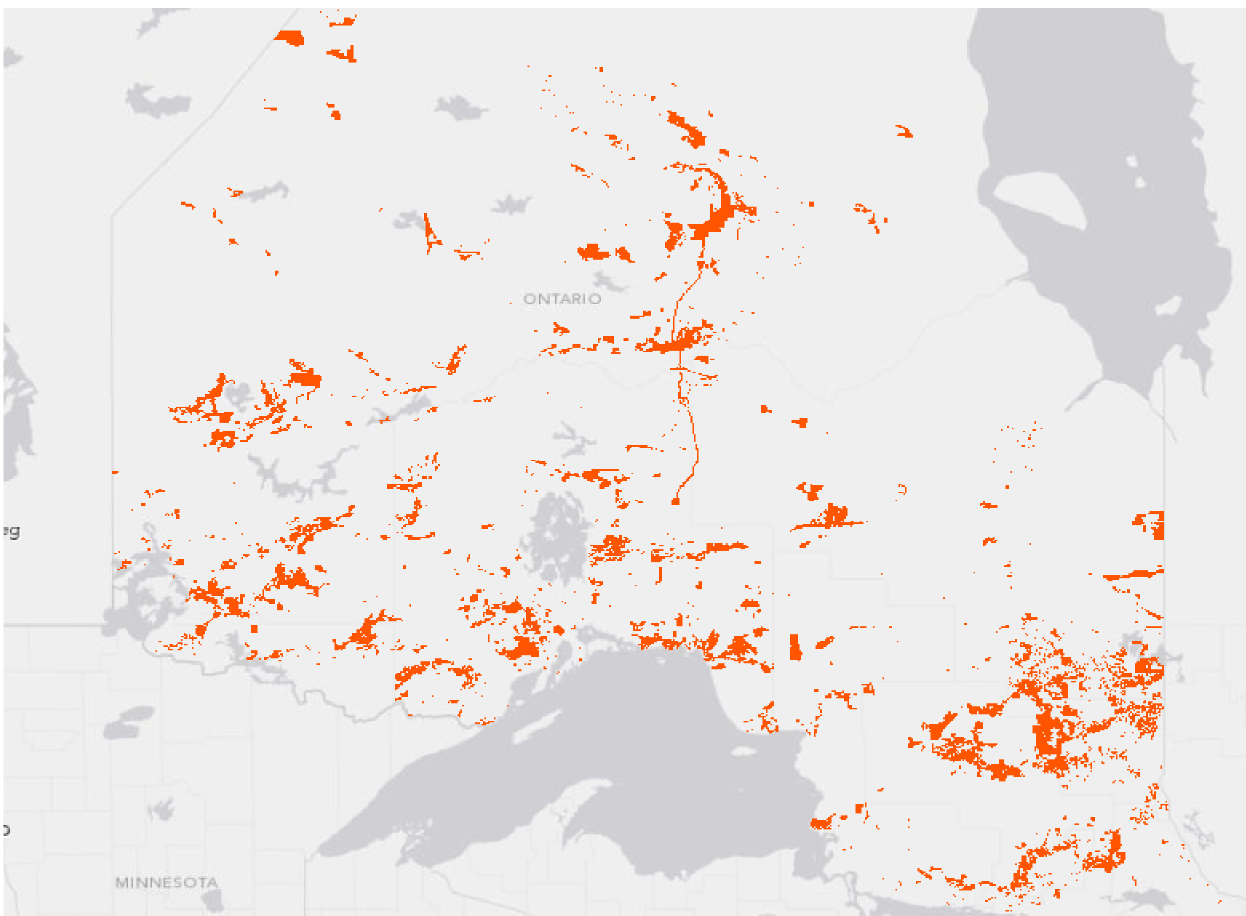


Figure 3. Active claims in Northern Ontario (MNDM, All Mining Claim Data, 2014).

2.1.2 Exploration: After staking, mining companies generally start two levels of exploration: primary and advanced. The purpose of primary exploration is to identify the capacity of the mining site and record the detailed geological structure of the site to determine the feasibility of mining production. During the advanced level of exploration, an area can be permanently damaged due to large-scale removal of vegetation and soil. The Mining Act has limited jurisdiction to control exploration (Ontario Nature, 2012). Any exploration of up to 10,000 square metres of land does not require a closure plan or rehabilitation. The cumulative impact of the large number of current explorations can result in significant environmental impact in a region. Figure 3 indicates the number of active mining claims and, by accumulating them, demonstrates the immensity of the impacts that might be caused by these exploration activities.

2.1.3 Mine Development and Operation: If potential economic viability is found, a mining facility may be built. A mining development can include an open pit or underground mining construction, road infrastructure development, soil and vegetation stripping, ore extraction, crushing and tailing, smelting, and many other associated activities (Ontario Nature, 2012). From the extraction of natural ores to the processing of metals, there are always residues left for disposal. The following sequence briefly explains the mining process and potential impact of the waste it produces:

a. **Ore Extraction:** Ore is a naturally occurring source of a metal that can be economically extracted from rocks. From both open pit and underground mines, ore is separated from the surrounding rocks. Open pit mining commonly disturbs more land surface and Earth material than underground mining (Fox, Hudson, & Plumlee, 1999). Large volumes of waste rock are created during the open pit mining process. The waste rock disposal areas that develop at an open pit mine sometimes cover hundreds or even thousands of acres (Fox, Hudson, & Plumlee, 1999). For underground mining, the size of the operation has less of an ecological impact because it produces less waste. It is common in underground mining for the volume of waste rock to be equal to or less than the volume of the ore produced. Waste rock may also be used to fill underground areas where access is no longer needed (Reynolds, 2002).

b. **Waste Rock Disposal:** Waste rock disposal areas are generally located close to the mine sites to minimize haulage costs. Waste rock of base metal mines may contain metals, such as lead, zinc, copper, or silver, but are still considered as waste because further processing would exceed the value of the metals it contains (Fox, Hudson, & Plumlee, 1999). If not properly managed, the erosion of mineralized waste rock may lead to contamination of surface water. Although contemporary mining facilities ensure that the permitted levels of metal concentration in adjacent bodies of water are maintained, conditions that do not meet current standards and regulations still exist, particularly in abandoned mining sites (Reynolds, 2002).

Figure 4. Mine effluent discharge from the bottom of a waste rock pile (Moncur, 2006).

Figure 5. Massive accumulation of iron hydroxides on a pond bottom (Moncur, 2006).

Potential Impact of Waste Rock Disposal: The most common environmental impacts caused by waste rock disposal are:

1. Development of metal-bearing as well as acidic soils and waters through rainwater run-off;
2. Physical disturbances to the landscape;
3. Damage of vegetation and physical barriers to alternative land use.

c. Milling: Large rotating mills use metal balls and rods to grind the ore into tiny particles to the consistency of silt, sand, and clay. The objective is to break the ore into individual mineral grains.

The crushed and ground ore is transformed into water-rich slurry that is later processed to concentrate the valuable metals (Fox, Hudson, & Plumlee, 1999). “Floating” is the most commonly used concentration process for most of the base metal mines that contain sulphide ores. In this process, the water-rich slurry from the mill is passed through large vats containing special bubble-making chemicals or “reagents.” Then, “the vats are agitated and the metal-bearing minerals selectively attach themselves to the reagent bubbles and float off the surface of the vats. The non-valuable minerals remain as part of the water-rich slurry in the agitated vats until almost all of the valuable metal-bearing minerals have been floated off” (Fox, Hudson, & Plumlee, 1999, p. 27). After the valuable materials are stripped off, the slurry of waste product (tailings) is taken into large ponds called “impoundments” (Fox, Hudson, & Plumlee, 1999). Tailings are a primary waste product and a potential source of water contamination should the tailings leach into the water supply. Impoundments often require clearing more land to hold mine waste than the rest of the mine combined. The failure of containment structures (tailings dams) that hold this waste can result in a massive release of toxic tailings material (Ontario Nature, 2012).

Figure 6. Nickel tailings in Sudbury, Ontario, 1996 (Burtynsky, 1996).

Potential Impacts of Tailings: As mentioned above, tailings are the materials left over after the valuable metals are separated from the uneconomic elements of an ore. Tailings ponds are areas of mining tailings wherein the waterborne refuse material is pumped into a pond to allow for the sedimentation of solid particles from the water. The pond is generally impounded with a dam. These dams are known as tailings impoundments or tailings dams. The potential impact of tailings can be extremely harmful to ecological balance because of the possibility of leaching into natural water supplies. There are at least four potential impacts of tailings:

1. Leaching of residual chemicals into natural water supplies;
2. Erosion of tailings by wind and water;
3. Development of acidic soils and waters;
4. Contamination of fish habitats and other species.

One example of a tailings dam failure occurred near Matachewan, Ontario, in 1990, and released over 195,000 cubic metres of tailings into a nearby creek leading into the Montreal river (Ontario Nature, 2012). The failure of the tailings dam caused a massive release of toxic tailings materials, which were potentially harmful to waterways (Ontario Nature, 2012). Mining and geological experts, according to an interview with a mining-related professional (Semi-structured Interview, 2014), believe that improperly maintained tailings ponds can also result in the slow and ongoing release of undetected pollutants into the environment. One of the reasons that tailings dams can remain inadequately maintained is the flexibility of federal legislation (MMER, under the Fisheries Act), which allows for the use of natural bodies of water for the use of tailings, subject to a limited effluent concentration that is considered not harmful to water habitats (Hart & Hoogeveen, 2012; Mining Watch, 2009).

d. Smelting: Often, smelting facilities are constructed inside mining sites to produce further concentrated metals from their parent minerals which might be economically beneficial for available transportation facilities, water, and energy supplies. In the smelting process, the concentrated ore collected from the milling process is mixed with other materials known as "fluxes" and then heated in furnaces until it melts (Fox, Hudson, & Plumlee, 1999). Fox, Hudson & Plumlee (1999) point out that "as the metal-bearing minerals separate from the other materials, they accumulate in the bottom of the furnaces and are removed. The other constituents, primarily iron and silica, float to the top of the furnaces" (p. 37). After they are removed, they are cooled and dumped in form of slag. Often these large piles of dark-coloured slag are dumped near smelters, making it the most visible solid waste product created by the process (Fox, Hudson, & Plumlee, 1999).

In addition to slag, the other significant by-products from smelting are gases, which contain suspended particles. In base metal mines, the typical gaseous by-product is sulphur dioxide. In modern smelting facilities, the gases are collected as they rise off the top of the smelter furnaces, and are then treated to remove sulphur dioxide gas. The gaseous form of sulphur dioxide is recycled in the form of sulphuric acid, which is sold as a by-product of the smelting process (Fox, Hudson, & Plumlee, 1999).

Potential Impacts of Smelting: Historically, smelting wastes have had massive impact on environment. Once, Sudbury was known as the largest single source of acidic sulphur dioxide emission in the world because of three major smelters at Copper Cliff, Falconbridge, and Coniston, respectively (Strauss, 1992). A century of sulphur dioxide fumigation resulted 10,000 hectares of barren land and 36,000 hectares of stunted, open birch-maple woodland in the Sudbury area.

Figure 7. In 1971, Copper Cliff smelter introduced a superstack facility to diffuse the gaseous fumes over a larger area (writer).

Figure 8. Sulfide layer on the Earth due to the emissions of the Copper Cliff smelter (writer).

Based on a report in 1996, there are 119 million tons of slag stored at the Copper Cliff operation and 10 million tons on Falconbridge land. A negligible amount of slag is recycled for use in road construction in Copper Cliff; otherwise, no environmentally acceptable use has been found for this waste material (Winterhalder, 1996). The main problems with slag are the physical disturbances and aesthetic impact associated with large slag piles that cannot support vegetation (Fox, Hudson, & Plumlee, 1999).

2.1.4 Mining Closure and Rehabilitation: Although the average lifetime of a mining production in Canada is relatively small (15-20 years), the time it requires to neutralize ecological impact can take hundreds of years (Ontario Nature, 2012). Most of the major mining sites in Ontario started their mining activities at the beginning of 20th century and subsequently expanded to surrounding areas (Jewiss, 1983). Due to a lack of regulations on mining closure and rehabilitation, mining companies were able to abandon their mining sites without any kind of rehabilitation process. Many abandoned mining sites were left with the traces of decades of mining production and dumping wastes. The Kam Kotia Mine in Timmins, for example, started its large-scale mining production at the beginning of 1940s and has been labelled one of the worst environmental disasters in Ontario because of massive-scale, acid-infused water pollution caused by the leaching of sulphur dioxide from the abandoned mine tailings (Reynolds, 2002). Kam Kotia ceased production in the 1970s but the surrounding natural environment continues to be adversely affected by the unrestricted pollution of the past (Reynolds, 2002). Although significant rehabilitation measures have been taken by the Ministry of Northern Development and Mines, many believe that it might take another 50 years to neutralize the adverse impact of the mining wastes (Louiseize, 2008).

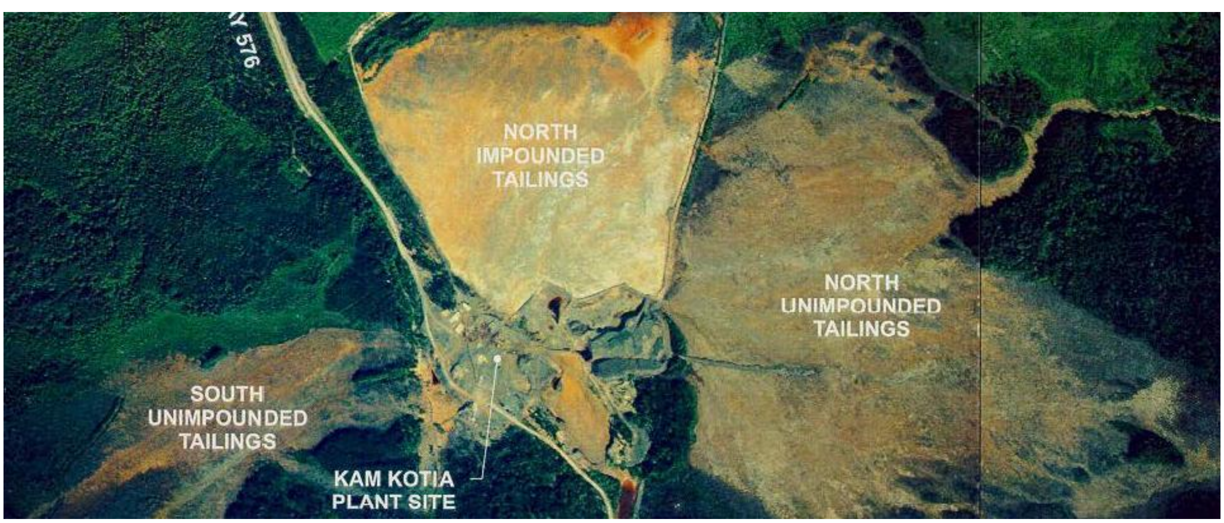


Figure 9. Kam Kotia mining site, Timmins, 1989.
source: http://www.miningwatch.ca/sites/www.miningwatch.ca/files/Kam_Kotia_air_photo_1989_0.pdf

Before 1992, Ontario had no legislation to mandate, ensure, or direct mine closures. Mining companies were able to abandon mines without rehabilitation, leaving all liabilities for rehabilitation measures to the province. The modernization of the Mining Act in 2009 made it mandatory that all mining companies have a closure plan in place and provide financial assurance to Ministry of Northern Development and Mines (2009). Mining companies are also required to update their closure plan and rehabilitation measures at regular intervals and to revise rehabilitation costs. However, concerns remain as to whether the laws are truly adequate to deal with a "worst case scenario" where decades of care required to mitigate ecological damage (Hart & Hoogeveen, 2012). Moreover, the province is currently overburdened with thousands of abandoned mining sites that require a long-term rehabilitation process. In 2005, an Ontario Auditor General's Report revealed that:

- There are at least 5,700 abandoned mine sites in the province, dating from the early 1900s;
- 4,000 of the abandoned mine sites may be hazardous to public health and safety;
- 250 of these sites pose an environmental risk due to potential leaching of minerals and other contaminants from mine tailings;
- In 2005, closure plans were not in place for 18 of the 144 mine sites that were required to have them;
- In 2005, about half of the closed mine sites that require regular follow-up inspections had not been inspected in over five years; and
- The Ministry of Northern Development and Mines has little evidence to prove that the financial assurances provided by mining companies are enough to ensure that mines are properly closed and maintained.

2.1.5 Monitoring and Maintenance: Both abandoned and existing mines require periodic monitoring and maintenance. A monitoring program is usually assessed by the mining company and the concerned government body. The monitoring and maintenance of an abandoned mine is governed by the Ministry of Northern Development and Mines and regulated by the 2009 Mining Act. The main purpose of monitoring is to identify how well the reclamation measures are working after the closure of a mine.

On the other hand, the management of active mine pollution is managed by Environment Canada under the Canadian Environmental Protection Act of 1999. Environment Canada enforces this and other protective laws and regulations to ensure that the level of environmental impact from mining and other industries remains at a minimum. There are two basic monitoring systems that are linked with scrutinizing the control of metal mining effluents:

- Environment Canada monitors, on a yearly basis, the metal mining effluents at downstream water points to ensure that the discharged substances are below the permitted level. The Ministry monitors mining wastes via the Metal Mining Effluent Regulations (MMER) under the Fisheries Act. It is notable that the MMER did not change the limits set in 1977 for mine effluent concentrations of arsenic, copper, lead, nickel, zinc, and radium-226, despite the fact that allowable levels for these metals are lower in many other countries (Hart & Hoogeveen, 2012). Nevertheless, in Ontario, in 2010, half of the 20 operating metal mines reported levels that were above the limit for effluent requirements. Although most of the levels did not greatly exceed the limit, several mines repeatedly reported serious issues, including a high concentration of effluents in waterways, which are lethal to fish habitats and other species. In 2001, MMER included an Environmental Effects Monitoring (EEM) program with the goal of assessing the overall effects of discharged metal effluents and testing whether the regulations are sufficient for the protection of water and fish habitats (Fisheries and Oceans Canada, 2014). Only two EEM reports have been published to date, both of which comprise a broad overview of the average effects of metal effluents (in mining and other industries) across Canada. Unfortunately, the conclusion of the report is limited by its broad-scale analysis and consequent lack of information regarding specific mine sites or regions.

- Environment Canada’s National Air Pollution Surveillance Network (NAPS) provides air quality data that is used to support the reporting of Canadian Environmental Sustainability Indicators (CESI). Air quality data for air pollutants such as sulphur dioxide (SO_2), carbon monoxide (CO), nitrogen dioxide (NO_2), ozone (O_3) and particulate matter (PM) are measured at approximately 300 stations in 200 communities in the ten provinces and three territories (Environment Canada, 2013). Air monitoring data indicate pollution levels at sampling sites only and may not necessarily represent community-wide air quality and hence not necessarily represent the air quality of adjacent areas of mining sites (Environment Canada, 2013). Community-wide comparisons can only be made by using data from all available sampling stations in a region, and interpreting them on the basis of specific monitoring site characteristics which are often difficult to accumulate.

The above review of mining process, potential impacts, and the role of various mining-related regulations, helps to understand the prevailing condition of mining activities in Ontario. This study helps to identify the various parameters (such as volume of waste, area of tailings, amount of discharged waste and proximity to sensitive areas) used to test mining sites and identify the degree of possibility for contamination. A priority ranking method that prioritizes these parameters was employed to identify a case study for a more in-depth analysis through land use planning in order to understand how the mining process and its consequent environmental impact affects the growth and patterns of adjacent communities.

2.2 METHOD OF STUDY FOR PRIORITY RANKING OF BASE METAL MINES

While this study investigates the impacts of mining activities in communities in Northern Ontario, it is well recognized that both abandoned and existing mining sites have significant impacts on the natural environment (AMEC, 2008). This research focuses on base metal mines because they produce a high volume of toxic wastes (metal and other substances). It is apparent that the pattern of contamination (considering metal and other toxic substances) to soil, air, and downstream water is similar for both active and abandoned mines (AMEC, 2008) (Environment Canada, 2014). Therefore, the priority ranking developed in this study for active and abandoned mines follows a similar approach. Two types of parameters are used to prioritize active and abandoned mining sites:

1. Priority ranking parameters based on produced wastes; and
2. Priority ranking parameters based on proximity to sensitive terrestrial features (water and settlements).

However, due to the differences in the physical conditions of abandoned and active mines, and the differences in available data, the parameters used for measuring wastes are not the same for active and abandoned mining sites. Table 1 below shows the differences in data sets for active and abandoned mines. Despite having differences in parameters, the scope of these analyses is to produce a short list of mining sites (active and abandoned) to identify the settlement areas in Northern Ontario that are most prone to the environmental effects of mining activity. This analysis will help to identify an area for case study, in order to further investigate how communities are experiencing physical changes (such as land use change) because of long-term mining activities.

Table 1: *Methods of Analysis for Active and Abandoned Mining Site.*

Data Set	**Method of Analysis**	
	1. Priority ranking parameters based on produced wastes	**2. Priority ranking parameters based on proximity to terrestrial features**
Active base metal mines	• Mean production capacity • Amount of pollutant discharge • Incidence of exceeding permitted limits **Data Source:** National Pollutant Release	• Proximity to human habitation • Proximity to downstream receivers **Data Source:** NPRI GIS data and

	Inventory (NPRI, Environment Canada, 2006-2012) and status reports on water pollution prevention and control (Environment Canada)	ArcGIS Based Map
Abandoned base metal mines	• Size of tailing areas • Volume of tailing areas • Waste rock dumping areas • ARD potential • Effluent limit in nearby water **Data Source:** AMEC Report on assessment of mine tailings sites located throughout Ontario, Ministry of Northern Development and Mines, 2008	• Analysis of proximity to human habitation • Proximity to downstream receivers **Data Source:** MNDM GIS data

After analyzing the two types of parameters in terms of mining waste and distance from sensitive features, both active and abandoned mining sites are ranked based on their average points. After finalizing the priority ranking of active and abandoned mines, the mining areas are mapped by geo-referencing to identify the regions that are at a higher risk of threat from mining-related contaminations. This identification is used to select an area for further research on changing patterns of settlement areas but it would also be useful for future research by providing a data inventory of potential mining threats in Northern Ontario.

2.3 DATA COLLECTION AND PRIORITY RANKING SYSTEM OF EXISTING BASE METAL MINES

This part of the analysis focuses on all active base metal mining sites in Northern Ontario to investigate their production capacity, amount of pollutant discharge, and threat to the adjacent natural and built environment. The purpose is to identify and analyze a short list of mining activities that have the potential to affect the ecological and physical qualities of adjacent communities.

2.3.1 IDENTIFICATION OF DATA SOURCE: One of the main challenges in identifying the potential threats posed by active mining sites is a lack of accessible environmental assessment data. The contamination of soil, air and water is a continuous process that is often only exposed in the event of a major impact. So-called minor incidents, such as exceeding the limit of effluent discharge, do not garner adequate media or political attention despite their cumulative impact via gradual processes of contamination of adjacent landscapes. To identify the existing base metal mining sites and prioritize their potential threats of contamination, this research has to rely on existing data that are available from multiple sources and provincial and federal databases. With regard to metal mines, two types of monitoring protocol have been identified and analyzed as primary data for the priority ranking of mining sites. These are as follows:

1. Status reports on water pollution prevention and control, as determined by the Metal Mining Effluent Regulations. These reports are periodically prepared by Environment Canada. The data includes the amount of discharge of eight effluent substances and pH level of discharge points. These reports also identify which mining sites have exceeded the prescribed limit of suspended metals and exceeded the recommended pH level.

In addition, these reports summarize the performance of Canadian metal mines with respect to the selected standards prescribed by the Metal Mining Effluent Regulations under the Fisheries Act, which came into accord in 2002. The present research uses these metal discharge exceedance reports as one of the data sources in prioritizing which mining sites present the greatest environmental threat. However, since the MMER data is only concerned with downstream water pollution and fish health, it is insufficient in the identification of other potential sources of environmental impact such as soil and air contamination.

2. The National Pollutant Release Inventory (NPRI) is Canada's legislated and publicly accessible inventory of pollutant releases and transfers. This is the most comprehensive inventory of pollutant release data in Canada, and it includes the total amount of on-site air pollutant emissions, water discharge, land discharge and recycling transfer. The present research uses this data as primary indicators to identify potential environmental threats and their consequent impact on land use in adjacent communities.

2.3.2 PRIORITY RANKING SYSTEM AND PARAMETERS: For this study, a weighted scoring system is used to prioritize the mining sites in order to identify the degree of threat they pose to the environment and adjacent communities. The parameters and priority scores are selected via consideration of their significance with respect to potential contamination. The two types of priority ranking, their parameters, scoring points, and scoring brackets are as follows:

Table 2: *Parameter Units and Scoring Brackets Based on Waste Production.*

<table>
<tr><th>Parameters (unit)</th><th>Parameter Weight</th><th>Scoring Bracket
Adapted from (AMEC, 2008)</th></tr>
<tr><td>1. Average on-site air emission of five years, 2006-2010, (kg.)</td><td>5</td><td rowspan="3">a. 0-10000= 1
b. 10001-50000=2
c. 50001-100000=3
d. 100001-500000=4
e. >500000=5
f. NA=1</td></tr>
<tr><td>2. Average on-site water discharge of five years, 2006-2010, (kg.)</td><td>5</td></tr>
<tr><td>3. Average on-site land discharge of five years, 2006-2010, (kg.)</td><td>5</td></tr>
<tr><td>4. The production Capacity of the mines, 2006-2010 (Ton/Day)</td><td>5</td><td>a. 100-1000= 1
b. 1001-10000=2
c. 10001-25000=3
d. 25000-50000=4
e. >50000=5
f. NA=1</td></tr>
</table>

5. The number of incidents of exceeding prescribed limit of pollutants, 2006-2012	5	a. 1-2=1 b. 3-5=2 c. 6-10=3 d. 11-15=4 e. >15=5 f. NA=0
6. Average pollutant recycling transfer of five years, 2006-2010, (kg.) (The mining sites which have recycling facility to transform wastes into alternative uses have negative value to add with the total point)	5	Negative value of: (Score Points of total on-site release X Total recycling) ÷ Total on-site release

Table 3: *Parameter Units and Scoring Brackets Based on Proximity to Sensitive Features.*

Parameters (unit)	**Parameter Weight**	**Scoring Bracket Adapted from (AMEC, 2008)**
1. Proximity to settlement areas (km)	5	a. 0-1 km = 5 b. 1<5 km =3 c. >5 km =1
2. Proximity to natural Water Course (km)	5	

First, two separate priority rankings were prepared based on waste production and proximity to sensitive features. The total value of the parameters for each mining site are arranged in descending order so as to identify the degree of potential threat posed by active base metal mining sites in Northern Ontario. Finally, a combination of these two rankings identifies the mining sites that pose the highest level of threat because of their higher production of mining waste and close proximity to sensitive features.

.

2.3.3 RESULT OF PRIORITY RANKING BASED ON WASTE PRODUCTION:

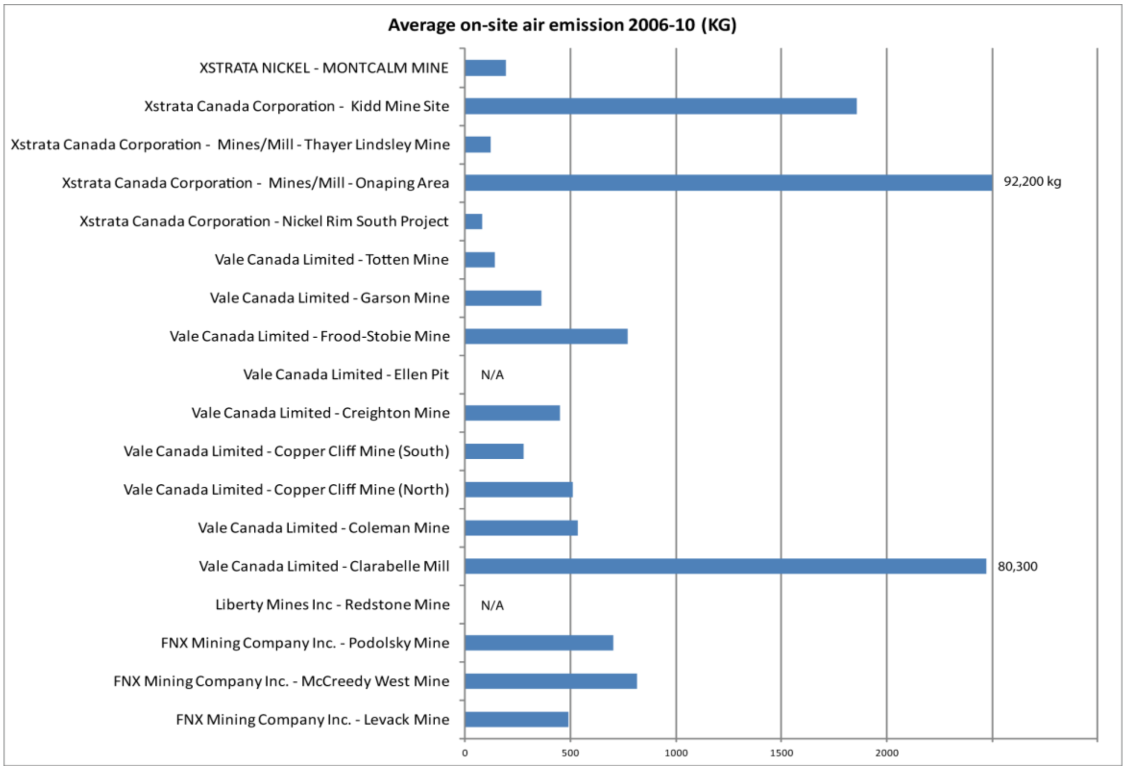


Figure 10. Average on-site air emissions of 18 mining sites between 2006 and 2012, prepared by the author; Data Source: CEC Facility Report (2012).

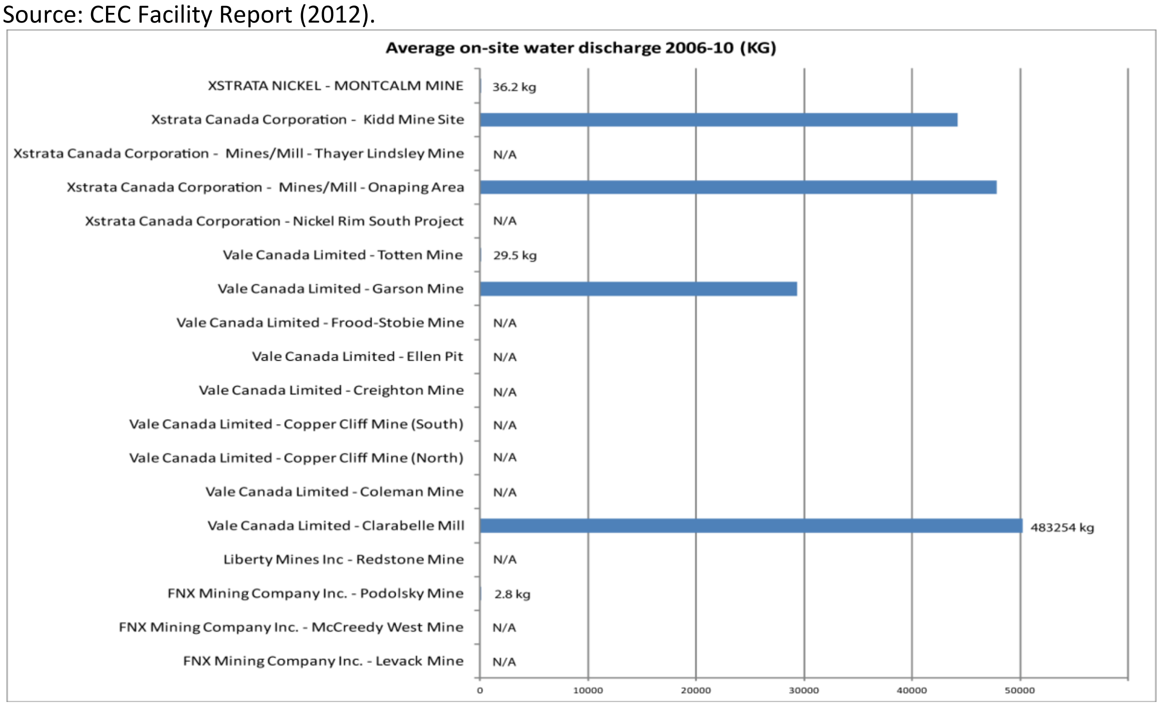


Figure 11. Average on-site water discharge between 2006 and 2012, prepared by the author; Data Source: CEC Facility Report (2012).

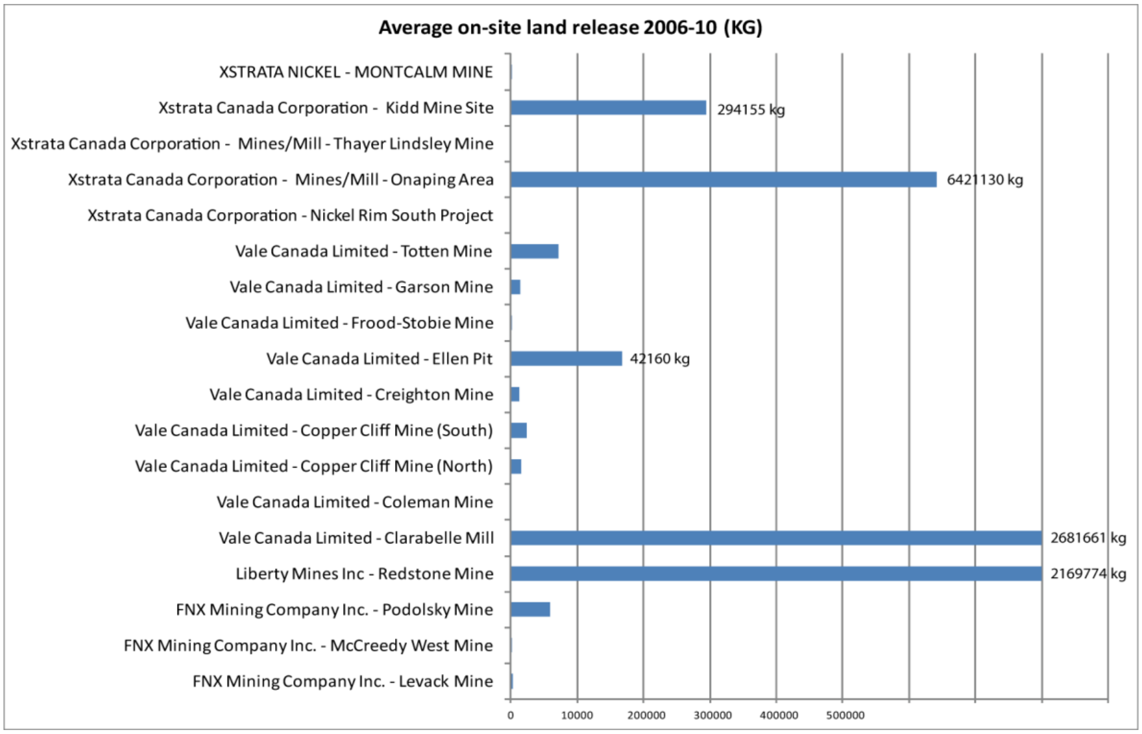


Figure 12. Average on-site land release between 2006 and 2012, prepared by the author; Data: CEC Facility Report (2012).

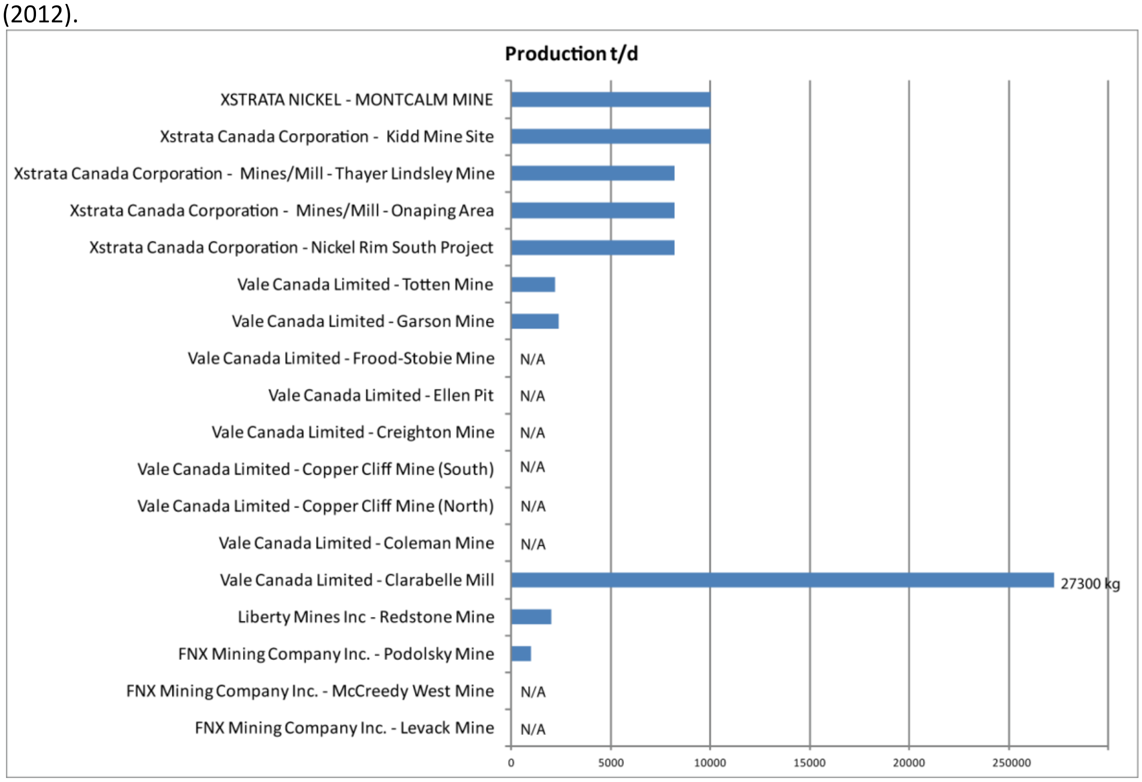


Figure 13. Average daily production between 2006 and 2012, prepared by the author; Data: CEC Facility Report (2012).

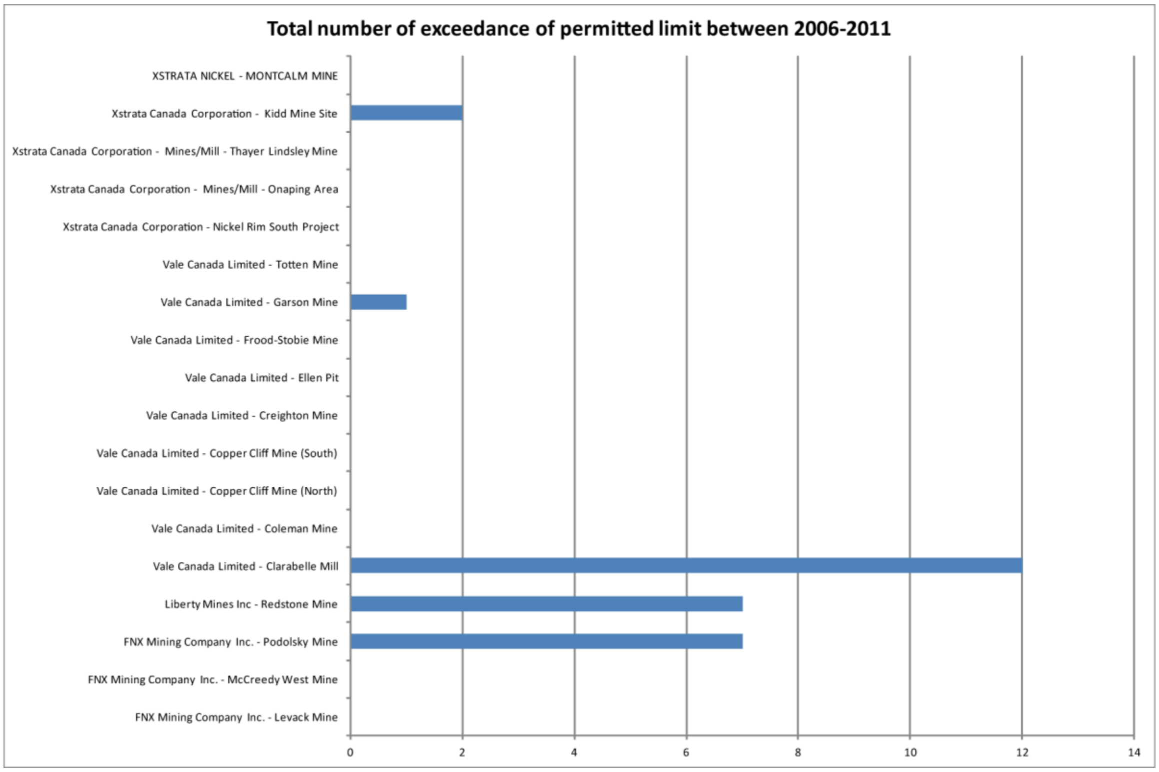


Figure 14. Total incidents of exceedence of the permitted level of pollutants in water discharge/treatment plant, prepared by the author; Data: Environment Canada (2012, 2011,2010,2008).

One of the limitations to the priority ranking of various waste productions is the lack of available data for the mining sites that reduced the accuracy of the ranking system. However, in cases where data is not available, the site is given a score of “1” (instead of “0”) so as to minimize the error. However, it is also apparent that, for most of the parameters, data for some mining sites are consistent and much higher than that of other mining sites. This indicates that the position of higher-ranked mining sites will be unchanged even if the missing data were available. The results of priority ranking based on mining wastes reveal that Clarabelle Mill in Copper Cliff has the highest rates of mining production, on-site land release, on-site water pollutant discharge and much higher air pollutant emissions when compared with other mining sites.

2.3.4 RESULT OF PRIORITY RANKING BASED ON DISTANCE TO SENSITIVE FEATURES:

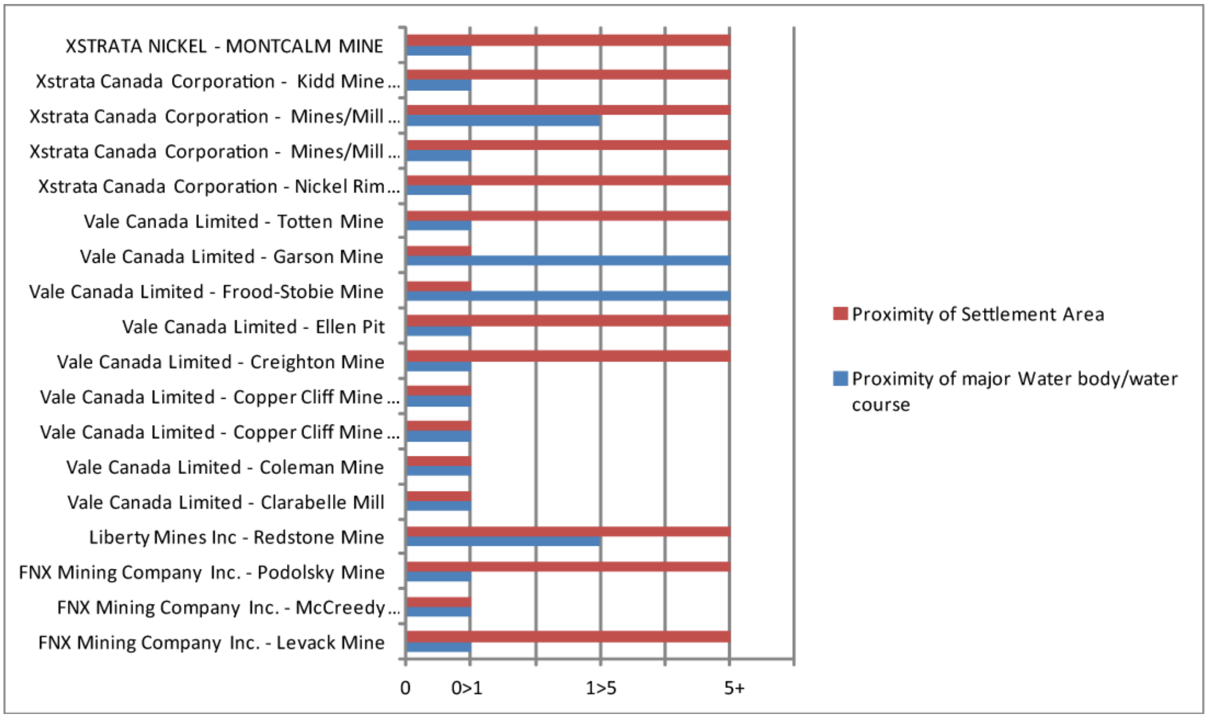


Figure 15. Proximity to settlement areas and natural water courses.

The proximity of mines to settlement areas and waterways are also considered to prioritize the mining facilities. The mining sites are categorized into three types based on their distance from settlement areas and natural water bodies. A higher ranking is given to mining sites that are less than one kilometre from settlement areas and water bodies while a lower ranking is given to sites that are greater than five kilometres from settlement areas and water bodies. This ranking identifies five mining sites that are located less than one kilometre from both settlement areas and natural waterways. Most of these sites are located in the Sudbury region.

Table 4: *Priority Ranking of Active Mining Sites to Explore the Degree of Threat on Adjacent Communities*

Facility Name	City/Region	Mine Types	Air Emission	Water Release	Land Release	Mining Production	Recycli-ng	Above Limit Occurrence	Proximity to Water	Proximity to Settlement Area	Total Score
Vale Canada Limited - Clarabelle	Copper Cliff/ Greater Sudbury	Nickel, copper, cobalt, platinum	3	4	5	4	0	4	5	5	20
Xstrata Canada Corporation - Onaping Area	Onaping/ Greater Sudbury	Nickel, copper, cobalt, platinum,	3	2	5	2	0	0	5	1	18
Liberty Mines Inc - Redstone Mine	South Porcupine/Timmins	Nickel	1	1	5	2	0	3	3	1	16
Xstrata Canada Corporation - Kidd Mine Site	Timmins	Zinc, copper, cadmium, cobalt, selenium, silver,	1	2	4	2	0	1	5	1	16
Vale Canada Limited - Coleman Mine	Levack/Greater Sudbury	Nickel, copper, precious metals	1	1	1	1	0	0	5	5	14
Vale Canada Limited - Copper Cliff Mine (North)	Copper Cliff/ Greater Sudbury	Nickel, copper, precious metals	1	1	1	1	0	0	5	5	14
Vale Canada Limited - Copper Cliff Mine (South)	Copper Cliff/ Greater Sudbury	Nickel, copper, precious metals	1	1	1	1	0	0	5	5	14
FNX Mining Company Inc. - Podolsky Mine	Sudbury	Nickel, copper, precious metals	1	1	2	1	0	3	5	1	14
FNX Mining Company Inc. – McCreedy West Mine	Levack/Greater Sudbury	NA	1	1	1	1	0	0	5	5	14
Vale Canada Limited - Garson Mine	Garson/ Greater Sudbury	Nickel, copper, cobalt, platinum	1	2	1	2	0	1	1	5	13
Xsatrata Nickel - Montcalm Mine	Timmins	Nickel, copper, cobalt	1	1	1	2	0.69	0	5	1	11.69
Xstrata Canada Corporation - Thayer Lindsley Mine	Val Caron/ Greater Sudbury	Nickel, copper, cobalt, platinum, palladium	1	1	1	2	0	0	5	1	11

Xstrata Canada Corporation - Nickel Rim South Project	Skead/Greater Sudbury	Nickel, copper, cobalt, platinum	1	1	1	2	0	0	5	1	11
Vale Canada Limited - Totten Mine	Worthington/Greater Sudbury	Nickel, copper, precious metals	1	1	1	2	0	0	5	1	11
Vale Canada Limited - Ellen Pit	Denison Township	Nickel, copper, precious metals	1	1	1	1	0	0	5	1	10
Vale Canada Limited - Frood-Stobie Mine	Sudbury	Nickel, copper, precious metals	1	1	1	1	0	0	1	5	10
Vale Canada Limited - Creighton Mine	Lively/Greater Sudbury	Nickel, copper, precious metals	1	1	1	1	0	0	5	1	10
FNX Mining Company Inc. - Levack	Levack/Greater Sudbury	NA	1	1	1	1	0	0	5	1	10

2.3.5 SUMMARY OF PRIORITIZED ACTIVE MINING SITES: According to the National Pollutant Release Inventory (Environment Canada, 2014) and the Commission for Environmental Cooperation (2009) there are 18 base metal mining sites in Northern Ontario that are active and list pollution release data on their inventories. However, not all of them are included in the periodic status report under Metal Mine Effluent Regulations because they are not regulated by them. Table 4 outlines the eight parameters and correspondent scoring for all 18 mining sites (see Appendix 1 for detailed site priority ranking). The data set illustrates that some of the mining companies that have a higher production capacity and higher pollutant discharge had more incidents in which they exceeded the permitted level of pollutants as set by MMER (see Figures 10-16). At these mining sites, the production, pollutant discharge, and frequency of exceeding limits are extensively higher than that of most other sites. Among all mining sites, only 38% are located adjacent to settlement areas; most of these are ranked higher in the priority list. Moreover, most of these more highly ranked mining sites are also adjacent to natural waterways. As a result, it is apparent that these mining sites pose a greater threat to adjacent communities and the natural environment, and should thus be prioritized in selecting the case study for this project.

Figure 16 below illustrates the concentration of active mines in different regions. It indicates that the active mines that pose the highest degree of threat are located in the cities of Sudbury and Timmins. However, a greater number of the mining sites in Sudbury are less than one kilometre from settlement areas and natural waterways.

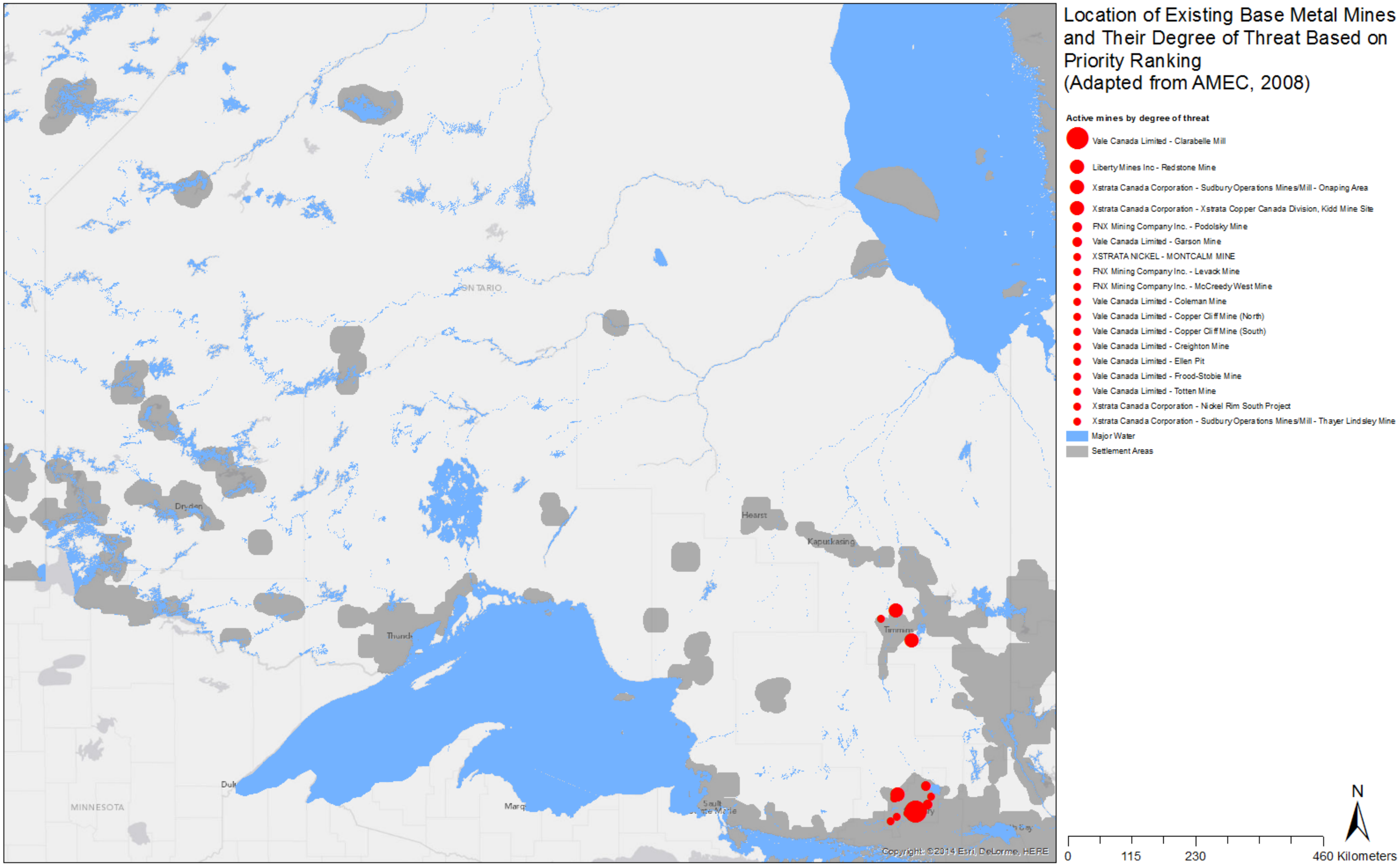


Figure 16. Locations of active base metal mines in Northern Ontario.

2.4 DATA COLLECTION AND PRIORITY RANKING SYSTEM OF ABANDONED BASE METAL MINES

This part of the analysis focuses on abandoned base metal mining sites in Northern Ontario to investigate the volume and size of their tailings areas, waste rock dumping areas, acid rain drainage (ARD) potential, as well as the water quality of adjacent waterways and the threat to adjacent natural and built areas. The purpose of this part of the analysis is to identify and analyze a short list of abandoned mining sites that contain the potential to affect the ecological and physical qualities of adjacent communities. From a land use perspective, abandoned mines are also important to investigate not only because they present varying degrees of threats but also because of their historical existence and long-term impact on adjacent communities.

2.4.1 IDENTIFICATION OF DATA SOURCE: The Ministry of Northern Development and Mines is the principal provincial authority that monitors, assesses, and rehabilitates all abandoned mining sites in Ontario. This part of analysis uses the existing data inventory of abandoned mines from MNDM and adapts their priority ranking system. However, taking into account the existing research and reports of environmental NGOs, the proposed ranking system also includes mining sites that are not included in MNDM reports but that are considered to be significant for potential environmental impacts. The MNDM identifies 95 abandoned mining sites to inspect the degree of threat and prioritize rehabilitation. The findings of their inspections are as follows (AMEC, 2008):

- 116 tailings areas;
- 113 waste rock areas;
- 52 containment structures (dams, berms, or dykes);
- 14 mine sites that have the potential to affect human habitations; and
- 24 mine sites that have the potential to affect the natural environment.

Seventeen of the base metal mining sites in this list have been analyzed for priority ranking in order to understand the degree of threat they present to adjacent communities.

2.4.2 PRIORITY RANKING SYSTEM AND PARAMETERS: The parameter setting and priority ranking system is primarily adapted from the MNDM tailings study report. However, since the present study only focuses on the environmental impacts and related consequences on land use patterns in adjacent areas, it is beyond the scope of the study to consider the physical hazards and related parameters identified by the report. Based on the findings of the MNDM tailings study (AMEC, 2008), two sets of parameters are identified as significant factors for potential environmental impact on adjacent areas: first, parameters based on the production of waste and the potential for contamination; and second, parameters based on the distance of mines from sensitive features.

Table 5: *Parameters and Scores of Abandoned Mining Sites, Based on Waste and Contamination.*

Parameters and Unit	**Parameter Weight**	**Scoring Bracket** **Adapted from (AMEC, 2008)**
1. Total Size of the Tailing Area (ha)	5	a. > 100 ha = 5 b.51 – 100 ha = 4 d.26 – 50 ha = 3 e.11 – 25 ha = 2 f.1 – 10 ha = 1 h. N.A. (Not Applicable)= 0
2. Total Tailing Volume (m^3)	5	a. > 1 Million = b.500,001 – 1 Million = 4 c.100,001 – 500,000 = 3 d.10,000 – 100,000 = 2 e. < 10,000 = 1 f. N. A. (Not Applicable) = 0
3. Total Waste Rock Volume **(m^3)**	5	
4. Acid Rain Drainage (ARD) Potential	5	a. High (Likely or Possible ARD potential) = 5 b. Low (Low ARD potential) = 1 c. None (No ARD potential) = 0
1. Water quality of adjacent water sources Scoring guideline: Metal effluent limit under Metal Mining Effluent Regulations (MMER), and Provincial Water Quality Object (PWQO) guidelines	5	a. Above MMER Effluent Limits (Score = 5) b. Above PWQO (Score = 3) c. Marginal PWQO (Score = 1) d. Below PWQO (Score = 0)

The tailings area is generally the most contaminated area at any abandoned mining site. The size and volume of the tailings area is chosen as one of the parameters because it influences the potential waste water runoff, acid drainage, and downstream leaching. The waste rock volume may also have an impact through acid rain drainage and wastewater run-off. There are few sites without waste rock dumping areas which are categorized as "not applicable." The data from surface water samples was compared to the Provincial Water Quality Objectives (PWQO) as well as the monthly Effluent Limit criteria in O. Reg. 560/94 of Metal Mining Effluent Regulations (AMEC, 2008).

Table 6: *Parameters and Scores of Abandoned Mining Sites, Based on Distance to Sensitive Features.*

Parameters (Unit)	Parameter Weight	Scoring Bracket Adapted from (AMEC, 2008)
1. Proximity to settlement areas (km)	5	d. 0-1 km = 5 e. 1<5 km =3 f. >5 km =1
3. Proximity to natural Water Course (km)	5	

2.4.3 RESULTS OF PRIORITY RANKING BASED ON WASTE AND CONTAMINATION:

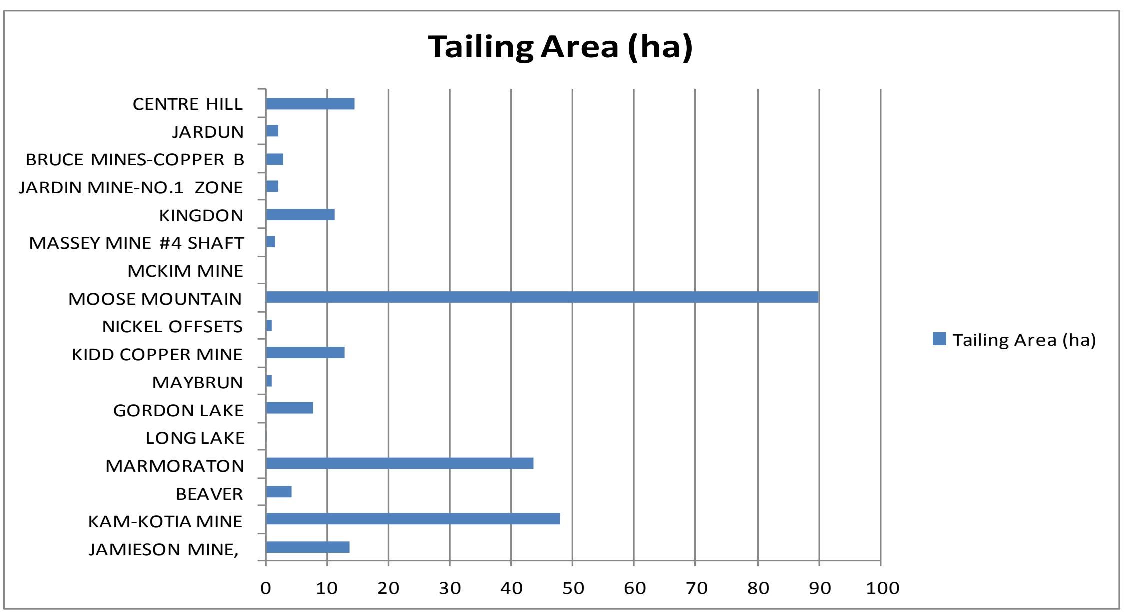


Figure 17. Comparison of area of tailing basins of 17 abandoned base metal mines, prepared by the author; Data: AMEC (2008).

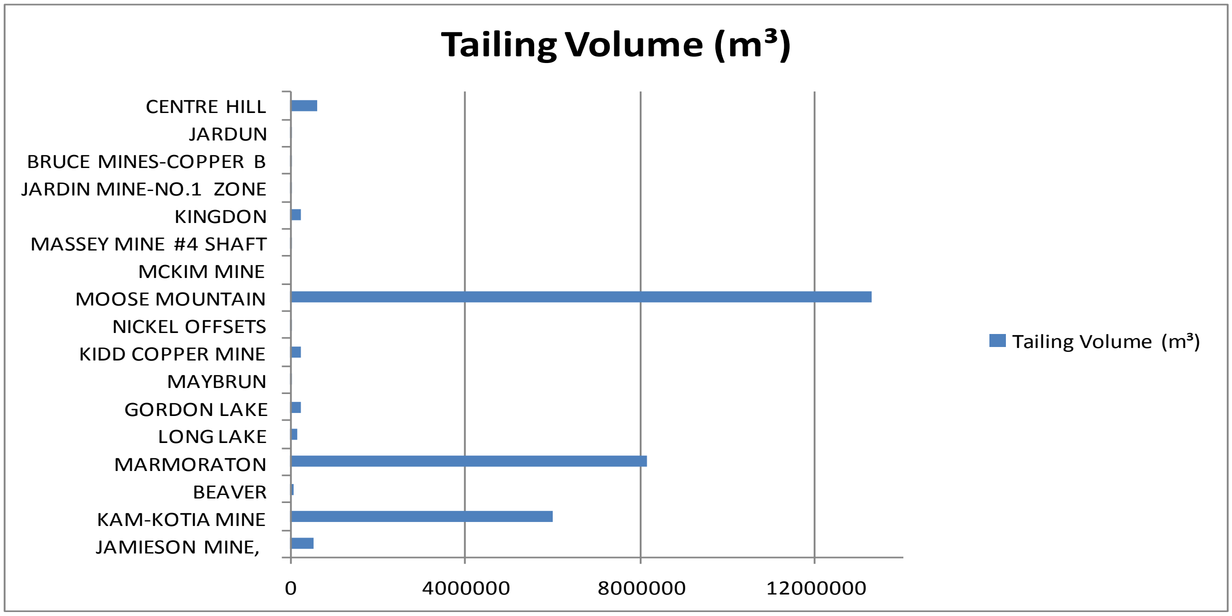


Figure 18. Comparison of tailing volumes of selected abandoned base metal mining sites, prepared by the author; Data: AMEC (2008).

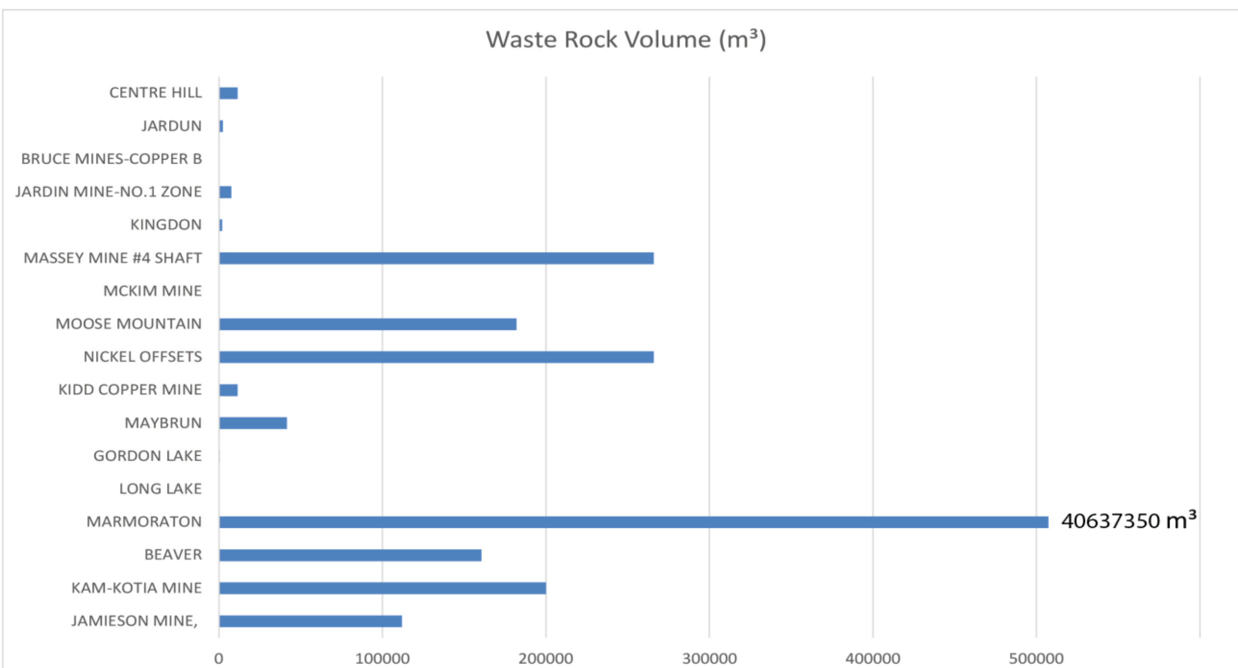


Figure 19. Comparison of waste rock volumes of selected abandoned base metal mining sites, prepared by the author; Data: AMEC (2008).

The comparison of volume of waste, tailings, and contamination potential among abandoned mining sites suggests that larger sites and tailings areas pose greater threats than smaller mining areas. This trend is similar to that of active mining sites.

2.4.4 RESULTS OF PRIORITY RANKING BASED ON PROXIMITY TO SETTLEMENT AREAS AND WATER SOURCES:

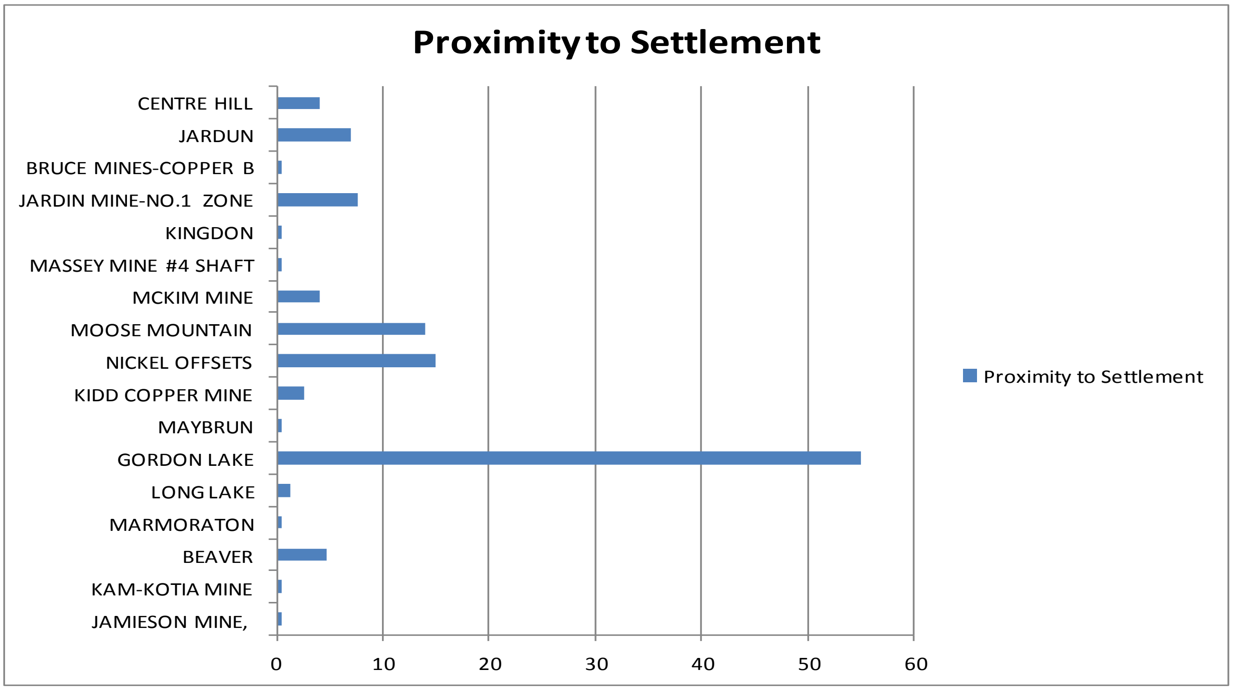


Figure 20. Proximity to settlement areas from tailing areas of abandoned mining sites.

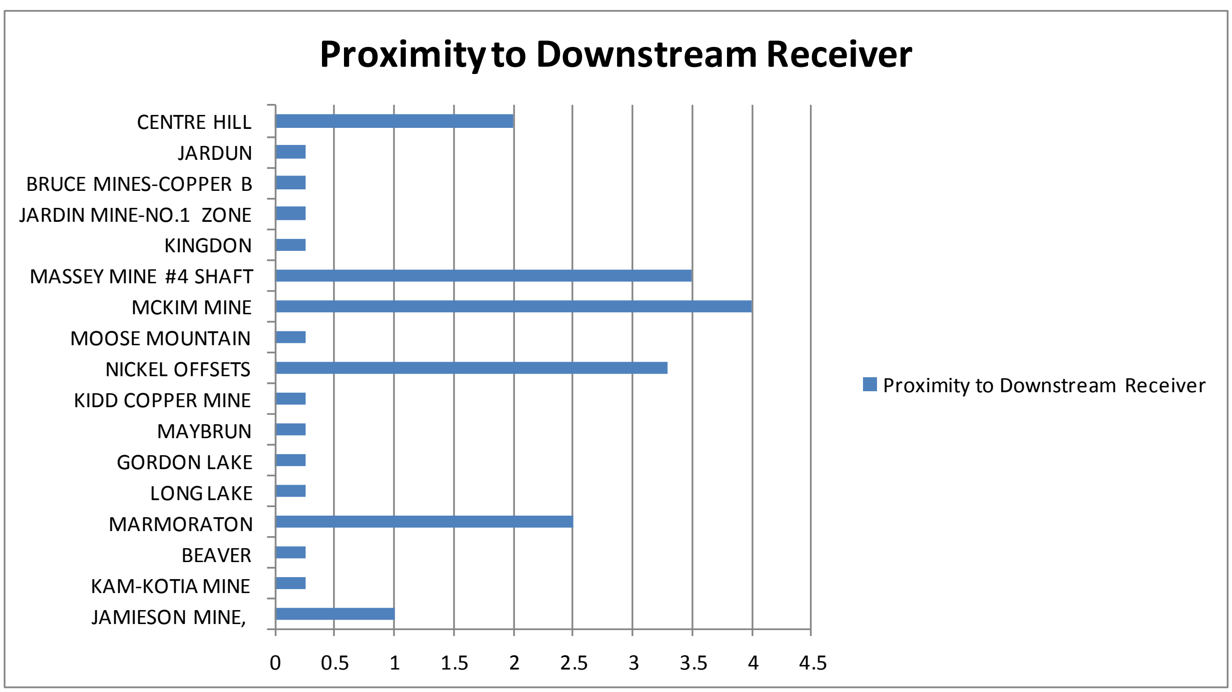


Figure 21. Proximity to downstream receivers from tailing areas of abandoned mining sites.

Table 7: *Priority Ranking of Abandoned Mining Sites, Based on Amount of Waste and Potential for Contamination.*

Facility Name	City/Region	Mine Types	Tailing Area (ha)	Tailing Volume (m3)	Waste Rock Volume (m3)	ARD Potential	Water Quality (MMER & PQWO Parameters)	Proximity to Water (km)	Proximity to Settlement (km)	Total Score
Kam-kotia Mine	Timmins	Copper	5	5	5	5	5	5	3	33
Jamieson Mine	Porcupine, Timmins	Copper	2	4	5	5	5	3	5	29
Kidd Copper Mine	Sudbury	Nickel	2	5	2	5	5	5	3	27
Maybrun	Kenora	Copper	1	2	2	5	5	5	5	25
Centre Hill	Larder Lake	Nickel	2	4	2	5	5	3	3	24
Long Lake	Sudbury	Zinc	1	5	0	5	5	5	3	24
Gordon Lake	Kenora	Nickel	1	5	1	5	5	5	1	23
Bruce Mines-Copper B	Sault Ste Marie	Copper	1	2	0	5	5	5	5	23
Beaver	Larder Lake	Lead	1	2	5	1	5	5	3	22
Nickel Offsets	Sudbury	Nickel	1	2	5	5	5	3	1	22
Massey Mine #4 Shaft	Sudbury	Copper	1	2	5	5	0	3	5	21

Moose Mountain	Sudbury	Iron	4	5	5	0	0	5	1	20
Jardin Mine-No.1 Zone	Sault Ste Marie	Lead	1	2	1	5	5	5	1	20
Jardun	Sault Ste Marie	Lead	1	1	1	5	5	5	1	19
Mckim Mine	Sudbury	Nickel	0	0	0	0	0	3	3	6

2.4.5 SUMMARY OF PRIORITIZED ABANDONED MINING SITES: This part of the analysis uses the data inventory of all abandoned mining sites in Ontario, as collected by MNDM under its Abandoned Mines Rehabilitation Program. In total, 17 base metal mining sites, two of which are located in Southern Ontario, are inspected and assessed by MNDM's tailings study (AMEC, 2008). One of the limitations of the present analysis is the lack of available data for all abandoned base metal mining sites. However, it is assumed that the identified metal mines in AMEC's (2008) study include most of the major mining sites. Moreover, apart from the list provided by the AMEC report, the present research also includes other mining sites which are reported for significant environmental impact by environmental NGOs. The final list consists of 15 abandoned mining sites located in Northern Ontario.

Although the Kam Kotia mine has been rehabilitated in five phases and is not included in AMEC's report, the present analysis includes the site in priority ranking system for the following reasons:

- The 500-hectare footprint of the Kam Kotia mining site is considered to be the largest and worst case of contamination among all abandoned mining sties in Ontario (Louiseize, 2008);
- The site contains 6 million tons of highly sulphide-rich wastes, one of the largest volumes of tailings;
- It remains one of the worst cases of contaminant leaching directly to adjacent water sources;
- It may take 50 years to completely remove the contaminants from the site (Louiseize, 2008).

From the analysis of prioritized abandoned mining sites (see Table 7, and Appendix 2 for more details), it is apparent that high priority is given to the abandoned mining sites which have a large volume and of tailings areas, a high risk of acid rain drainage, evidence of water pollution and close proximity to water and settlement areas. Table 6 indicates that Kam Kotia is identified as the most hazardous threat to environmental contamination despite being considered rehabilitated for many years by Ministry of Northern Developments and Mines. The high volume of tailings and close proximity to water sources has made the area vulnerable to toxic waste leaching and acid rain drainage, which has been recorded as a source of water contamination in recent years (Louiseize, 2008). Jamieson Mine, located in the Porcupine region near Timmins, is ranked as the second-most hazardous mining site. Similar to Kam Kotia, the Jamieson Mine contains a high volume of tailings and waste rock. In addition, this mining facility is located in close proximity to the settlement area, which may result in a greater risk from the perspective of quality of life of adjacent communities. Both of these mining sites are located in Timmins.

From Table 6, it is apparent that: 80% of abandoned mining sites contain a high probability of acid rain drainage; 80% of have a high record of exceeding the limit of effluent discharge in water; 67% are in close proximity to natural waterways; and 27% are in close proximity to human settlements. While most of the top-ranked mining sites are in close proximity to natural waterways, only Jamieson Mine in Porcupine and Mayburn mine in Kenora are adjacent to settlement areas and thus may have a potential impact on the adjacent settlement areas. In the context of the city, the result of the prioritized abandoned mining list indicates that Timmins faces the greatest risk of potential impact on human and natural communities considering higher waste production, effluent discharge and close proximity to waste and settlement areas.

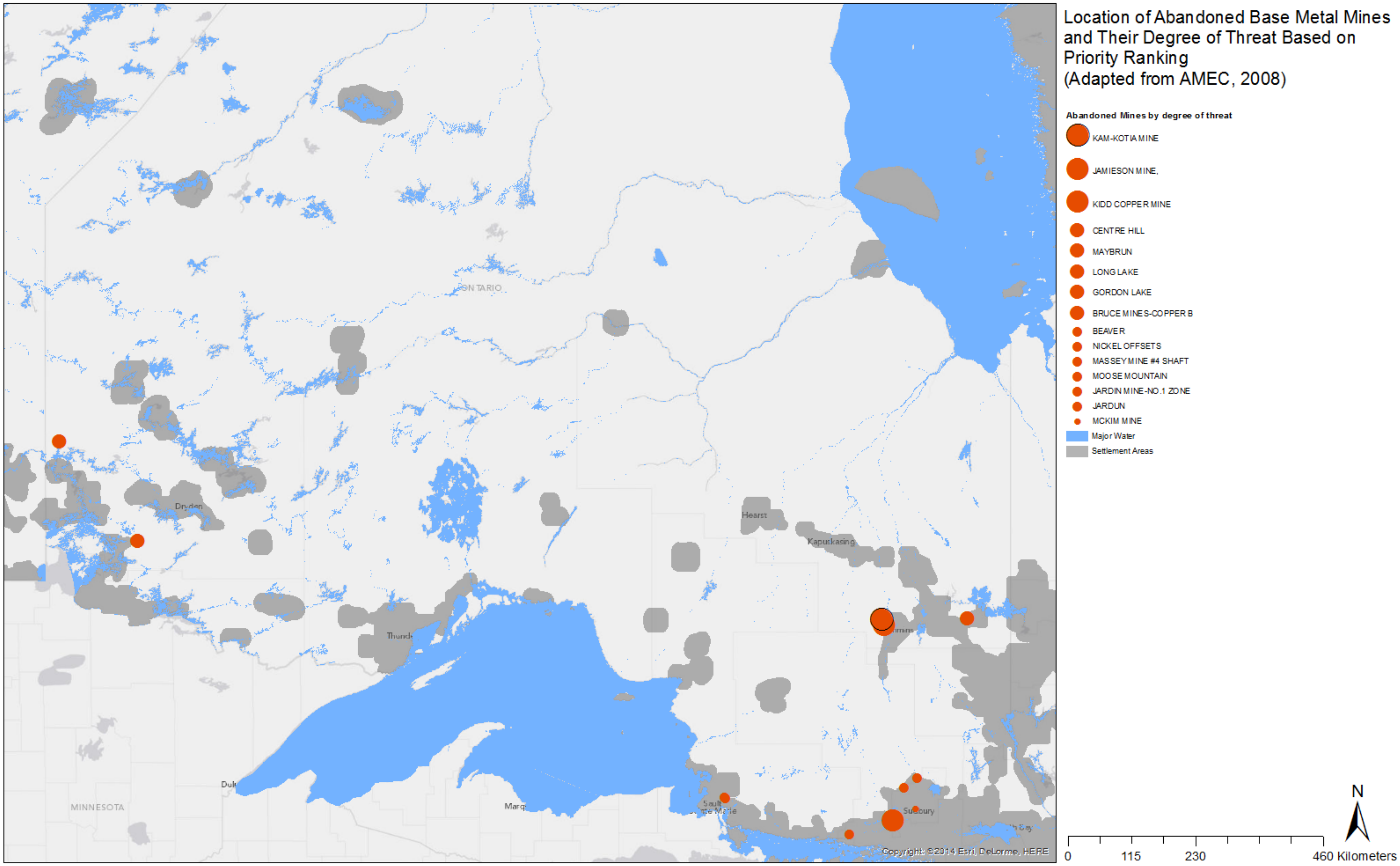


Figure 22. The location of abandoned base metal mines in Northern Ontario.

2.5 DEGREE OF THREAT FROM REGIONAL CONTEXT: From the data analysis of all prioritised mining sites, it is clear that most of the active threats (both active and abandoned mining sites) are located in either Greater Sudbury or Timmins region. Figure 23 shows that 78% active mines and 35% abandoned mines which have potential threat to adjacent communities are located in Sudbury region. Figure 24 also clarifies that as a region Sudbury is more prone to large scale ecological damage and human impacts because of higher number of mining sites close to water courses, large scale water bodies and human settlements.

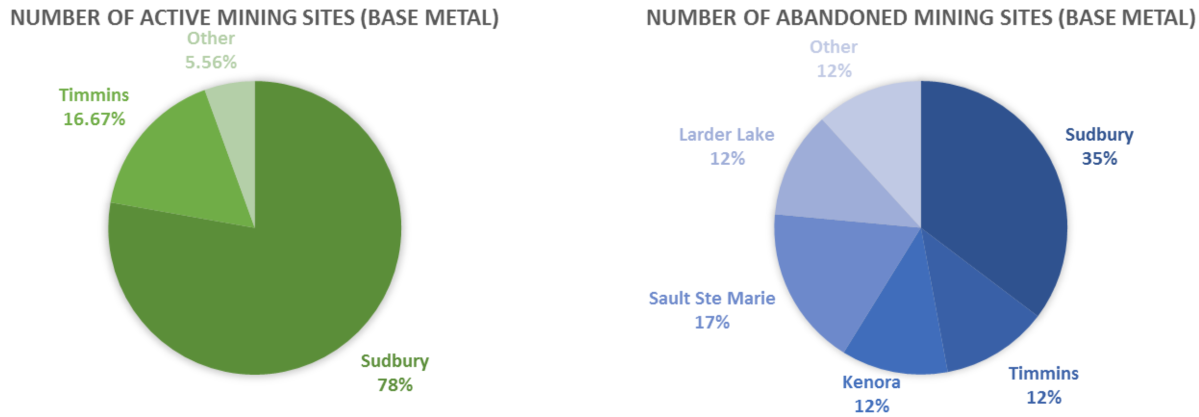


Figure23. Percentage of base metal mining sites in municipal regions that are identified based on prioritized ranking.

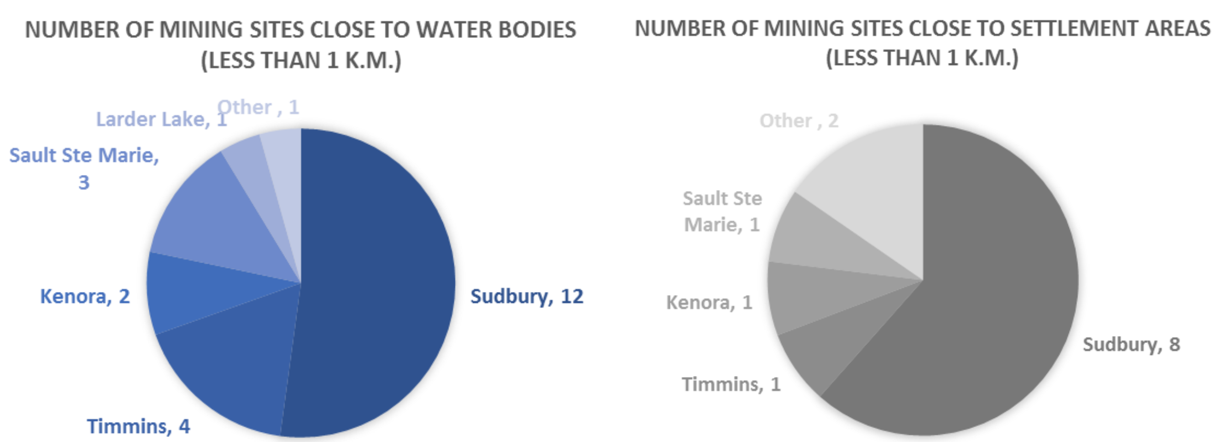


Figure 24. Number of all base metal mining sites close to waterways and human settlements in municipal regions based on prioritized ranking.

The history of the mining industry in Sudbury illustrates a century's worth of waste dumping, water contamination, and pollution caused by smelters. At one time, the city was the largest source of air and soil contamination by sulphur dioxide (Strauss, 1992). It is evident that Sudbury is the only region in

Ontario where mining companies are directly dumping their tailings into the adjacent lakes (Mining Watch, 2012). The environmental degradation that Sudbury notoriously experienced in 1960s and 1970s is still visible and affecting thousands of hectares of lands in the inner-city region. Because of the close proximity to core settlement areas of Sudbury, it would be useful to identify a mining site from this region as a case study for additional research.

3.0 A STUDY OF THE IMPACT OF MINING ON SETTLEMENT PATTERNS (CASE STUDY)

The priority ranking of active and abandoned mining sites indicates that the mining activities of the Copper Cliff area in Sudbury, which comprises two mining sites—a processing mill (Clarabelle mill), and a smelter facility—are together producing the largest amount of waste in Ontario. This waste takes the form of airborne chemicals, slag, waste rock, and tailings dumps. A comprehensive soil monitoring study completed by the City of Greater Sudbury revealed similar results by testing 11 concentrations in the urban soil from 1971-2000 (Jones, Fiore, Davis, & Eby, 2001). The study results identified that the highest levels of soil contamination in Sudbury occurred in the Copper Cliff area (see Appendix 3). The greatest concentration of soil contamination (metal) was evident within 7-10 km from the historical smelting facility at Copper Cliff. Prior to 1972, before the Copper Cliff Superstack was introduced to spread out the gaseous fumes into the sky to mitigate local pollution, the air pollutants from Sudbury's smelter facilities caused chronic effects on thousands of hectares of land. An earlier study by Dreisinger and McGovern (1969) includes a pollution map of the Sudbury region (between 1953 AND 1967), which illustrates that the airborne pollutants discharged by the smelting facilities in Copper Cliff, Falconbridge, and Coniston caused various levels of soil contamination and acidic precipitation over the whole region. Massive soil contamination resulted from the sulphur dioxide, copper, nickel, and iron particulate fallout from the smelters, which were carried as far as 20-35 kilometres from the smelter facilities and which severely damaged the landscape in Sudbury (Winterhalder, 1996).

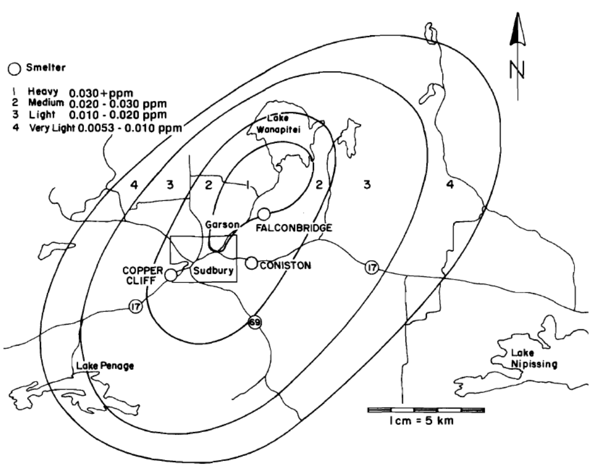


Figure 25. Map of the pollution zone based on air borne pollution of 1950s and 1960s.

Source: (Winterhalder, 1996)

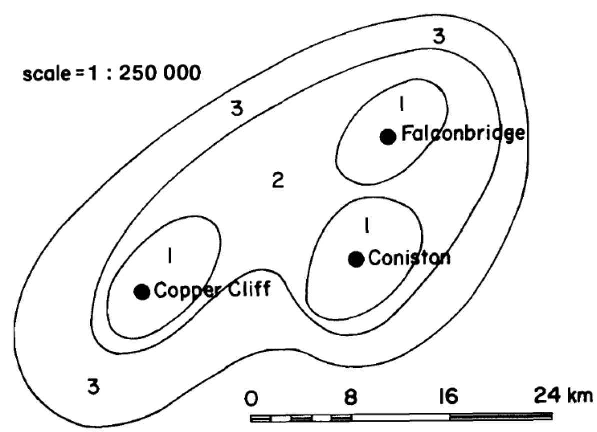


Figure 26. Zones of vegetation damage in the 1970s.
Zone 1: Sites left completely barren
Zone 2: Sites left semi-barren
Zone 3: Unaffected sites
Source: (Winterhalder, 1996)

A second major waste product from Sudbury's mining industry is the production of slag. Copper Cliff alone stores 119 million tons of slag near the mining operation; there are no longer trees in this area, which creates a physical barrier in the city (Winterhalder, 1996). Moreover, in 1995, the tailings area at the Copper Cliff facility covered more than 2,225 hectares of land and stored approximately 450 million tons of waste (Winterhalder, 1996). These tailings areas are also of serious concern due to acid mine drainage and dust storms that occur when the surface dries out.

The case study area is located less than one kilometre from the large-scale water source of Meatbird Lake, the human settlements in Copper Cliff, and the central Sudbury city area, all of which provide an opportunity to investigate how the mining activities have affected land use patterns in the area. Another reason why the Copper Cliff area is chosen is because of the availability of data on contaminants from the comprehensive soil monitoring study completed jointly by the City of Sudbury and the Ministry of the Environment. Soil monitoring has been periodically recorded from the 1970s through to 2013. Satellite data for studying the historical changes of land use patterns is also available through Landsat data from the U.S. Geological Survey, NASA, and Google's Earth Engine. The satellite data demonstrates how the mosaic of various land uses, including mining activities and area of impact, may be interacting with each other within a given time frame.

3.1 PRECEDENT[1]: Settlement in the Sudbury region began with the westward expansion of the Canadian Pacific Railway (City of Greater Sudbury, 2012), which resulted in the discovery of nickel in late 19th century (Wallace, 1996). Between 1900 and 1910, the provincial government invested in internal road connections between what was then the town of Sudbury, and the individual mining camps (Wallace, 1996). These internal connections later allowed Sudbury to develop into a centre for professional services (e.g., lawyers, doctors) and retail establishments that serviced the entire region. Over time, miners began to live in Sudbury rather than in camps surrounding the mines, and, within the town, high densities with poor servicing led to poor living conditions (Wallace, 1996).

After WWII, mining companies began to develop modern standalone towns due to the limited housing supply available in Sudbury, which resulted in the early suburbanization of Sudbury (Wallace, 1996).

[1] Precedent Study: This part of the writing has been extracted from a studio work 'Mining the new town' of School of Urban and Regional Planning, Ryerson University (Contributors: Alam, M.; McCaines, K.; Finley, B.; Miller, K., Plant, G.; Tetsaguzza, M.; Wu, H.; Cogliano, D. And McCartney, S.)

New residential and commercial development during the early 20th century began to sprawl into the area known as “the Valley.” Suburbanization led to the duplication and expansion of “hard” services, such as roads and sewage treatment plants, which led to high servicing costs due to the large distance to be covered (City of Greater Sudbury, 2012).

In the 1960s and 1970s, provincial regulation forced mining companies to reduce pollution (Wallace, 1996), and the municipality of Sudbury began its re-greening program. This program resulted in 3,300 hectares of land being remediated between 1978 and 2003 (Wallace, 1996). Due to international competition and increased mechanization, mining employment in Sudbury began to decrease in the mid-1970s (Wallace, 1996). This decrease created significant unemployment within the population, but led to Sudbury’s long-term economic diversification. This diversification was achieved as a result of the Federal and Provincial governments’ relocation of white-collar government jobs into the area, and the creation of new external connections via road and air that turned Sudbury into a regional service centre for Northeastern Ontario.

Despite having significant success in economic diversification, the mining industry continues to expand and still represents the leading employment sector in Sudbury. Although mining regulations and waste management processes have modernized and are far more stringent than they previously were, the City of Greater Sudbury can still be identified by 100 years of “unsustainable and unattractive mining practices that left the landscape blackened and devoid of most vegetation” (Winterhalder, 1996). The purpose of this study is to explore how these long-lasting impacts on Sudbury’s landscape interact with settlement patterns and what unique land use dynamics are associated with the mining activities.

Case Study: Copper Cliff Mining Facilities: Early studies (Winterhalder, 1996) indicate that, historically, the mining activities of Copper Cliff have contributed to massive ecological damage. At the beginning of the 1970s, a major part of the city of Sudbury, which includes the Copper Cliff area (10,000 hectares of barren land and 36,000 hectares of stunted woodland compared to 338,200 hectares of land in the Greater Sudbury area), was found greatly damaged by decades of sulphur dioxide fumigation, copper and nickel particulate deposits, leaching, and soil erosion (Winterhalder, 1996). The City of Sudbury Soil Survey reveals that the impact of the mining activities in Copper Cliff was most devastating in terms of ecological impact within a 10 kilometre radius, which includes the Copper Cliff residential area and a major part of the city core (Jones, 2001). This area of Copper Cliff impacted by mining activities (see

Figure 25) helps to identify the area of inquiry for the present study, considering its immediate impact on adjacent settlement areas. Figure 26 shows the Copper Cliff mining facilities within a 20 x 20 kilometre study area.

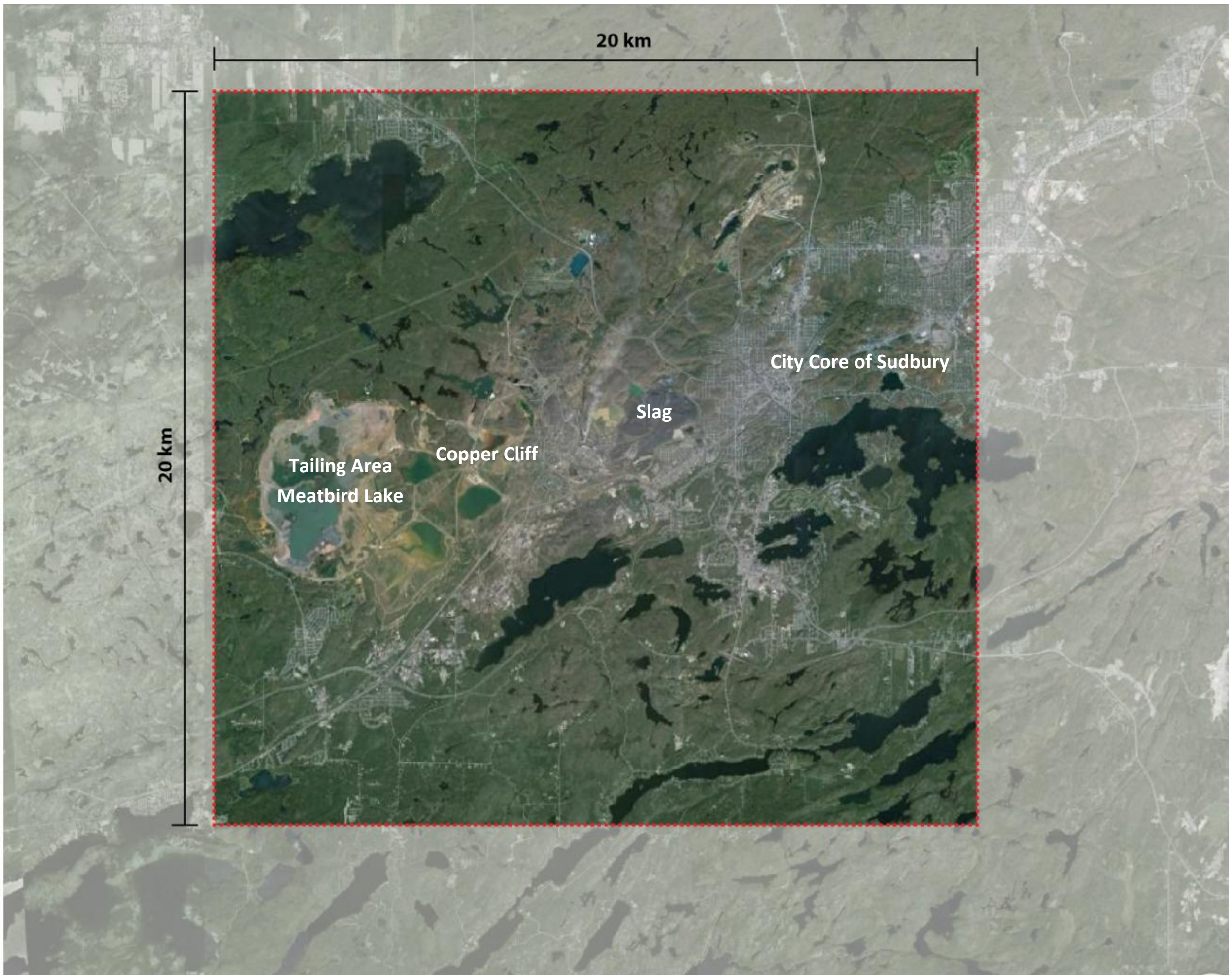


Figure 26. Study Area: Copper Cliff mining facilities and surrounding settlement areas (Copper Cliff and city core) Source: Google (2014).

3.2 METHOD OF STUDY

The purpose of this case study is to investigate how mining activities and the wastes produced as a result may have affected adjacent settlement patterns in Copper Cliff. The research hypothesis is tested primarily through the analysis of direct and indirect impacts on people and the natural environment. These impacts are investigated through an understanding of the land use dynamics of the study area. This research adopts Forman's (2008) "structure-function-change feedback" model to define land use dynamics and attempts to identify the role of mining activities in the changing pattern of land uses (p. 239). In Forman's (2008) feedback model, "structure" refers to the elements of land mosaic. Land mosaic is a composition of heterogeneous elements that are aggregated with different shapes in the landscape that define their boundary (Forman, 1995). Land mosaic "describes the pattern of elements that form a landscape in its entirety" (Forman, 1995, p. 5). "Function" refers to the land use types in this mosaic, while "change" refers to the transformation and alteration of land mosaics (Forman, 2008). Forman (2008) suggests, then, that structures or patterns of landscape help to control their function, which changes structures and, in turn, causes functions to change. The process of "structure-function-change" or "land-mosaic-function-land-change" is continuous and dependent on how land elements interact with one another. For example, a particular land mosaic, such as an industrial zone, may experience an increase in its production (i.e., function) and cause a high volume of discharge of toxic wastes, which will eventually change the soil conditions and damage adjacent vegetation (i.e., land change). The ecological damage might force the mining production to limit its waste production or perform rehabilitation to mitigate the changes to adjacent lands. In this way, structure-function-change contains a continuous feedback loop and creates a unique land use dynamic. The present research also added another layer of interaction identified as institutional feedback, which addresses changes in planning policies in response to changes in land mosaic. The following diagram illustrates this feedback loop of land use dynamics which is utilized in this research to investigate the changing pattern of the study area and its potential relationship with mining activities.

Structure (land mosaic) + Function → Change (land change) → Policy Response

Figure 27. Land use dynamics, adopted from Forman (2008).

1. **Land Mosaic–Function–Land Change:** The first segment of the investigation is a "land mosaic-function-land change" analysis, employed to identify the pattern of land mosaics, their functions, and their changing patterns. This segment of analysis investigates the physical changes of various land types, both natural and human-made, in order to understand their changing patterns and relationship to related functions. The "functions" of land mosaic in this case refer to specific uses and actions such as mineral extraction of mining areas, ecological function such as woodland areas or waterways, or food production in agricultural areas, among other things. The function of a specific land mosaic might impact a number of other land mosaics and influence changes in their physical patterns. The "land-mosaic-function-land-change" analysis may identify specific elements of land mosaic that are transferred or altered into other elements due to specific functions. This research speculates that this analysis may identify the role of mining activities in the changing patterns of surrounding areas. The approach of this analysis covers the following three sequences:

   a. Understanding a land mosaic; b. Composition of a land mosaic; and c. Configuration of a land mosaic and its function.

a. Understanding a Land Mosaic: Forman (2005) describes a "land mosaic" as a landscape or region consisting of a number of heterogeneous areas where similar types of objects are aggregated to form distinct boundaries. However, the land mosaic of a landscape and a region are distinct, primarily due to differences in scale. He writes that "from an airplane, land almost always appears as a mosaic. The individual trees, shrubs, rice plants, and small buildings are aggregated to form the pattern of patches and corridors on landscape" (Forman, 1995, p. 3). If we observe this landscape from a further distance in the sky, we do not see these details; rather, we see a mosaic of multiple landscapes. Forman defines this as a "region," which is a broad geographic area that consists of a number of distinctive landscapes. Regions are formed by a coarse-grained pattern because of the diversity in their ecological pattern and networks of natural and human-made elements. Due to the diversity of multiple landscapes, a region tends to be less repetitive in character and needs more data than a smaller landscape to be effectively analyzed. In contrast, although the elements of a landscape have noticeable boundaries, elements such as agricultural land, building blocks, and small waterways are more repetitive in nature. The structure of the land mosaic of a landscape is easier to analyze than that of a region, due to the lower number of land classifications and distinguishable structures. In this research, the boundary of the study area falls into the landscape category considering the smaller scale of land mosaic with repetitive patterns of bodies of water, green space, and built forms present. Figure 28 illustrates the differences in the patterns of land mosaic between the larger scale of the Sudbury region and the study area.

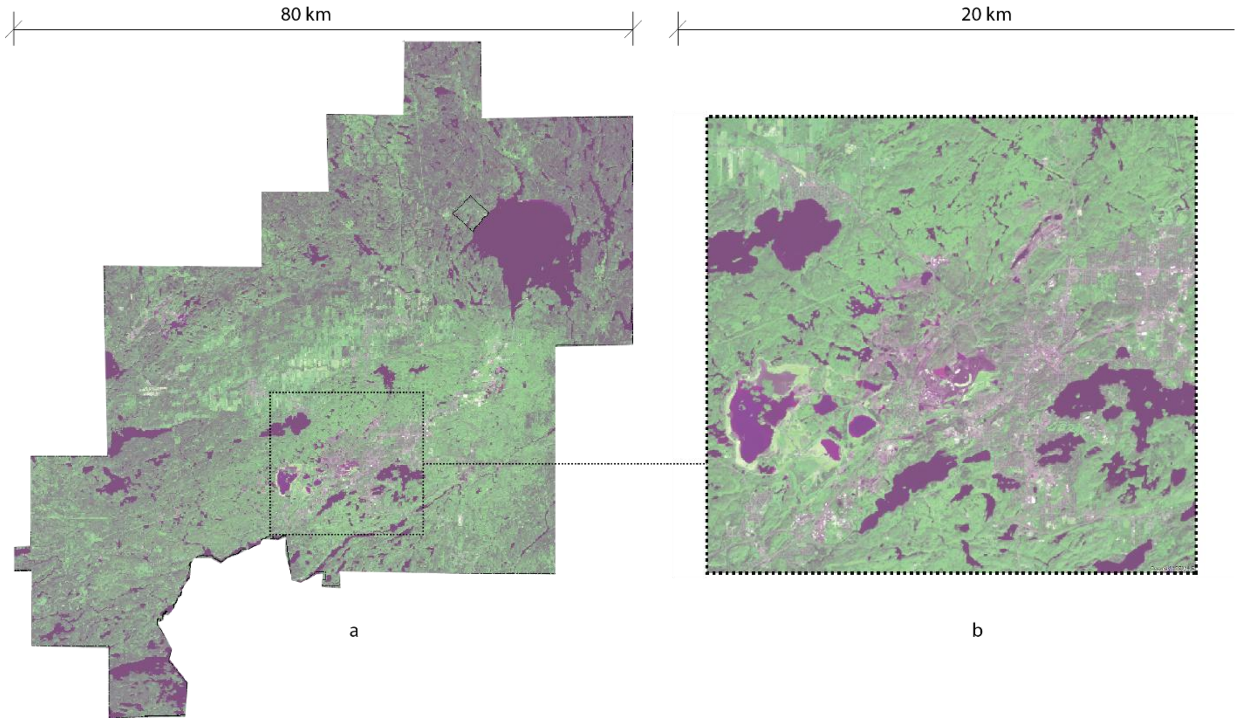


Figure 28. Land mosaic in regional and landscape scale. a) In regional scale the area includes large landscape of wood land (dark green), low height vegetation and flat lands (light green), network of water bodies (black) and settlement areas (grey); b) In landscape scale the area includes repetitive small scale water bodies (black), Agricultural parcels (light yellow-green) and built forms (light pink). Source: U.S. Geological Survey, (2013)

b. Composition of a Land Mosaic: Foreman (2005) writes that "every point in a landscape is either within a patch or inside a corridor, and this holds in any land mosaic, including forested, dry, cultivated, and suburban. This sample model provides a handle for analysis and comparison, plus the potential for detecting general patterns and principles" (p. 135). A "patch" is a relatively homogeneous area that differs from its surroundings. Patches have a definite shape and spatial configuration, and can be described compositionally by their shape and characteristics (Forman, 1995). A patch "can vary from large to small, elongated to round, and convoluted to smooth. Patches are the basic unit of the landscape that change and fluctuate over time. Their typically distinct boundary, plus the sharp difference in appearance or predominant land uses, provides a high contrast pattern that can be identified through observations" (Forman, 1995, p. 5). In contrast, a "corridor" is a linear connection between patches or a network of specific elements in the landscape, such as the network of an aquifer, a corridor of woodlands, or a network of transportation.

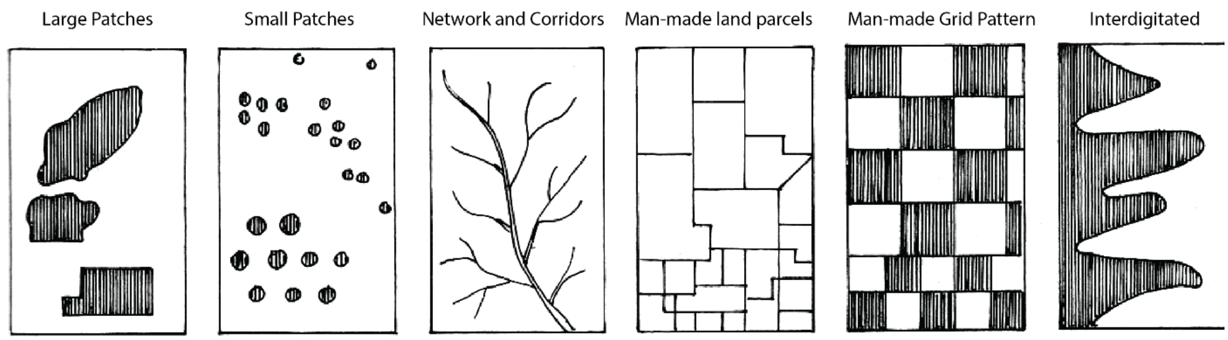


Figure 29. This image illustrates the different elements in a land mosaic adapted from Forman (1990). A landscape can be composed of any one or a number of these elements. The present research focuses on different sizes and shapes of patches, human-made parcels, and grid pattern developments. Natural corridors are not evident in the study area. As the transportation network is beyond the scope of this research, it is not considered in this analysis.

c. **Configuration of Land Mosaic and its Function:** The arrangement or structural pattern of patches and corridors that constitute a landscape is a major determinant of changes in its pattern and process over time (Forman, 1995). In this research, only patches are considered for analysis because natural corridors are not evident in the study area. The transportation network is beyond the scope of this research. To identify the structural pattern of the patches, this study makes use of satellite imagery and selected aerial photos to determine the land mosaics and their functions. Geographic Information System (GIS) data is used to extract the desired patches from the satellite imagery and to configure their characteristics such as shape and area. The following steps have been followed to identify different patches and their functions in the study area:

Step 1: To configure the land mosaic and identify its elements, a base map of Landsat 8 satellite geospatial images with a 30-metre cell size is generated from the website of the U.S. Geological Survey. Landsat 8 satellite images are represented by 2013 data, with 12 bands of colour spectra. Each band represents a particular electromagnetic spectrum (see Appendix 4). The data can be organized using a specific combination of colour spectra that has the ability to separate red, green, and blue, as well as more advanced bands. The use of a specific band combination can separate heterogeneous elements such as urban areas, forests, and bodies of water from each other.

Step 2: The Landsat 8 satellite data is then imported into ESRI ArcGIS 10.1 to manipulate the image by creating a desired combination of bands. This research uses a band combination of 7,4,2 (RGB) for Landsat 8, which is commonly used to separate urban forms and natural elements such as green plane and woodlands (see Appendices 5 and 6).

.

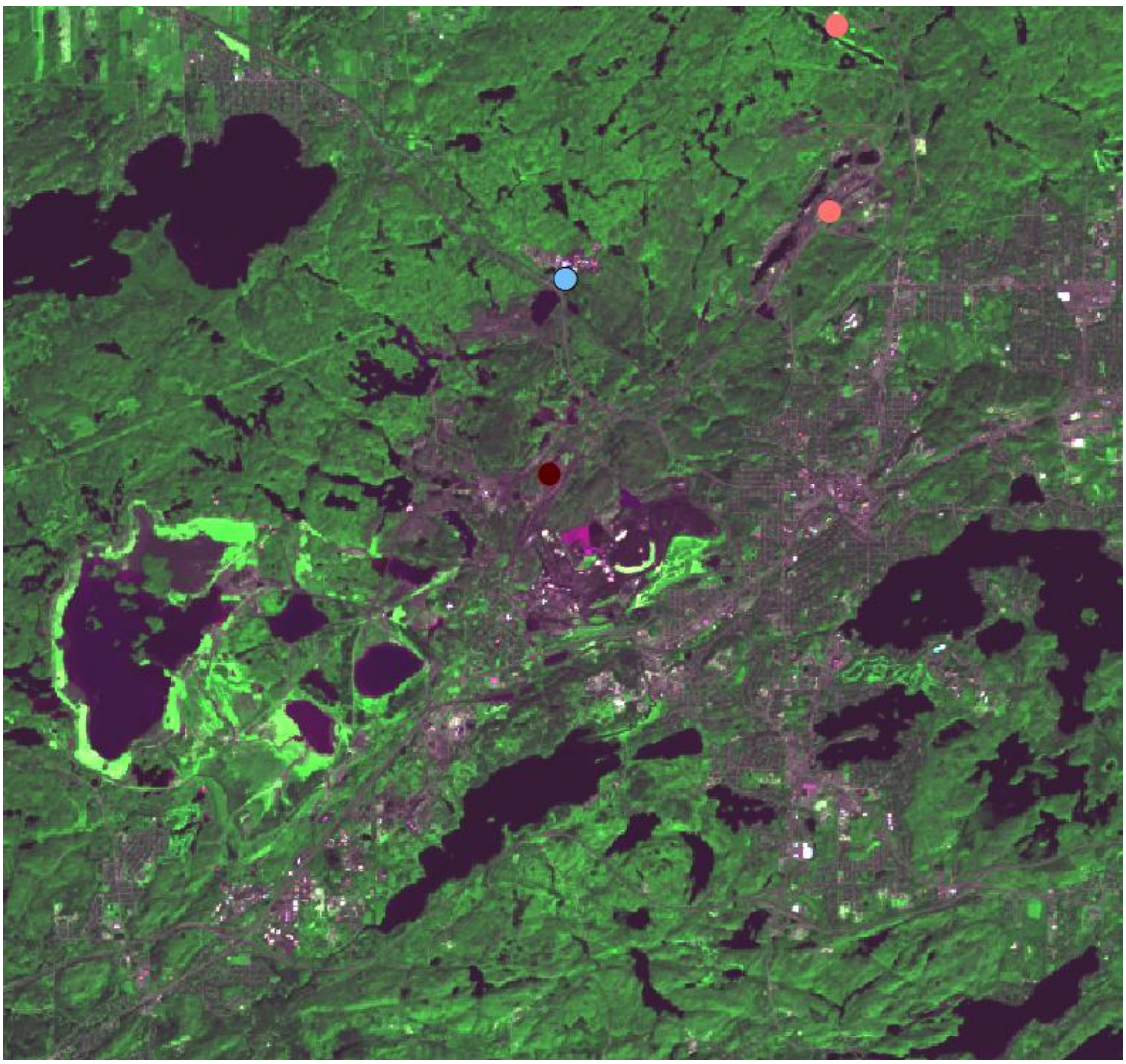


Figure 30. Proccessed image of 7,4,2 band to delineate key patches of the study area. Source: U.S. Geological Survey (2013).

Step 3: The processed image is then analyzed to delineate key, noticeable, physical elements for further investigation. Key elements are identified via visual cues from the processed satellite image. The processed image is continuously compared with aerial images that are available from Google Earth and other Earth observation tools such as Earth Engine to minimize observational error. The observation and comparison techniques identify the following attributes, which help to configure the heterogeneous patches of the study area.

Settlement areas: Urban areas consisting of residential and commercial buildings are rendered distinctive through the use of the colour pink. However, since there is a difference between the core city area and low-density built forms, these are made evident through the use of different shades of pink. The original aerial image confirms that the lighter pink represents core office buildings and large infrastructures such as highways, rail facilities, and industries; the grey-pink shade that surrounds the light pink aggregates represents relatively low-density built forms. Each built form is connected by curvilinear lines (lighter pink), which are mostly highways. In contrast, the darker shade of grid pattern marks secondary and local roads. Several satellite settlements are also visible. These are connected by highways and mostly characterized as low-density development.

Figure 31. The difference in patches between city core and residential blocks. Source: U.S. Geological Survey, (2013) and Google Earth.

Large and small scale waterways: The black patches in the images represent the numerous small and large lakes of Sudbury and are probably the most distinctive and delineated elements.

However, some of the waterways are used as tailings areas, as identified in external references such as aerial imagery and the geo-referencing of pollution data by the National Pollutant Release Inventory (NPRI). The lakes are observed to be dispersed and a continuous linkage or network is not visible in the satellite image.

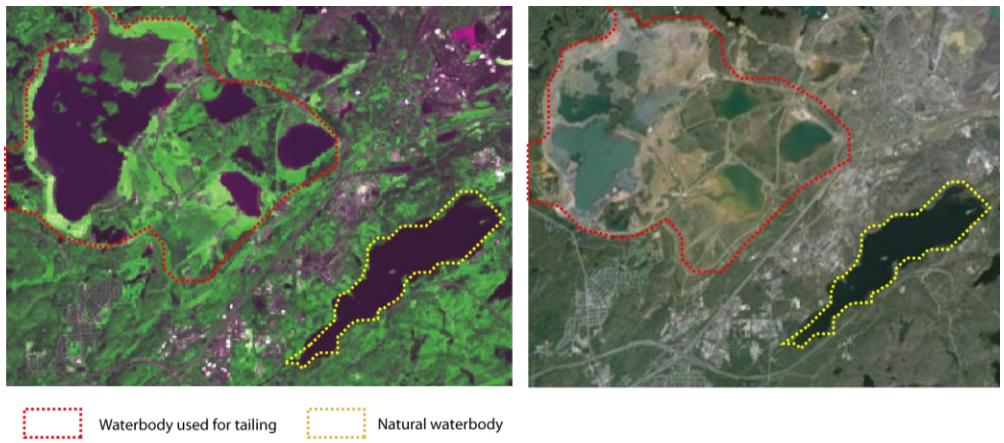


Figure 32. Crosschecking with aerial images to identify special features that are not distinctive in satellite images. The boundary of tailings areas is identified by crosschecking with aerial images and geo-reference of pollution data from NPRI; Source: U.S. Geological Survey, (2013) and Google Earth.

Mining Areas: Mining areas are not clearly distinguishable from built-up areas. However, close observation reveals that mining-related built forms are generally not as aggregated as low density residential areas presumably due to their large infrastructure facilities and surrounding homogeneous disturbed soils. From the aerial image it is also observed and then a defined boundary of the mining areas is outlined. The function of the mining facilities is noticeable when they are observed alongside surrounding elements such as tailings areas, slag areas, and the surrounding ecologically disturbed areas.

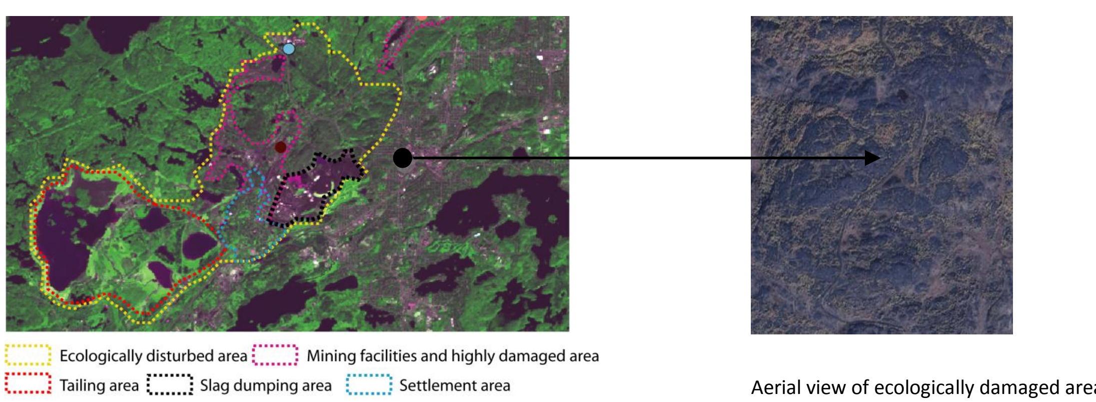


Figure 33. Tailing area, slag, and ecologically damaged area; U.S. Geological Survey, (2013) and Google map

Ecologically disturbed areas: Although there is no distinct colour that represents an ecologically damaged area, the literature and existing aerial image reveals that there is a difference in colour between the surrounding vegetated lands of mining area and other green areas (see Figure 33). The processed image shows a homogenous, dark grey patch that surrounds all of the mining facilities, which is different from the dark shade of settlement areas that are more aggregated in nature.

Vegetated Area: The green space in the processed image is characterised by the dominant elements of grassland with low- to medium-high vegetation. The forest and woodlands are observed to be mostly outside of the study area, which is clearly visible in the satellite image of the whole region in Figure 34 below:

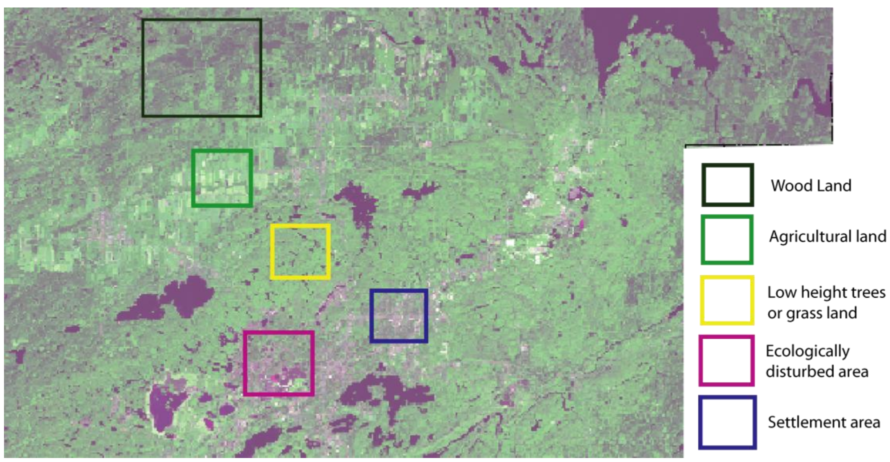


Figure 34. Identification of woodland, agricultural area, and grassland from satellite image. Source: U.S. Geological Survey, (2013) and Google Earth.

Agricultural Land: There are a few agricultural lands at the north-west corner of the study area that are characterised by light, yellow-green regularized land parcels.

Step 4: Based on the above observation and cross-checking with aerial images, polygon lines are drawn to outline the boundary for each attribute, thereby representing their shape and total area. Almost all of the attributes represent landscape patches which are prepared in layers in ESRI ArcGIS 10.1. Each group of patches is configured with accurate area by using the ArcGIS measurement tool and transferred into an attribute table for analyzing their changes for a given time period.

Although there are computerized applications available to configure the elements of satellite sensing image, many researchers (e.g., Forman, 2008; McCartney, 2012) rely on visual cues and their knowledge base to interpret the changing patterns in urban areas. Avoiding computer-based configurations of land mosaic is advantageous not only due to the cost of the technology but also because extensive verification skills are required to avoid errors. Moreover, the present research focuses more on the process of changes than recording the amount and scale of changes. Therefore, marginal error due to minor variations in deciding the boundary of the patches will not have a significant effect on understanding their functions and impacts.

d. **Understanding Land change:** Land change or landscape change is the interaction between patches, either internally or within corridors, which results in a changing pattern in the land mosaic. According to Forman (1995), landscape change is a process that simultaneously acts with the interaction of two different mechanisms:
   i. The first mechanism is composed of the heterogeneous natural patches, which includes the woodlands, waterways, and grasslands that maintain a natural ecosystem and sustain the environment;
   ii. The second mechanism is composed of human activity, such as cutting woodlands, the development of settlement areas (i.e., built forms), building roads and industrializing industrial areas, all of which have an impact on both natural and human-made attributes.

This research adapted these two mechanisms by categorizing the attributes that identified the configuration of land mosaic to investigate the changing pattern of the study area. As per the "land mosaic-function-land change" model, explained at the beginning of the methodology section, the function of any one of these mechanisms (natural or human-made) can alter the shape and size of their patches. For example, air pollution from mining activities can damage the natural ecosystem, reduce the amount of vegetated land, and increase ecologically disturbed areas. Nature has its own healing system that may be able to change barren lands into green space in the long term. Human actions such as rehabilitation of such areas can also accelerate the healing process. Thus, each of these two mechanisms simultaneously interacts with the other and create a unique landscape pattern, depending on the nature of their functions. As the next section explains, this study identifies these interactions by observing their physical changes over a given period of time. Illustrating the attributes, as derived from the configuration of land mosaics, Figure 35 is subdivided into these two mechanisms to analyze their interactions during the process of land transfer.

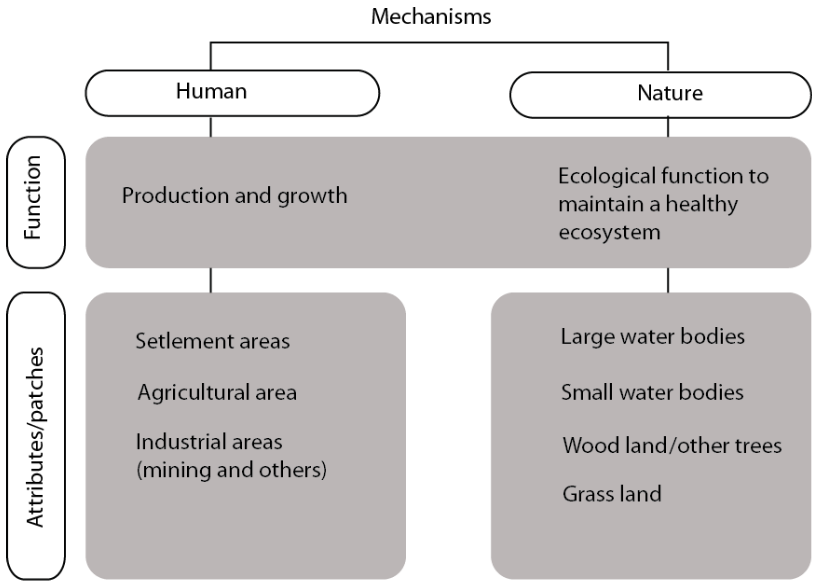


Figure 35. The category of land mosaic attributes found in the study area based on two mechanisms: natural and human-made.

e. Configuration of Land Change: The purpose of this analysis is to investigate the changes in the land mosaic of the Copper Cliff area, with particular emphasis on how mining activities affect other land uses. The mapping analysis of this study helps us to understand how different patches of the Copper Cliff area have been transformed and the extent to which mining activities have influenced these changes. To investigate these changes, the following steps have been taken:

Step 1: Three points in time (the 1970s, 1980s, and 2013) were chosen in order to capture the changes in the land mosaic. Data from the 1990s was not used, due to both lack of availability and a lack of incidences of land change. When selecting the time frames, the key terms “human-made” and “natural” were considered in light of the preceding study.

i. The first phase under study is the 1970s. The population of Sudbury was at its highest in 1971. Since then, mining activity in Copper Cliff began to decline, and the city experienced a massive shortage of employment due to the unstable market conditions. Moreover, due to decades of uncontrolled mining-related pollution, the 1970s are representative of the time in which the area was the most ecologically damaged.

ii. The second phase under study is the 1980s. During this decade, from an ecological perspective, Sudbury's environmental situation was enriched due to a series of improvements in mining-related processes (Strauss, 1992). As soon as the smelter reduced its emissions, there was a dramatic improvement in water quality (Strauss, 1992). Concurrently, the Sudbury re-greening program also achieved significant success by reclaiming and rehabilitating a significant part of the damaged area (Strauss, 1992). The difference in natural features during this period indicates a positive change in a larger part of the contaminated area.

iii. The third and final phase to be studied is the 21st century. Due to a significant improvement in legislation, which started in the 1990s with the introduction of the Metal Mining Effluent Regulation (MMER) and was followed in the early 21st century with the modernization of the Mining Act (2009), water and air pollution in the area were greatly reduced through the process of mining waste management. Considering the gradual shift in the economy and significant improvements in waste management processes, 2013 is the year chosen as the last phase of this investigation aimed at understanding the influence of these forces on Sudbury's settlement patterns.

Step 2: Due to differences in timeframe and to technical changes, Landsat data with similar colour spectra are not available for analysis. Satellite images for the 1970s were collected from Landsat 1 (the first satellite), which captured Earth images with only three colour bands. Satellite images for the 1980s were collected from Landsat 5, which has a more advanced dataset with seven colour bands. Satellite images for 2013 were collected from Landsat 8, which is the most contemporary dataset, as it has 12 colour bands.

Step 3: Following the selection of the three different satellite images for three time frames, the images are added as layers in ESRI ArcGIS 10.1 through steps previously used to configure patches of the land mosaic. To crosscheck for errors, aerial images are also collected and compared with the satellite images. Due to the differences in the datasets, it is important to choose appropriate band combinations so that the images appear with similar visual characteristics. Appendix 6 provides a guideline of the characteristics of each band. Using the guidelines and a "trial and error" method, two different band settings were chosen for the three images that provide maximum similarity in their appearance. The most appropriate band settings that illustrate similar results are as follows:

Table 8: *Time of the Satellite Images, Data Type, and Band Combination.*

Time frame	Landsat type	Band Setting
Satellite image of 1974	Landsat 1	Red:4 Green: 1 Blue: 3
Satellite image of 1986	Landsat 5	Red: 7 Green: 4 Blue: 2
Satellite image of 2013	Landsat 8	Red: 7 Green: 4 Blue: 2

Step 4: Polygon boundaries were identified in order to configure the patches for both the human and natural attributes of the Copper Cliff area. The previous method of land mosaic configuration was followed for all time frames. Two types of analysis were conducted in order to understand the changing pattern and interaction between attributes.

i. A comparative analysis of size and shape of patches was completed for 1974, 1986, and 2013 using a land transfer matrix to identify the transfer of lands from one attribute to another. This analysis allows for an understanding of the function and impact of both human-made and natural attributes. The land transfer matrix also reveals the dominance of one attribute over others. This will create a base through which to discuss possible forces of both human-made and natural mechanisms.

ii. The collection of numeric data of all attributes from polygons, as prepared in ArcGIS 10.1, is used to understand the level of changes of each attribute. The numeric value of changes will support the land transfer matrix and provide information on the degree of changes at different times. Both of these analyses will identify the role of mining activities in the changing patterns of the study area and will be discussed in the results.

2. **Planning Decisions and Development Responses:** After analysing the "land mosaic-function-land change" model, the final segment of this research examines the changes in planning policies and development strategies that may catalyze or restrict the changes in the landscape, according to Forman's (2008) feedback loop model. Historically, both mining activities, including their physical characteristics, and mining reserves played key roles in determining development strategies in the Greater Sudbury area (Hall, 2009). Official plans and other planning initiatives are analyzed to understand how these policies are influenced by "land mosaic-function-land change" feedback and

to determine their responses to different changes. Planning policies and development initiatives can focus on both long-term and immediate goals. This part of the analysis adopts Forman’s (2008) three levels of planning initiatives to capture a wide range of planning responses that may help to relate them with different levels and periods of physical changes in the study area. The three levels are:

i. **Planned Trajectory Approach:** Focusing on long-term policy objectives, the Official Plan of 1977 and Official Plan of 2006 are used, as they are the most comprehensive and developed 25 years of strategy for Sudbury’s future growth and development.
ii. **Significant Projects:** Sudbury’s Re-greening Program is considered to be one of the most successful rehabilitation and reclamation programs in that it has had a direct impact on the environment. The positive impact of this initiative on both human-made and natural attributes are identified and examined with respect to how land use policies utilize this outcome to catalyze their growth strategy.
iii. **Other Policies and Initiatives:** Implementable policies and small- to mid-size plans such as the Sudbury corporate plan in 1986 (to restrict dispersed development), and the City of Sudbury secondary plan in 1987 (for community conservation and redevelopment) are two examples that focus on specific objectives and are indicative of the city’s immediate response to various land use changes.

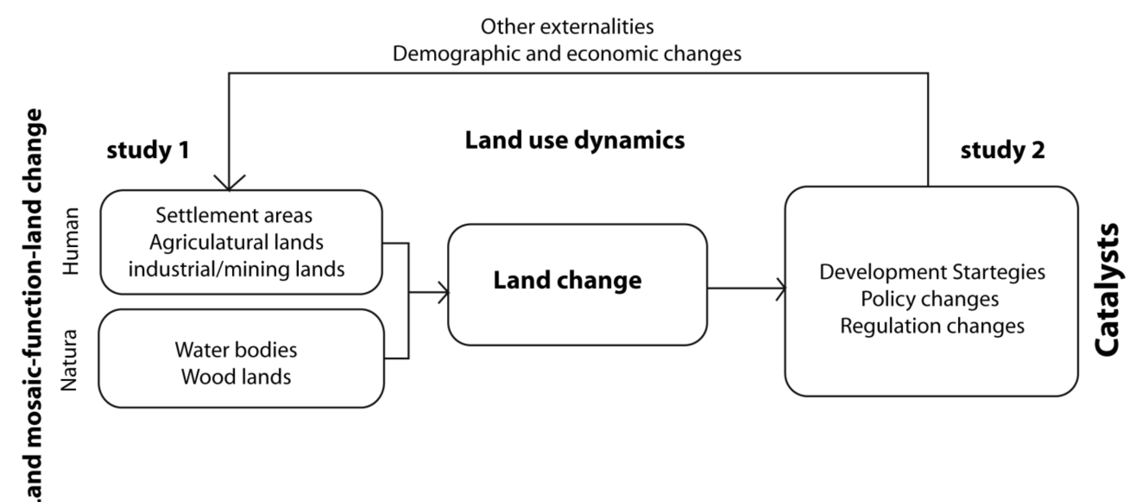
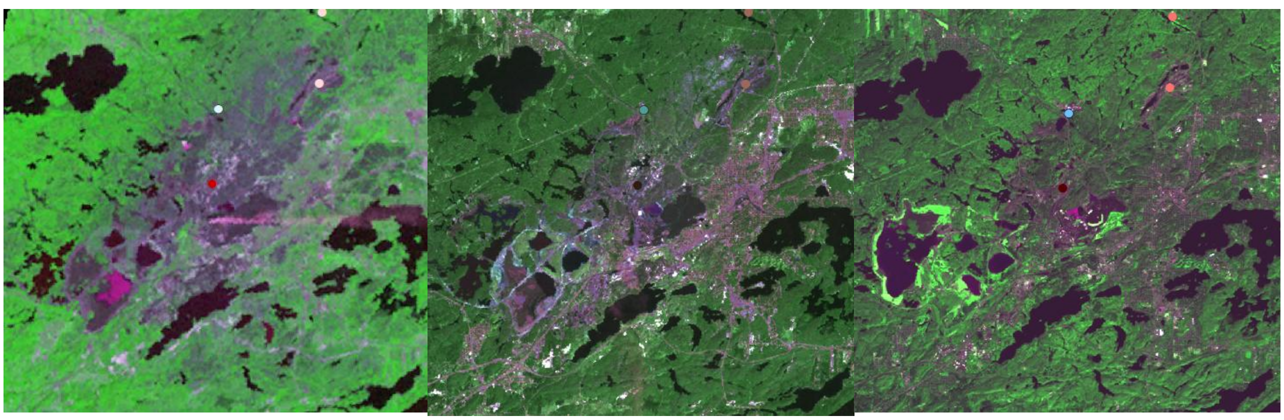


Figure 36. This conceptual diagram is adapted from Forman’s (2008) feedback loop between land changes and policy responses.

Based on the "Land mosaic-function-land change" matrix and policy feedback, this study attempts to understand the critical relationship between various types of land attributes, their changes, institutional responses, and consequent changing patterns of the study area. As illustrated in Figure 36, the changes in land mosaic (human-made and natural) depends on various forces, including development policies and other externalities, including demographic and economic changes (Forman, 2008). The changes (or lack of changes) to individual mosaics (human-made and natural) create an overall land transfer between one another. Over time, the land transfer may be altered due to development strategies and land use policies. This cycle is observed to be continuous and can be used to identify a unique set of land use dynamics. The final output of this analysis demonstrates a combined timeline of the land mosaic changes and policy changes that may reveal a relationship between mining activities, changing patterns and policy responses. An understanding of the process of this complex relationship can support the hypothesis that addresses the question of the impact of mining activities on settlement patterns, which can then be further tested in the context of other mining sites.

3.3 LAND MOSAIC-FUNCTION-LAND CHANGE ANALYSIS:

3.3.1 Understanding the Land Change Pattern: The three satellite images, as shows in Figure 37, illustrate the gradual changes to various elements in the landscape. From general observation, it is possible to identify these elements based on the differences in colour, shade, and pattern. Figure 37 also shows that these changes are not independent: a pattern of change in one attribute influences the change in other attributes as well. For example, from 1974 to 1986, there is an increase of density of pink aggregates at settlement areas that reduce the green dots inside. This indicates that an increase in the number of settlements may reduce the green space inside the city area. Similarly, a close observation can reveal how different attributes change and, in turn, influence a change in other attributes. To this end, this study identifies the patches of these attributes and then transforms them into polygons to extract the key layers for analysis.



1974 1986 2013

Figure 37. Satellite image of three different phases shows physical changes of its various patches.
Source: U.S. Geological Survey (1974); U.S. Geological Survey (1987); U.S. Geological Survey (2013)

3.3.2 Identification of Patches and their Changing Pattern: The key attributes identified from the processed images are: dark black patches, representing waterways; pink-grey patches, representing ecologically damaged areas; light pink patches, which depict settlement areas; dark grey patches that show a slag dumping area; dark purple patches that show a tailings area; and, light green patches to depict an agricultural area. The remainder of the green surfaces in the background indicate vegetated areas and green spaces. From the available satellite images, it is difficult to distinguish vegetated land from grass land. However, in aerial images, it is apparent that, in the study area, there is no forest or woodland containing high density trees. In some cases, there is no clear boundary between patches, which is crosschecked with aerial images.

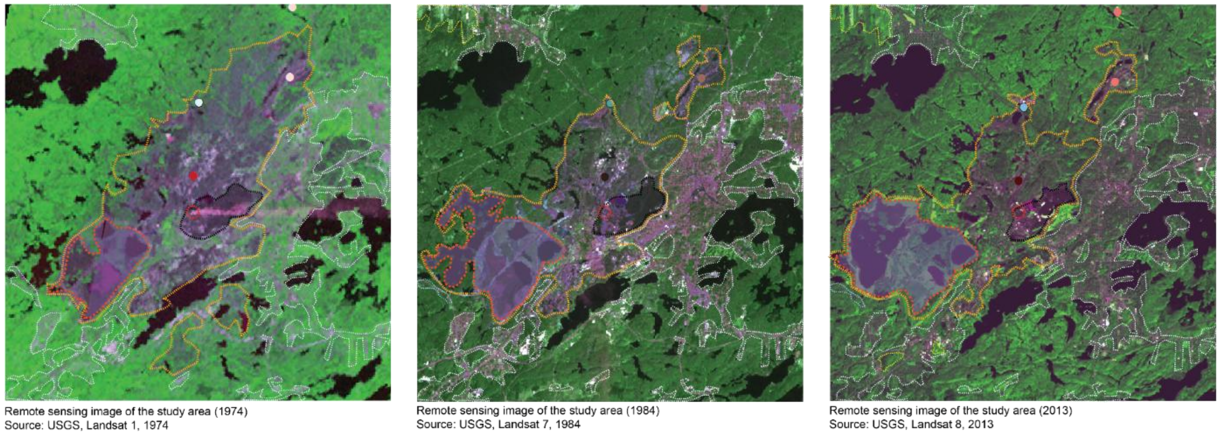


Figure 38. Identification of patches of different land use to analyze changing patterns. Source: U.S. Geological Survey (1974); U.S. Geological Survey (1987); U.S. Geological Survey (2013).

The transformation of patches into polygons, conducted initially in ArcGIs 10.1 and later in Adobe Illustrator, provides a clearer pattern of changes of identified attributes. The most noticeable landscape change appears in Figure 39, which represents the gradual improvement of ecologically damaged area, and also indicates that there is an increase in overall vegetated and green spaces surrounding the mining site. It is also apparent that with the improvement of the landscape, the amount of agricultural land has increased, as has the amount of vegetated and free lands in the north-west part of the study area. However, it also appears that the improvement of soil conditions did not influence any new land use, such as residential or agricultural, inside the rehabilitated areas. Moreover, the settlement area continues to expand away from the mining site. This indicates that the location of the mining site acts

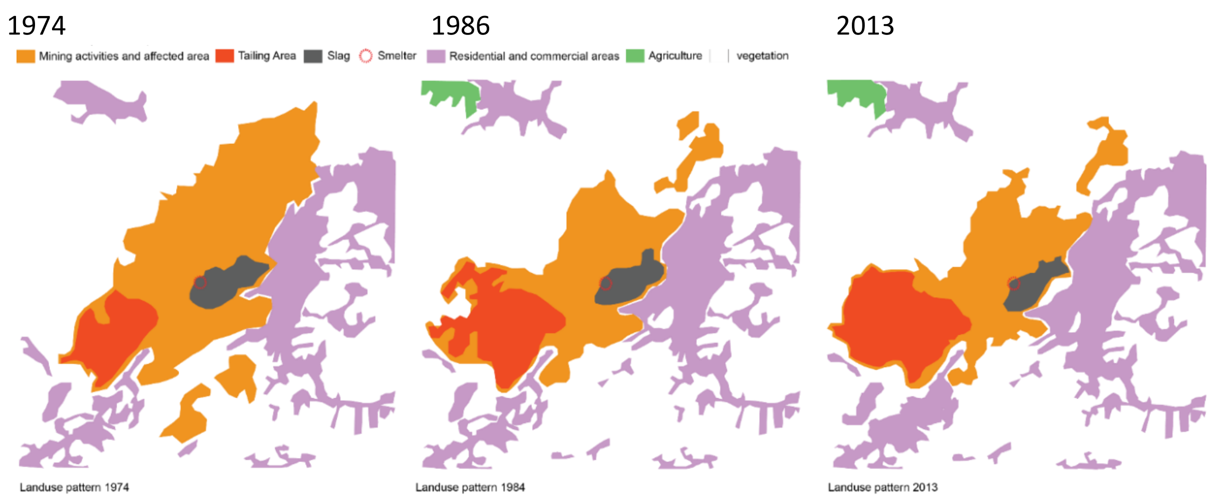


Figure 39. Comparative analysis of changes of land mosaic based on remote sensing images. Data Source: U.S. Geological Survey (1974), U.S. Geological Survey (1987), and (U.S. Geological Survey, 2013).

as a physical barrier and that the environmental improvement of the affected area did not influence alternate uses of these areas. Another important observation is a gradual increase in tailings area. The increase in tailings area indicates that mining production has continued to expand its activities, which may be another reason for the lack of significant growth adjacent to the mining site.

3.3.3 Configuration of Land Change of Various Land Uses within the Boundary of the Study Area in Copper Cliff and the Central City Area: This analysis attempts to quantify the level of changes of various attributes of the study area. The purpose is to identify the land uses that saw major changes during the specified time frame. This part of the analysis is supported by a land use change matrix that, in a later section, provides information about how much area of one attribute has transferred into others.

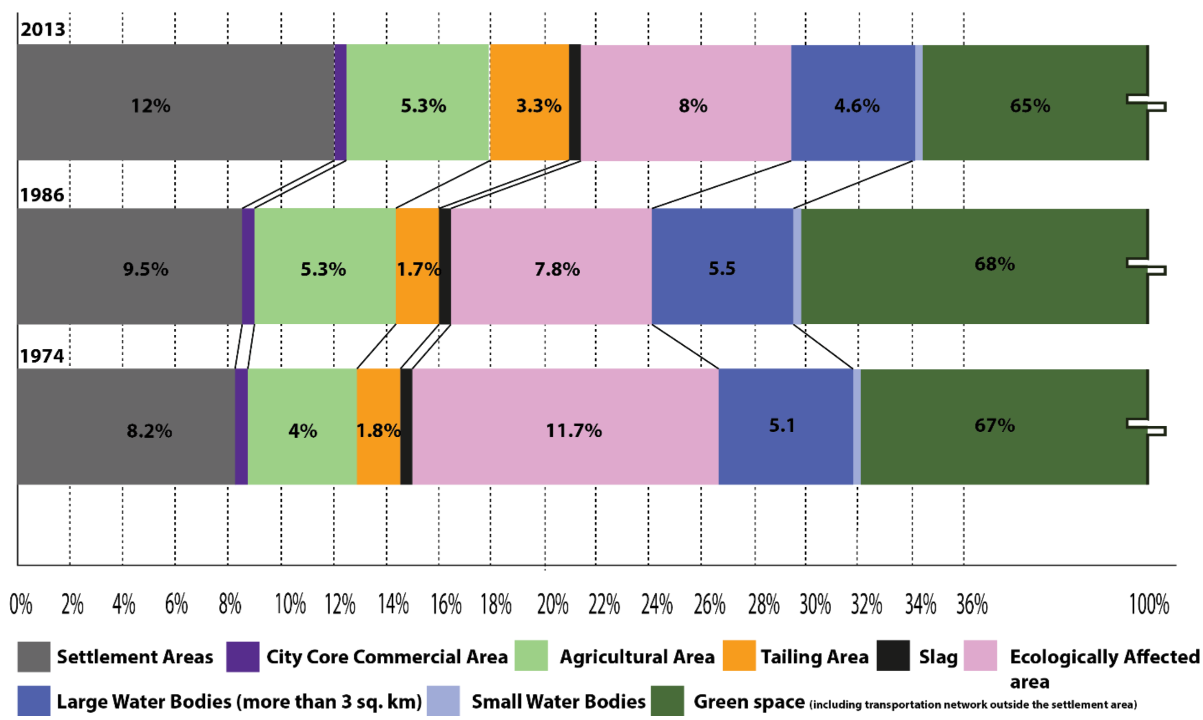


Figure 40. The numeric value of land changes of various attributes of the land mosaic of the study area. The illustration technique is adapted from Malaque and Yokohari (2007).

Figure 40 indicates that the value of land use change in terms of area is most prominent for the settlement area and the ecologically damaged area in Copper Cliff and the surrounding region. While the ecologically damaged area decreased from 11.7% (1974) to 8% (2013), the settlement areas increased from 8.2% to 12%, respectively. This trend might suggest that there is a link between environmental improvement and urban expansion; however, population change also needs to be analyzed to understand whether the change is due to the improved environmental conditions or to other reasons, such as commercial development. Another observation is an increase in agricultural area from 4% (1974) to 5.1% (1986) which may also be a typical response to the improved soil conditions and reduced contamination in the study area. There is also a connection between increased mining activities, such as tailings expansion, and decreased water and vegetated lands in the study area. The tailings area nearly doubled from 1.8% (1974) to 3.3% (2013) whereas the waterways and vegetated lands decreased over time. From the analysis, it is apparent that most of the changes of land mosaic attributes are the result of their activities or functions and influences of other attributes, which was explained by the Land mosaic-function-land change feedback model. For example, a decrease in natural water bodies may also indicate its relationship with the increase of tailings areas. The value of changes of all attributes helps to create a detailed understanding of this kind of relationship, which is explained in the next section through a land change matrix.

3.3.4 Analysis of Changing Pattern and Interaction Between Attributes:

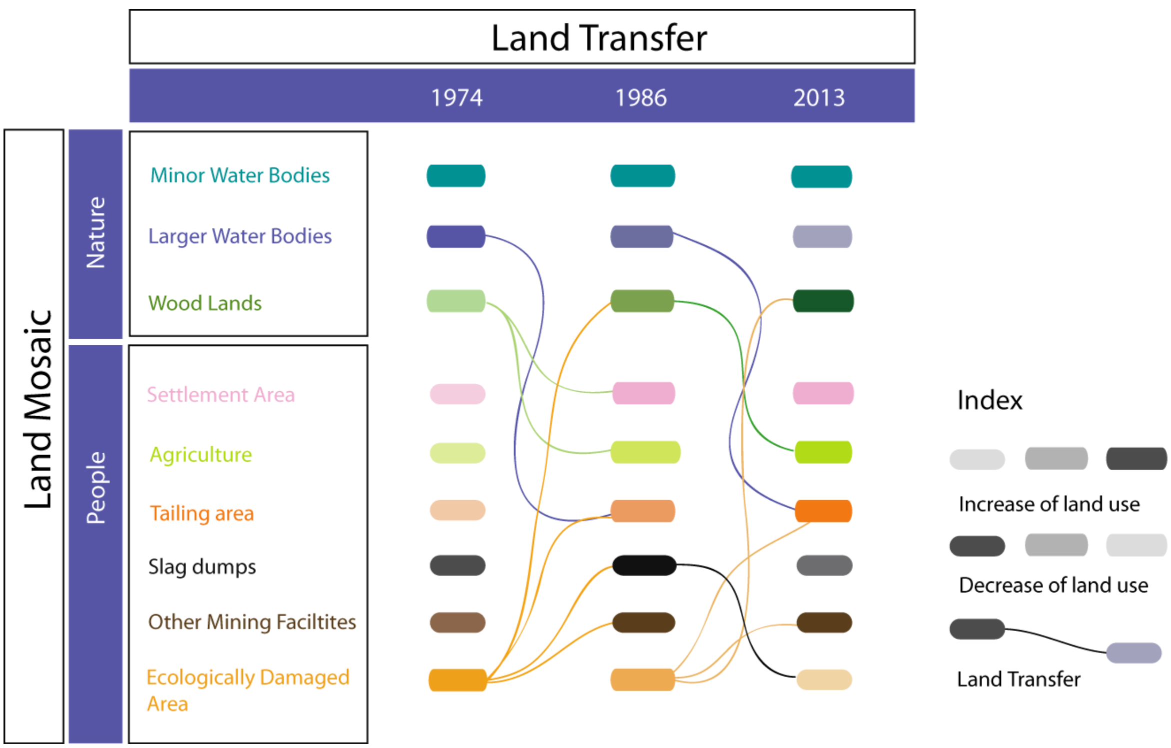


Figure 41. Land change matrix that illustrates the level of changes and interaction between changing attributes in the study area.

Based on the analysis of land change and the configuration of their values, a conceptual land transfer matrix has been prepared. The land transfer matrix provides a high-level, overall understanding of how different land mosaics have been transferred into other uses. From the configuration of land change, three major interactions are identified:

I. Transformation of the ecologically damaged area into vegetated area;
II. Loss of woodlands and waterways for the expansion of the tailings area; and
III. Loss of woodlands and waterways for the expansion of settlement areas.

I. **Transformation of the ecologically damaged area into vegetated area:** The Sudbury Re-greening Program was extremely successful in transforming the ecologically damaged area into green spaces. However, the land use matrix identified that the new green spaces did not have any alternate uses other than minor agricultural activities. An analysis of how land use policy addresses these reclaimed spaces might indicate why the areas did not have any other uses since the reclamation occurred in the 1970s.

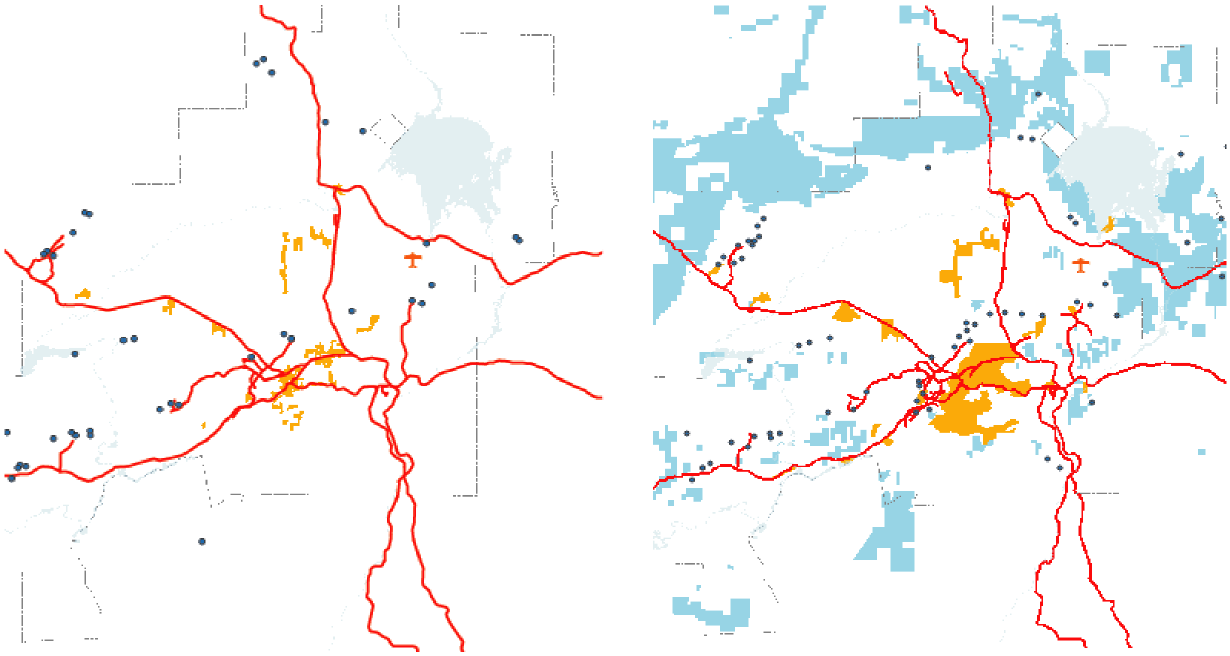
II. **Loss of woodlands and waterways for the expansion of the tailings area:** The land use change identified by the previous analysis indicates that mining activities caused a gradual change in physical characteristics. While there was a significant improvement in the control of smelting-related pollution, Copper Cliff experienced a massive increase in its tailings area. At Copper Cliff, the tailings storage area covered 2,225 hectares in 1996 (Winterhalder, 1996). Vale Inco was heavily criticized for using the natural lake, Meatbird Lake, for dumping tailings (Mining Watch, 2012). Metal Mining Effluent Regulations (MMER) data indicates that the mines at Copper Cliff had been charged several times in recent years for exceeding the limit of discharge of metal effluent in surface water (Environmental Canada, 2012, 2011, 2010, and 2008). However, more concern was raised by geologists and other mining professionals about the lack of available data on potential ground water contamination, which is not generally monitored by the government and poses a greater potential threat for large-scale water contamination (Interview, 2014).

III. **Loss of woodlands and waterways for the expansion of settlement areas:** Indicated in figure 41, there was an increase of settlement areas, which was mostly occurs in vegetated land away from the mining sites. But, it appears from the land change matrix, that there is no direct relationship between the expansion of the urban settlement area and the improvement of the ecologically damaged area. Moreover, there was little change in the population between the 1970s and 2013 (Hall, 2009), which also indicates that the environmental improvement might not be the reason for urban expansion. A further investigation that considers other factors, including the city's land use planning strategy, may be necessary to understand why the city expanded despite little growth in the population of the study area.

3.4 PLANNING DECISIONS AND DEVELOPMENT RESPONSES:

The study of land use planning decisions and development responses over the last 40 years are useful in order to understand how planning policies have responded to land use changes as well as what strategies have been taken to address the uniqueness of the land use patterns in mining cities. The location and size of the Copper Cliff mining site (one of the largest mining sites in Canada, see Figure 25) has significantly influenced growth in the city of Greater Sudbury. The massive soil contamination that occurred in the first part of 20th century, the vast areas of mineral reserves in the western part of the city, and the close proximity of the city to a number of mining and industrial facilities were critical in city's land use planning decisions (The City of Sudbury, 2006). An understanding of why mining activities have had such a strong influence on settlement patterns first requires a critical understanding of how the city responded through its strategic planning as well as an awareness of how people and settlement areas have changed over the years.

1. **The City's Planned Trajectory Approach:** Mining activities in the Sudbury region started in the late 19th century, when infrastructures such as road and rail networks were developed to facilitate industrialization (Bray, 1992). As new mining sites evolved, new settlements were also developed to cater to the needs of mining workers (Bray, 1992). As illustrated in Figure 42, most of these settlements were developed along the infrastructure near the mining sites. In official city documents, it is well-known that this kind of dispersed development is unique to areas where mining activities have played a key role in how the cities have developed and expanded (The City of Sudbury, 1977; 2006). The pattern of dispersed development has posed a major challenge for Sudbury in terms of the provision of municipal services, which is a significant focus in official documents. Official city documents also recognize that more than 300 natural lakes, as well as numerous mining sites and mining reserves present a significant barrier to attaining the typical growth patterns that other cities experience (Hall, 2009). As illustrated in Figure 42, the growth in the city centre is significantly aided by the location of the mining sites. Furthermore, massive soil contamination in the inner-city region also played an important role in planning decisions. In light of these circumstances, the present analysis will explore Sudbury's two major long-term official documents—the Official Plans of 1977 and 2006—to analyze the municipal response to the expansion of mining activities, environmental impacts, and dispersed settlement patterns.



Sudbury 1960s

Sudbury 2011

Figure 42. Growth of the Sudbury region with the growth of mining activities and mining reserves.

Source: Adapted from a studio work entitled “Mining the New Town” of School of Urban and Regional Planning, Ryerson University (Contributors: Alam, M.; McCaines, K.; Finley, B.; Miller, K., Plant, G.; Tetsaguzza, M.; Wu, H.; Cogliano, D. and McCartney, S.)

The Official Plan of the Regional Municipality of Sudbury, 1977: Sudbury’s official plan of 1977 adopted a set of strategies focusing on the following three issues (Regional Municipality of Sudbury, 1977):

I. **Improvement of community facilities and infrastructure to make them attractive for future growth:** The city recognized that many dispersed settlements, which started as company towns that were initially developed either by mining companies or as agricultural service centres, are still significant contributors to the city’s economy. Despite major challenges in providing municipal services, the city was forced to improve community facilities to make them economically viable. In the 1977 Official Plan, the city adopted a well-defined hierarchy of 19 urban centres based on the population at the time. The principal goal, as outlined in the Plan, was to recognize those communities for further development while restricting any new settlement in the region (Regional Municipality of Sudbury, 1977). Sudbury’s move to revitalize these mining towns and other service centers attracted people because of new facilities, employment opportunities, and affordable housing facilities (Hall, 2009).

II. **Continuity of resource development while minimizing the disruption of the natural environment:** Despite the city's dependency on mining, the mining industry changed dramatically in 1970s. Although Sudbury experienced massive cuts to employment during the early 1970s, the region's existing mining reserves and historical trends suggested that, at the time, mining activities would continue to grow in the near future (Hall, 2009). One objective outlined in the Plan was to ensure that the development pattern did not preclude future extraction (Regional Municipality of Sudbury, 1977, p. 137). Due to the continuation of mining activities in urban regions, settlements extended into non-urban areas. However, the Official Plan also recognized that there was a growing concern for ecological damage, which Sudbury had experienced for the last 50 years. To overcome the problem of ecological damage, the city has since created various initiatives such as the periodic Soil Study, which monitors the level of soil contamination, and the Sudbury Re-greening Program, which works to rehabilitate and reclaim affected areas (VETAC, 2014).

III. A development strategy that allows further growth while utilizing existing infrastructure and utility services: In 1974, the city conducted an area study plan to identify the development corridors and growth directions (see Figures 43 and 44), which provided a number of scenarios that considered engineering, agricultural, and environmental constraints. The Official Plan of 1977 adopted these scenarios in its development strategy to support future developments.

The area study plan illustrates two primary development corridors and few regional development possibilities. The two major development corridors are: Along South-west to North-east direction bisecting the city core toward the major settlement areas of Town of Nickel Center, and further expansion of City core towards South-east part of the city and Town of Nickel Center. It was also predicted that other settlement areas in Town of Valley East and Rayside-Bafour would continue to expand (See Fig. 43). In the Sudbury Official Plan of 1977, the city took a development strategy that suggests a combination of these two scenarios where the South-west to North-east corridor has been recognised as future growth axis. The development strategy also illustrated that there would be a natural growth of population in urban areas and development would continue to be guided by reserved areas such as mineral resources, agriculture and environmentally sensitive and hazardous areas.

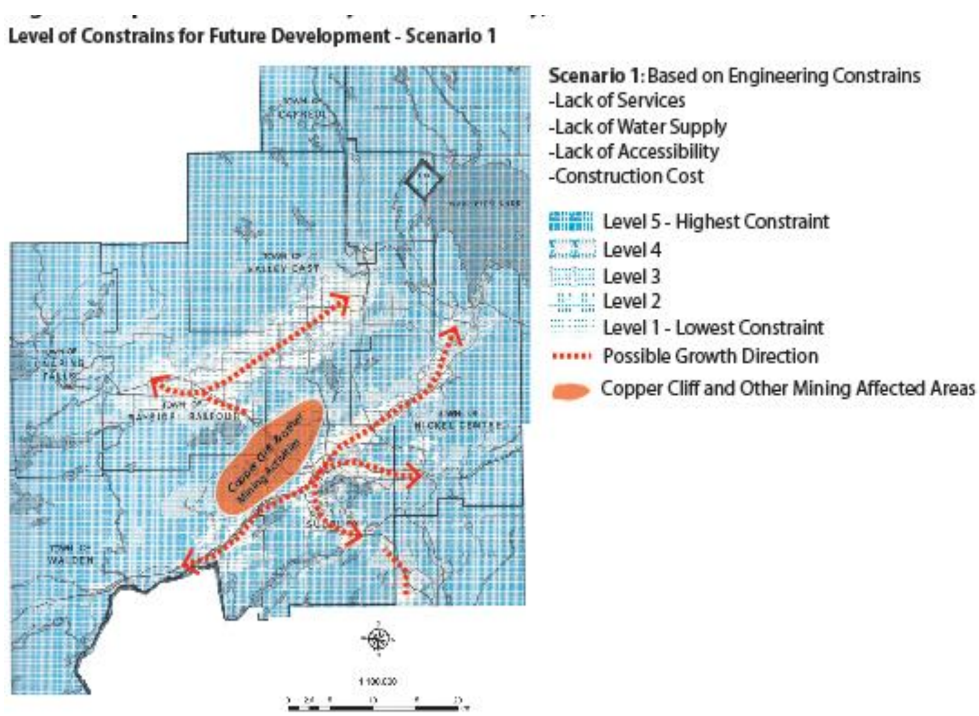


Figure 43. Scenario 1: The level of constraints for future development, adapted from the Sudbury Study Plan, 1974.

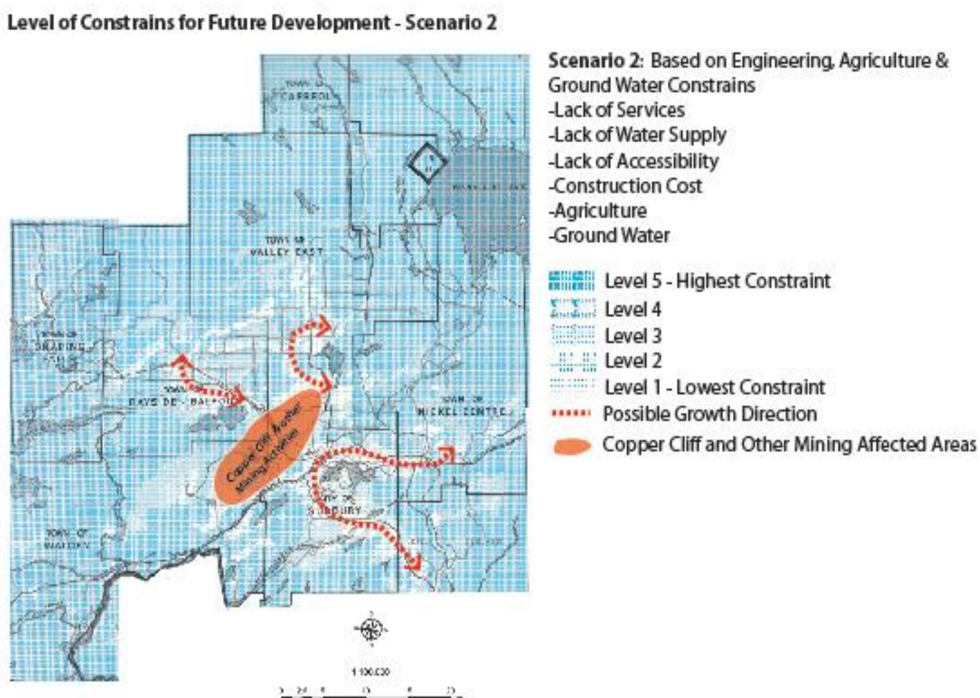


Figure 44. Scenario 2: The level of constraints to future development, adapted from Sudbury Study Plan, 1974.

Figure 45 below illustrates the growth strategy as outlined in the Official Plan of 1977. This strategy clearly indicates that there was a conscious recognition of pursuing further growth of satellite towns, with the development of the central city guided by the physical attributes of surrounding areas such as mining areas and reserves.

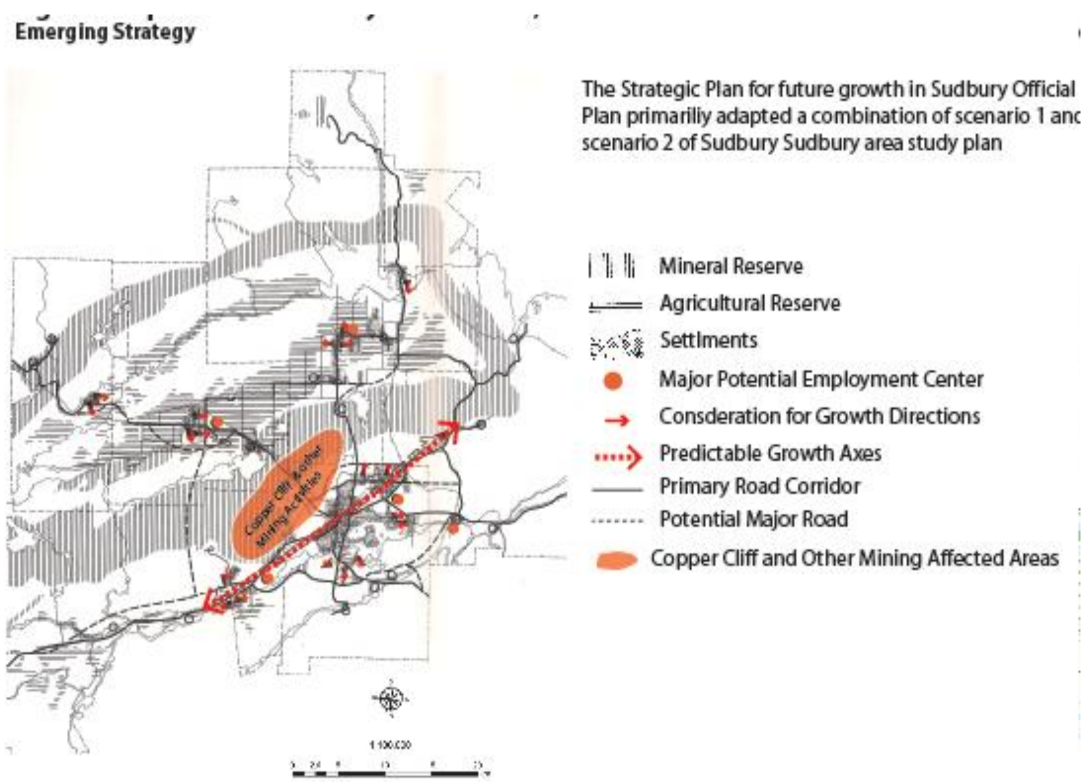


Figure 45. Emerging Growth Strategy, adapted from the Official Plan of 1977.

The City of Sudbury Official Plan of 2006: Despite seeing minor urban expansion along the major growth axis as mentioned in the Official Plan of 1977, the new Official Plan of 2006 for the City of Greater Sudbury continued to be confronted with what is described as a “dispersed pattern” of development (see Figure 46). This plan does not establish a hierarchy for development based on distance from the city core even though some of the towns are located in excess of 40 kilometres from the city centre, which is the economic, service, and population core (Hall, 2009). The Official Plan of 2006 came into effect in a different scenario, one in which environmental degradation had been greatly reduced and economic diversification was significant in urban areas but where there was little to no change in the population (see Figure 46). However, the land mosaic analysis reveals that the urban expansion occurred much like that of any other city, despite the lack of population growth. The central city area expanded in a dispersed manner and was directed outward from the mining facilities. The urban expansion of the city area indicates that physical expansion and population growth may not be co-dependent. In the case of Sudbury, the growth of the city was mostly due to the development of the service sector (e.g., health, education, recreation, and hospitality) (Bray, 1992). Economic development did not necessarily influence the residential development of that area. In these circumstances**,** the Official Plan of 2006 adapted the following strategies:

I. **The need for residential intensification to efficiently use municipal services and infrastructures:** Unlike the Official Plan of 1977, the new Official Plan created a hierarchy of settlement areas based on the level of service provided by the municipality. The approach outlined in this Official Plan is to encourage more development where full municipal services are available. Infill development and residential intensification were highly encouraged in the city centre and other growth areas. Sudbury has experienced significant success in terms of environmental improvement, economic development, and other services which also supported the city's plan to intensify growth in areas where contamination had previously occurred. Mining activities and their potential impacts are not considered as a major challenge to the future growth of the city (Hall, 2009) because mining companies were able to significantly reduce mining-related pollutants in recent years.

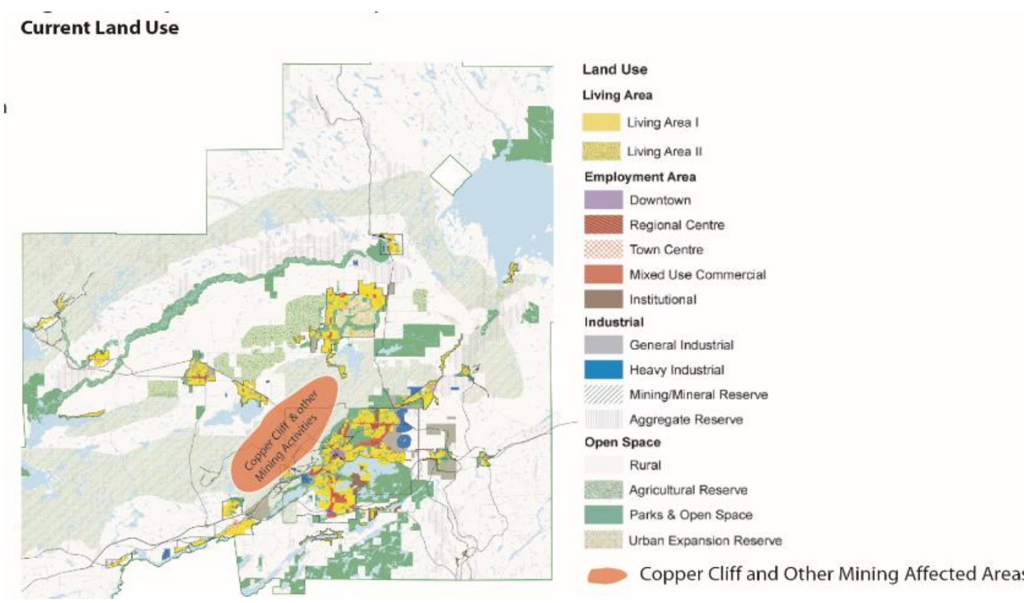


Figure 46. Adapted from the City of Sudbury Official Plan, 2006.

II. **Alternative use of mining reserves that do not preclude future mining activities:** As illustrated in Figure 38, mining and aggregate reserves have a significant impact on development patterns in Sudbury. Historically, development patterns were guided away from their location near mining sites and reserves due to potential sources of contamination. However, significant improvement has been made in terms of managing mining-related pollution and increased demand for agricultural lands (from land change analysis) may have influenced the city to adopt alternative land use for mining reserves.

III. **Redevelopment and reuse of brownfield development and contaminated land:** In the Official Plan of 2006, for the first time, Sudbury provided a policy to guide new developments on abandoned mining sites and rehabilitated lands. The timing of this new policy is significant considering the city's new approach to intensification. The land change analysis conducted in the present study indicates a positive interaction between human-made and natural communities with increased agricultural and vegetated lands and decreased contaminated lands. At this stage, an alternative use of reclaimed and rehabilitated land would promote growth and economic development.

2. **Big Projects:** Considering centuries of mining-related pollution, ecological damage, and the negative environmental image of Sudbury, a comprehensive land reclamation and rehabilitation program was necessary to restore the natural environment and mitigate subsequent impacts. The Sudbury Re-greening Program started in the 1970s with a goal of reclaiming 10,000 hectares of barren land. The Re-greening Program is a good example of how the negative impact of one human action (i.e., contamination) can influence a positive response in city policies. However, it remains unclear what attributes of land use and its function will be adopted for the contaminated lands through the Re-greening Program. Until now, the areas reclaimed by the Re-greening Program are under the rehabilitation process and no new development has been observed in that area in the last 30 years. Until 2006, the city did not have any strategy to utilize this vast vacant land, which was mostly under the authority of Vale Inco (now Vale Canada Limited). As a result, most of the rehabilitation resulted in an increase of green space but did not allow for growth in the brownfield settlements in the contaminated area. However, the Official Plan of 2006 recognized the potential of massive abandoned lands and in turn initiated a new policy for the redevelopment of these lands for various purposes, such as agricultural or other uses, confirming that: "[a]ll applications for redevelopment in areas known or suspected of former land use activities that may lead to soil contamination [are]

supported by Environmental Site Assessment (ESA)" (The City of Sudbury, 2006) The City may also consider financial and other incentives to promote the redevelopment and reuse of brownfield properties that are subject to environmental constraints. However, until now, there is little evidence that the reclaimed lands in the study area are utilized by alternative land use with the exception of converting them into leftover green field or space.

3.5 SUMMARY OF LAND MOSAIC-FUNCTION-LAND CHANGE AND POLICY RESPONSES

Sudbury's land use policy initiatives have evolved in response to various human-made and natural activities (e.g., mining, agriculture, pollution, urban growth, etc.). It may be helpful to explore the interaction between physical patterns, their changes, and policy responses in order to understand the land use dynamics of the study area. Figure 39 illustrates a synchronization of all identified land mosaic attributes, land changes, and policy responses in a timeline so as to understand the causes, effects, and responses of the development patterns of the Copper Cliff area. The land changes and policy responses are divided into three phases based on an analysis of what forces may cause land changes, what responses the city adopted, and what impacts the policy changes have had.

Land Change in the 1970s and Subsequent Policy Response: As mentioned in the land change analysis, the uncontrolled mining practice of first half of the 20th century caused massive ecological damage in the Sudbury area. Over 10,000 hectares of land became barren due to soil contamination. That incident was one of the driving forces, along with dispersed settlement patterns and population increases in the early 1970s, for the initiation of a new growth strategy that is reflected in Sudbury's Area Study Plan of 1974 and Official Plan of 1977. The city responded to this situation by addressing the need for the revitalization of services and infrastructure for dispersed settlement areas. In the 1970s document, the City predicted homogeneous growth in all settlement areas and addressed a growth axis for the city centre away from the existing mining activities. The direction of growth in the city was evident in next decade, but the prediction for population growth was incorrect. In the 1970s, the most outstanding land use policy response was the Sudbury Re-greening Program, which improved the damaged landscape in decades that followed. However, the lack of strategy to deal with Sudbury's "no growth" situation resulted in a dispersed development pattern.

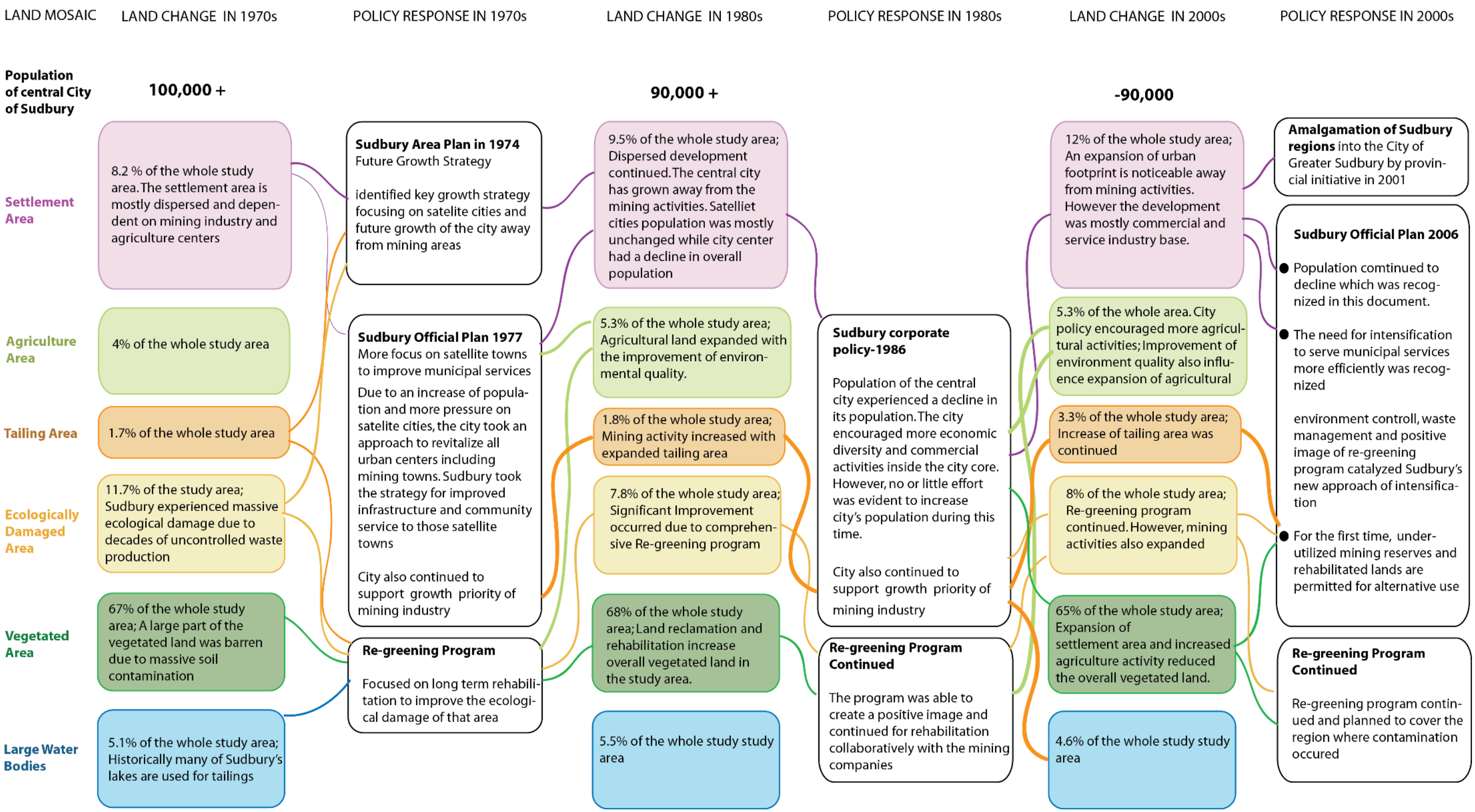


Figure 47. The interaction between land change and policy responses is synchronized to understand the land use dynamics of Copper Cliff in the City of Sudbury.

Land Change in the 1980s and Subsequent Policy Response: Several key land changes occurred in the 1980s: continued city expansion outward; a decline in the mean population; expanded tailings activities; infringement of natural waterways; and an increase of agricultural land and improvement of ecologically damaged areas. Sudbury's strategy for the improvement of communities in satellite cities and the expansion of the main city based on natural growth did not provide significant opportunity through which to intensify the residential growth of the study area. Moreover, the City adopted a new strategy to try to encourage more diverse commercial activity. This plan was called the Sudbury Corporate Plan and, in 1986, it indicated that the city was still too far behind in residential intensification to deal with a stagnant population. However, more land has since been rehabilitated and converted into green space or vegetated land. The previous land change analysis indicates that, during the 1980s, there was no initiative to reuse these reclaimed lands. But, due to the increased agricultural activities, more vegetated lands have since been converted into agricultural land. It was apparent that, despite the success of the Re-greening Program, the city did not integrate this initiative into their land use policy.

Land Change in the 2000s and Subsequent Policy Response: In the 2000s, several major land changes took place: noticeable expansion of settlement areas in the outer city; increased mining activities and infringement of large waterways; and loss of vegetated lands for agricultural activities. This decade started with the recognition that the Sudbury region requires a greater commitment to integration in its development policies and service management. The 2001 amalgamation of the Sudbury region into the City of Greater Sudbury was the response chosen over continuous dispersed development in urban and non-urban areas. The Official Plan of 2006 also recognized the need for intensification and infill development in already-existing urban areas, not only for the efficient use of services but also to capitalize on the city's growing success in the rehabilitation of contaminated areas adjacent to the central part of the city. Moreover, for the first time, the city identified the under-utilization of mining reserves and rehabilitated lands as a potential place for alternative use. These initiatives indicate that the City has started to identify opportunities from the environmental improvement in addition to the accomplishments of the last 20 years from re-greening program.

4.0 CONCLUSION

The first part of this analysis provides an understanding of the base metal mining process, the potential threats it poses in terms of ecological contamination, and the application of a priority ranking system to identify a list of categorized base metal mines(abandoned and active). An understanding of the type and extent of environmental impact also helps to clarify that long-term mining activities have a direct influence on how settlement patterns have changed. The priority ranking also helps to identify the regions of key concentration of mining activities in Northern Ontario. Because of their proximity to natural water sources and settlement areas, many of these mining sites may have an influence on how the city is shaped and expanded. Figure 48 uses a simple visual comparison of two Northern Ontario mining cities based on a time fame of 1984-2012 to illustrate the fundamental similarity of land attributes and changing patterns. Both Sudbury and Timmins are characterized by settlements that evolved based on mining activities. People follow opportunities, and services and infrastructure follow people; shortly thereafter, settlements form (Alam, et al., 2013). In the early 20th century, as people came to settle in these areas after having secured mining-related employment, these areas became resource towns (Bray, 1992). However, as mining activities expanded with increased reserve areas and processing and tailings facilities, it became a physical barrier and source of contamination in adjacent settlement areas. The first part of this research identifies Sudbury and Timmins as two regions where several mining sites contain the potential to cause environmental degradation and subsequently impact land use in adjacent areas.

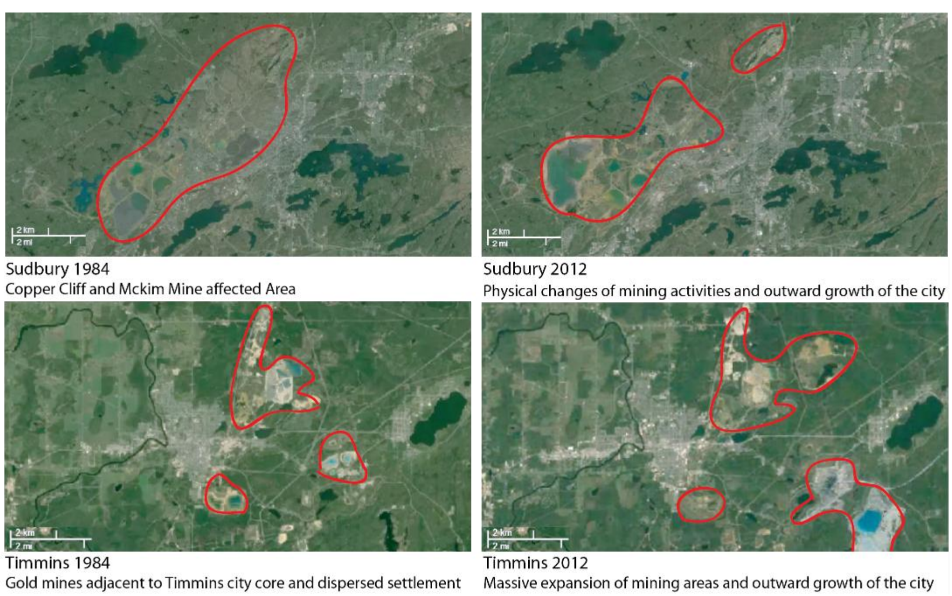


Figure 48. Comparative analysis of the change of urban pattern in two major mining cities, Google Earth Engine (2014)

An understanding of the threat of mining activities and its existence in regional context helped this research to identify a case study to look at how mining activities influence adjacent settlement areas. While investigating the relationship between mining activities and changing pattern of a case study, the analysis reveals that the interaction between mining and land change is not as direct as it is presumed, rather to understand a more complete interaction it is necessary to add another layer of communication from the context of land use policy.

The second part of this project identifies that there is a feedback loop between land mosaic, land change, and policy response. The analysis illustrates that specific function of land use, such as mining activities, may influence land change, such as transformation of vegetated land into barren land. In turn, such shifts influence policy changes, including the restriction of particular land use, which eventually influences land use patterns. Forman's (2008) model of "land mosaic-function-land change" may be true for every landscape, but the case study indicates that mining cities are a unique setting where mining and its influence on land use changes play important role in shaping the settlement pattern. The study indicates that, in this process, land use policies need to respond effectively to mitigate the potentially adverse effects. Below are the key issues identified as intertwined factors of the land use dynamics of the study area:

1. Historically, most of the mining cities in Northern Ontario experienced a very slow rate of growth—or, in some cases, no growth—in their major settlement areas (Hall, 2009). While there are definitely opportunities for mining-related economic growth, there are also challenges in terms of environmental threats and consequent impacts on land use change, as well as the health and living conditions in adjacent settlement areas. This unique condition is further challenged by the need for costly infrastructure services to dispersed developments that are evident in the Sudbury region. The case study of Sudbury suggests that alternative uses of rehabilitated lands and mining reserves that typically stay under-utilized could open up new possibilities and stimulate positive land use changes.

2. The success of the "Sudbury Re-greening Program" proves that collaborative planning initiatives are crucial for the ecological success of mining cities. Acknowledging the unique characteristics of mining cities, the mining companies, residents and other corporate stakeholders should work together and towards progressive planning. While the Re-greening Program has been successful

from an environmental perspective and from a land use perspective, the city could engage a more integrative approach to revitalize the underutilized space that is adjacent to the city centre.

3. It is also notable that Sudbury's slow rate of population growth does not reflect similar patterns in its physical growth and economic development (The City of Greater Sudbury, 2013). This is a unique case, and this study identifies that, while the location of mining sites may have an influence on dispersed development, the slow growth of population may not have a direct relationship to mining activities; rather, rates of population growth are reliant on the city's growth strategy. Sudbury had two different approaches to address this issue in its 1977 and 2006 Official Plans. The earlier Plan (1977) focused on the revitalization of satellite communities whereas the later Plan initiated infill development and intensification strategies. It remains to be seen how this strategy influences Sudbury's future growth.

This research identifies that mining cities are unique in their land use dynamics due to the physical attributes of mining sites and their impact on human and natural communities. While the mining industry inevitably plays a central role in the city's economy, sustainable growth is often reliant on how land use policies and initiatives address these unique characteristics. The influence of mining activities on overall land use patterns in cities in Northern Ontario has received little attention in panning dialogues and this research is an attempt to address this vital issue and inspire further research.

APPENDICES

Appendix 1. Data of all active base metal mining sites of Northern Ontario and calculation of priority ranking system.

Facility Name	City	I	Average on-site air emission 2006-10 (KG)	Point Score 1	Average on-site water discharge 2006-10 (KG)	Point Score 2	Average on-site land release 2006-10 (KG)	Point Score 3	Average of total on-site release	Average Recycling transfer 2006-10 (KG)	Point Score 4	Production t/d	Point Score 5	Total number of exceedance of permitted limit betv	Point Score 6	Total Score
FNX Mining Company Inc. - Levack Mine	Levack/Greater Sudbury	I	491.3699667	1	--	1	223.5853333	1	714.9553	0	0	0	1	0	0	4
FNX Mining Company Inc. - McCreedy West Mine	Levack/Greater Sudbury	I	815.148	1	--	1	112.3683333	1	815.148	0	0	0	1	--	0	4
FNX Mining Company Inc. - Podolsky Mine	Sudbury	I	704.0563333	1	2.805666667	1	5947.6765	2	6654.5385	0	0	1000	1	7	3	8
Liberty Mines Inc - Redstone Mine	South Porcupine/Timmins	I	--	1	--	1	21697746.41	5	21697746.41	0	0	2000	2	7	3	12
Vale Canada Limited - Clarabelle Mill	Copper Cliff/City of Greater Sudbury	I	92215.0734	3	483254.52	4	26241147	5.00	26816616.59	0	0	27300	4	12	4	20
Vale Canada Limited - Coleman Mine	Levack/Greater Sudbury	I	532	1	--	1	--	1	532	0	0	0	1	--	0	4
Vale Canada Limited - Copper Cliff Mine (North)	Copper Cliff/City of Greater Sudbury	I	509.162	1	--	1	1605	1	2114.162	0	0	0	1	0	0	4
Vale Canada Limited - Copper Cliff Mine (South)	Copper Cliff/City of Greater Sudbury	I	276.14	1	--	1	2430	1	4186.698	0	0	0	1	0	0	4
Vale Canada Limited - Creighton Mine	Lively/Greater Sudbury	I	450.698	1	--	1	1306	1	1756.698	0	0	0	1	--	0	4
Vale Canada Limited - Ellen Pit	Denison Township	I	--	1	--	1	42160	2	42160	0	0	0	1	--	0	5
Vale Canada Limited - Frood-Stobie Mine	Sudbury	I	769.62	1	--	1	72	1	841.62	0	0	0	1	--	0	4
Vale Canada Limited - Garson Mine	Garson/Greater Sudbury	I	359.651	1	29323.3402	2.00	1476.8	1	31159.7912	0	0	2400	2	1	1	7
Vale Canada Limited - Totten Mine	Worthington/Greater sudbury	I	141	1	29.5	1	7165	1	7335.5	0	0	2200	2	0	0	5
Xstrata Canada Corporation - Nickel Rim South Project	Skead/Greater Sudbury	I	79.36133333	1	--	1	--	1	79.36133333	0	0	8200	2	--	0	5
Xstrata Canada Corporation - Sudbury Operations Mines/Mill - O	Onaping/Greater sudbury	I	80340.2602	3	47844.5416	2.00	6421130.648	5.00	6549315.45	0	0	8200	2	--	0	12
Xstrata Canada Corporation - Sudbury Operations Mines/Mill - Tl	Val Caron/Greater sudbury	I	119.287	1	--	1	--	1	119.287	0	0	8200	2	--	0	5
Xstrata Canada Corporation - Xstrata Copper Canada Division, Kic	Timmins	2	1858.6276	1	44213.069	2	294155.2115	4	340226.9081	0	0	10000	2	2	1	10
XSTRATA NICKEL - MONTCALM MINE	Timmins	I	190.82075	1	36.209	1	20.60533333	1	247.6350833	57.489	0.696456244	10000	2	0	0	5.69
				Point Scoring Parameters 1		Point Scoring Parameters 2		Point Scoring Parameters 3			Point Scoring Parameters 4		Point Scoring Parameters 5		Point Scoring Parameters 6	
				0-10000= 1		0-10000= 1		0-10000= 1			(Total scores for on-site release X		100-1000= 1		1-2=1	
				10001-50000=2		10001-50000=2		10001-50000=2			Total Recycling transfer)/Total		1001-10000=2		3-5=2	
				50001-100000=3		50001-100000=3		50001-100000=3			of average on-site release		10001-25000=3		6-10=3	
				100001-500000=4		100001-500000=4		100001-500000=4					25000-50000=4		11-15=4	
				>500000=5		>500000=5		>500000=5					>50000=5		>15=5	
				NA=1		NA=1		NA=1					NA=1		NA=0	

Data Source: Environment Canada (2012, 2011,2010,2008); CEC Facility Report (2012)

Appendix 2. Data of all abandoned base metal mining sites of Northern Ontario and calculation of priority ranking system.

Facility Name	Minig Types	Features	Mining District	Tailing Area (ha)	Point Score 1	Tailing Volume (m³)	Point Score 2	Waste Rock Volume (m³)	Point Score 3	ARD Potential	Point Score 4	water quality issue	Point Score 5	Proximity to Downstream Receiver	Point Score 6	Proximity to Settlement	Point Score 7	Total Scores
JAMIESON MINE,	COPPER	TAILINGS - UNCONFINED	PORCUPINE	13.75	2	550000	4	111900	3	High	5	above effluent limits	5	1	3	< 1	5	27
KAM-KOTIA MINE	COPPER	TAILINGS - UNCONFINED	Timmins	48	3	6000000	5	200000	3	High	5	above effluent limits	5	< 1	5	3	3	29
BEAVER	LEAD	TAILINGS - UNCONFINED	LARDER LAKE	4.29	1	85800	2	160500	3	Low	1	above effluent limits	5	< 1	5	4.7	3	20
MARMORATON	IRON	TAILINGS - CONFINED	S ONTARIO	43.5	3	8140000	5	40637350	5	Low	1	Marginal PWQO	1	2.5	3	< 1	5	23
LONG LAKE	ZINC	TAILINGS - UNCONFINED	SUDBURY	0.05	1	162000	3	0	0	High	5	above effluent limits	5	< 1	5	1.3	3	22
GORDON LAKE	NICKEL	TAILINGS - UNCONFINED	KENORA	7.8	1	234000	3	400	1	High	5	above effluent limits	5	< 1	5	>55	1	21
MAYBRUN	COPPER	TAILINGS DAMS	KENORA	1.17	1	46800	2	41600	2	High	5	above PWQO	3	< 1	5	< 1	5	23
KIDD COPPER MINE	NICKEL	TAILINGS - UNCONFINED	SUDBURY	13	2	263000	3	11400	2	High	5	above effluent limits	5	< 1	5	2.5	3	25
NICKEL OFFSETS	NICKEL	TAILINGS DAMS	SUDBURY	1	1	25000	2	266000	3	High	5	above effluent limits	5	3.3	3	15	1	20
MOOSE MOUNTAIN	IRON	TAILINGS - CONFINED	SUDBURY	90	4	13305000	5	182000	3	None	0	below PWQO	0	< 1	5	14	1	18
MCKIM MINE	NICKEL	TAILINGS - UNCONFINED	SUDBURY		0	0	0	0	0	unknown	0	unknown	0	4	3	4	3	6
MASSEY MINE #4 SHAFT	COPPER	TAILINGS - UNCONFINED	SUDBURY	1.5	1	25000	2	266000	3	high	5	N.A	0	3.5	3	< 1	5	19
KINGDON	LEAD	TAILINGS - UNCONFINED	S ONTARIO	11.25	2	225000	3	2000	1	low	1	above PWQO	3	< 1	5	< 1	5	20
JARDIN MINE-NO.1 ZONE	LEAD	TAILINGS - CONFINED	SAULT STE MARIE	2.21	1	44000	2	7500	1	High	5	above PWQO	3	< 1	5	7.7	1	18
BRUCE MINES-COPPER B	COPPER	TAILINGS - UNCONFINED	SAULT STE MARIE	2.87	1	37800	2	0	0	High	5	above PWQO	3	< 1	5	< 1	5	21
JARDUN	LEAD	TAILINGS - UNCONFINED	SAULT STE MARIE	2	1	2000	1	2450	1	high	5	above PWQO	3	< 1	5	7	1	17
CENTRE HILL	NICKEL	TAILINGS DAMS	LARDER LAKE	14.49	2	611000	4	11400	2	High	5	above affluent limit	5	2	3	4	3	24
					Point Score 1		**Point Score 2**		**Point Score 3**		**Point Score 4**		**Point Score 5**		**Point Score 6**		**Point Score 7**	
					> 100 ha = 5		>1 Million = 5		>1 Million = 5		High (Likely ARD potential)=5		Above O. Reg. 560/94 Effluent Limits=5		Adjacent, <1 = 5		Adjacent = 5	
					51 – 100 ha = 4		500,001 – 1 Million = 4		500,001 – 1 Million = 4		Low (Low ARD potential)=1		Above PWQO=3		1-5 km = 3		1-5 km = 3	
					26 – 50 ha = 3		100,001 – 500,000 = 3		100,001 – 500,000 = 3		None (No ARD potential)=0		Marginal PWQO=1		>5 = 1		>5 = 1	
					11 – 25 ha = 2		10,000 – 100,000 = 2		10,000 – 100,000 = 2				Below PWQO=0					
					<10 ha = 1		< 10,000 = 1		< 10,000 = 1									
					N.A. = 0		N. A. = 0		N. A. = 0									

Data Source: AMEC (2008)

Appendix 3. Summary and ranking of the concentration of 11 elements in the 0-5 cm layer of urban surface in the city of Greater Sudbury by community.

Table 7.0.1: Summary and Ranking of the Concentrations of 11 Elements in the 0 - 5 cm Layer of Urban Surface Soils in the City of Greater Sudbury By Community (cont'd).

Community	n	Cd			Cr			Fe			Zn			Ba		
		10th	median	95th	10th	median	95th	10th	median	95th	10th	median	95th	10th	median	95th
Onaping Falls	6	0.4	0.4	0.4	26	30	32	11500	12500	14750	22	31	37	25	30	41
Dowling	36	0.4	0.4	3.2	24	43	53	13000	17000	20000	30	37	56	35	54	72
Wahnapitae	11	0.4	0.4	0.4	30	39	41	15500	18000	19000	25	33	35	35	45	50
Skead	10	0.4	0.4	0.4	21	24	42	11000	12500	16000	16	26	46	24	38	69
Val Therese	16	0.4	0.4	0.4	25	28	32	12000	13000	14750	18	23	34	27	33	40
Wanup	26	0.4	0.4	0.7	22	25	33	10560	13000	16000	22	24	33	29	33	49
Hanmer	54	0.4	0.4	0.4	24	26	38	11000	12000	17000	19	25	45	24	32	43
Naughton	6	0.4	0.4	0.4	19	25	33	10000	12000	14900	16	25	37	28	36	45
Levack	32	0.4	0.4	0.4	31	34	42	12000	15000	17100	26	37	54	32	45	56
Whitefish	40	0.4	0.4	0.4	23	38	64	13400	20000	28100	25	56	76	31	74	141
Capreol	19	0.4	0.4	0.6	23	26	36	11000	13000	16450	19	29	56	23	34	49
Chelmsford	12	0.4	0.4	0.4	21	27	38	10300	13000	17350	20	29	42	24	34	47
Blezard Valley	7	0.4	0.4	0.4	23	24	29	9960	11000	13000	22	26	31	28	31	40
Val Caron	10	0.4	0.4	0.4	23	27	57	10900	12000	20000	19	26	43	25	30	51
Azilda	156	0.4	0.4	0.4	25	35	51	11000	14500	19000	25	33	73	28	39	68
Sudbury (New)	74	0.4	0.4	0.4	25	31	43	11600	14000	18000	23	32	57	31	44	82
Sudbury (East)	62	0.4	0.4	0.4	23	31	43	11100	14000	19000	22	35	72	31	47	85
Garson	104	0.4	0.4	0.4	21	26	35	11000	12000	15000	21	32	70	24	36	52
Lively	187	0.4	0.4	0.9	24	32	47	12000	15000	21000	22	34	64	30	48	89
Sudbury (South)	92	0.4	0.4	0.9	24	32	47	11000	14000	18250	19	29	53	29	40	82
Sudbury (Core)	324	0.4	0.4	1.9	25	32	53	12000	15000	24850	24	47	159	31	50	119
Coniston	301	0.4	0.4	1.8	22	29	44	11000	15000	24000	27	51	140	33	52	90
Falconbridge	219	0.4	2.1	4.3	27	40	73	12800	21000	38000	29	66	150	31	50	69
Copper Cliff	290	0.4	1.4	3.4	29	38	60	14000	19000	33000	38	77	180	45	67	120

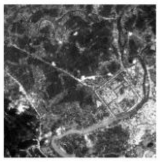
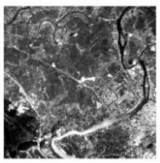
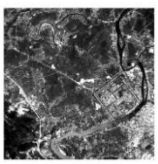
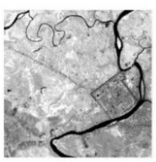
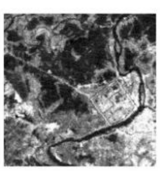
Communities ranked from lowest to highest by the Nickel 95th percentile concentration. All results are in µg/g dry weight.

Source: The City of Greater Sudbury, Urban Soil Survey, 2001 (Randall Jones, 2001).

Appendix 4. Landsat Spectral Band Information.

Landsat Spectral Band Information

Landsat images are composed of seven different bands, each representing a different portion of the electromagnetic spectrum. In order to work with Landsat band combinations (RGB composites of three bands) first we must understand the specifications of each band.

	**Band 1** (0.45-0.52 µm, blue-green) This short wavelength of light penetrates better than the other bands, and it is often the band of choice for monitoring aquatic ecosystems (mapping sediment in water, coral reef habitats, etc.). Unfortunately this is the "noisiest" of the Landsat bands since it is most susceptible to atmospheric scatter.
	**Band 2** (0.52-0.60 µm, green) This has similar qualities to band 1 but not as extreme. The band was selected because it matches the wavelength for the green we see when looking at vegetation.
	**Band 3** (0.63-0.69 µm, red) Since vegetation absorbs nearly all red light (it is sometimes called the chlorophyll absorption band) this band can be useful for distinguishing between vegetation and soil and in monitoring vegetation health.
	**Band 4** (0.76-0.90 µm, near infrared) Since water absorbs nearly all light at this wavelength water bodies appear very dark. This contrasts with bright reflectance for soil and vegetation so it is a good band for defining the water/land interface.
	**Band 5** (1.55-1.75 µm, mid-infrared) This band is very sensitive to moisture and is therefore used to monitor vegetation and soil moisture. It is also good at differentiating between clouds and snow.
	**Band 6** (10.40-12.50 µm, thermal infrared) This is a thermal band, which means it can be used to measure surface temperature. Band 6 is primarily used for geological applications but it is sometime used to measure plant heat stress. This is also used to differentiate clouds from bright soils as clouds tend to be very cold. The resolution of band 6 (60m) is half of the other bands.
	**Band 7** (2.08-2.35 µm mid-infrared) This band is also used for vegetation moisture although generally band 5 is preferred for that application, as well as for soil and geology mapping.

Source: biodiversityinformatics (2013) retrieved on April, 2014 from http://biodiversityinformatics.amnh.org/file.php?file_id=203

Appendix 5: Common Landsat Band Combinations.

Common Landsat Band Combinations

Individual bands can be composited in a Red, Green, Blue (RGB) combination in order to visualize the data in color. There are many different combinations that can be made, and each has their own advantages and disadvantages. Here are some commonly used Landsat RGB band combinations (color composites):

	**3,2,1 RGB** This color composite is as close to true color that we can get with a Landsat ETM image. It is also useful for studying aquatic habitats. The downside of this set of bands is that they tend to produce a hazy image.
	**4,3,2, RGB** This has similar qualities to the image with bands 3,2,1 however, since this includes the near infrared channel (band 4) land water boundaries are clearer and different types of vegetation are more apparent. This was a popular band combination for Landsat MSS data since that did not have a mid-infrared band.
	**4,5,3 RGB** This is crisper than the previous two images because the two shortest wavelength bands (bands 1 and 2) are not included. Different vegetation types can be more clearly defined and the land/water interface is very clear. Variations in moisture content are evident with this set of bands. This is probably the most common band combination for Landsat imagery.
	**7,4,2 RGB** This has similar properties to the 4,5,3 band combination with the biggest difference being that vegetation is green. This is the band combination that was selected for the global Landsat mosaic created for NASA.
	**5,4,1 RGB** This band combination has similar properties to the 7,4,2 combination, however it is better suited in visualizing agricultural vegetation.

Source: biodiversityinformatics (2013) retrieved on April, 2014 from http://biodiversityinformatics.amnh.org/file.php?file_id=203

Appendix 6. Band Designations to identify specific physical elements of satellite image.

Spectral bands	Wavelength (micrometers)	Resolution (meters)	Use
Band 1–coastal/aerosol	0.43–0.45	30	Increased coastal zone observations.
Band 2–blue	0.45–0.51	30	Bathymetric mapping; distinguishes soil from vegetation; deciduous from coniferous vegetation.
Band 3–green	0.53–0.59	30	Emphasizes peak vegetation, which is useful for assessing plant vigor.
Band 4–red	0.64–0.67	30	Emphasizes vegetation slopes.
Band 5–near IR	0.85–0.88	30	Emphasizes vegetation boundary between land and water, and landforms.
Band 6–SWIR 1	1.57–1.65	30	Used in detecting plant drought stress and delineating burnt areas and fire-affected vegetation, and is also sensitive to the thermal radiation emitted by intense fires; can be used to detect active fires, especially during nighttime when the background interference from SWIR in reflected sunlight is absent.
Band 7–SWIR-1	2.11–2.29	30	Used in detecting drought stress, burnt and fire-affected areas, and can be used to detect active fires, especially at nighttime.
Band 8–panchromatic	0.50–0.68	15	Useful in 'sharpening' multispectral images.
Band 9–cirrus	1.36–1.38	30	Useful in detecting cirrus clouds.
Band 10–TIRS 1	10.60–11.19	100	Useful for mapping thermal differences in water currents, monitoring fires and other night studies, and estimating soil moisture.
Band 11–TIRS 2	11.50–12.51	100	Same as band 10.

Instrument-specific relative spectral response functions may be viewed and compared using the Spectral Viewer tool: *http://landsat.usgs.gov/tools_spectralViewer.php*.

Source: The U.S. Geological Survey (2013) retrieved on April 2014 from http://pubs.usgs.gov/fs/2012/3072/fs2012-3072.pdf

Appendix 7. Ethics approval for semi structured interview with relevant professionals.

RYERSON UNIVERSITY
RESEARCH ETHICS BOARD

To: Mohammad Ariful Alam
School of Urban and Regional Planning

Re: REB 2014-003: Mapping the Mining Wastes: An Investigation of Ontario's Mining Waste Management Practice and Its Impact on Northern Communities

Date: February 3, 2014

Dear Mohammad Ariful Alam,

The review of your protocol REB File REB 2014-003 is now complete. The project has been approved for a one year period. Please note that before proceeding with your project, compliance with other required University approvals/certifications, institutional requirements, or governmental authorizations may be required.

This approval may be extended after one year upon request. Please be advised that if the project is not renewed, approval will expire and no more research involving humans may take place. If this is a funded project, access to research funds may also be affected.

Please note that REB approval policies require that you adhere strictly to the protocol as last reviewed by the REB and that any modifications must be approved by the Board before they can be implemented. Adverse or unexpected events must be reported to the REB as soon as possible with an indication from the Principal Investigator as to how, in the view of the Principal Investigator, these events affect the continuation of the protocol.

Finally, if research subjects are in the care of a health facility, at a school, or other institution or community organization, it is the responsibility of the Principal Investigator to ensure that the ethical guidelines and approvals of those facilities or institutions are obtained and filed with the REB prior to the initiation of any research.

Please quote your REB file number (REB 2014-003) on future correspondence.

Congratulations and best of luck in conducting your research.

Lynn Lavallée, Ph.D.
Chair, Research Ethics Board

REFERENCES

Alam, M., McCaines, K., Finley, B., Miller, K. P., Tetsaguzza, M., Wu, H., & Cogliano, D. a. (2013, December). Mining the New Town, Studio Poject. Toronto.

AMEC, A. L. (2008). *DETAILED REVIEW and ASSESSMENT of MINE TAILINGS SITES LOCATED THROUGHOUT ONTARIO, Vol 1.* Sudbaury: Ministry of Northern Development and Mining .

biodiversityinformatics. (2013). Landsat Band Combination. Retrieved April 2014, from http://biodiversityinformatics.amnh.org/file.php?file_id=203

Bray, M. &. (1992). *At the end of the shift:Mines and single-industry towns in northern Ontario.* Toronto: Dundurn Press Limited.

Burtynsky, E. (1996). *Tailing's Photographs*. Retrieved March 09, 2014, from http://www.edwardburtynsky.com: http://www.edwardburtynsky.com/site_contents/Photographs/Tailings.html

CCSG, A. (2004). *Overburdened: Understanding the impact of Mineral Extraction on Women's Health in mining Communities.* Ottawa: Mining Watch Canada.

CEC, C. f. (2009). *Anual Report.* montreal: Commission for Environmental Cooperation (CEC). Retrieved from http://www.cec.org/Storage/151/17762_CEC_2009_AR-e3-rev.pdf.

CEC, C. f. (2012). *Facility Report*. Retrieved February 21, 2014, from Commission for Environmental Cooperation : http://takingstock.cec.org/QueryBuilder.aspx#report=Facility|year=2010|chemicalsmedia=TotalReleaseTransfers,Air,Water,Land|naics=5|menu=adv|ungroupbypollutant=true|country=1|state=9|industry=21223|

City of Greater Sudbury. (2012). *About Greater Sudbury.* Sudbury.

Commission for Environmental Cooperation. (2009). *Anual Report.* montreal: Commission for Environmental Cooperation (CEC). Retrieved from http://www.cec.org/Storage/151/17762_CEC_2009_AR-e3-rev.pdf.

Dudka, S. a. (1997, May). Environmental Impacts of Metal Ore Mining and Precessing: A Review. *Journal of Environmental Quality, 26*(3), 590.

Engine, G. E. (2014). *Landsat Annual Timelapse 1984-2012*. Retrieved March 2014, from https://earthengine.google.org/#intro/

Environment Canada. (2013). *National Air Pollution Surveillance (NAPS) Monitoring Results*. Retrieved March 20, 2014, from http://ec.gc.ca: http://ec.gc.ca/rnspa-naps/default.asp?lang=En&n=8BA86647-D7CB-40B7-931E

Environment Canada. (2014, February 17). *National Pollutant Release Inventory and Air Pollutant Emission Summaries and Trends Downloadable Datasets*. Retrieved February 21, 2014, from http://www.ec.gc.ca: http://www.ec.gc.ca/inrp-npri/default.asp?lang=en&n=0EC58C98-

EnvironmentCanada. (2008, February). *Summary Review of Performance of Metal Mines Subject to the Metal Mining Effluent Regulations in 2006*. Retrieved February 23, 2014, from http://http://publications.gc.ca: http://publications.gc.ca/site/eng/320745/publication.html

EnvironmentCanada. (2010, March). *Summary Review of Performance of Metal Mines Subject to the Metal Mining Effluent Regulations in 2008*. Retrieved February 23, 2014, from http://publications.gc.ca: http://publications.gc.ca/site/eng/356148/publication.html

EnvironmentCanada. (2010, September). *Summary Review of Performance of Metal Mines Subject to the Metal Mining Effluent Regulations in 2009*. Retrieved February 32, 2014, from http://publications.gc.ca: http://publications.gc.ca/site/eng/377286/publication.html

EnvironmentCanada. (2011). *Summary Review of Performance of Metal Mines Subject to the Metal Mining Effluent Regulations in 2010.* Environment Canada.

EnvironmentCanada. (2012). *Summary Review of Performance of Metal Mines Subject to the Metal Mining Effluent Regulations in 2011*. Retrieved February 23, 2014, from http://www.ec.gc.ca: http://www.ec.gc.ca/Publications/default.asp?lang=En&xml=46B34093-B1E0-4B3C-9C70-31B361106D56

EnvironmentCanada. (2014, February 17). *National Pollutant Release Inventory and Air Pollutant Emission Summaries and Trends Downloadable Datasets*. Retrieved February 21, 2014, from http://www.ec.gc.ca: http://www.ec.gc.ca/inrp-npri/default.asp?lang=en&n=0EC58C98-

Fisheries and Oceans Canada. (2014). *A PRACTICAL GUIDE TO THE FISHERIES ACT AND TO THE COASTAL FISHERIES PROTECTION ACT*. Retrieved March 02, 2014, from www.dfo-mpo.gc.ca: www.dfo-mpo.gc.ca/Library/282791.pdf

Fisheries-and-Oceans-Canada. (2014). *A PRACTICAL GUIDE TO THE FISHERIES ACT AND TO THE COASTAL FISHERIES PROTECTION ACT*. Retrieved March 02, 2014, from www.dfo-mpo.gc.ca: www.dfo-mpo.gc.ca/Library/282791.pdf

Forman, R. T. (1990). Ecologically sustainable landscapes: the role of spatial configuaration. In R. T. I. S. Zonneveld, *Changing Landscape: An Ecological Perspective* (pp. 1-14). New York: Springer-Verlag.

Forman, R. T. (1995). *Land Mosaic: The ecology of Landscapes and regions .* Cambridge : Cambridge University Press.

Forman, R. T. (2005). Some general principles of landscape and regional ecology. *Landscape Ecology, 10*(3), 133-142.

Forman, R. T. (2008). *Urban Regions: Ecology and Planning Beyond the city.* Cambridge: Cambridge University Press.

Forman, R. T. (2008). *Urban Regions: Ecology and Planning Beyond the City.* Cambridge : Cambridge University Press.

Fox, F., Hudson, T., & Plumlee, G. (1999). *Metal Mine and the Environment.* Virginia: American Geological Institute. Retrieved March 20, 2014, from http://www.agiweb.org/environment/publications/metalsfull.pdf

Hall, H. M. (2009). Slow Growth and Decline in Greater Sudbury: Challenges, Opportunities, and Foundations for a New. *Canadian Journal of Urban Research, 18*(1), 1-26. Retrieved Mach 12, 2014, from http://ezproxy.lib.ryerson.ca/login?url=http://search.proquest.com/docview/807665455?accountid=13631

Hart & Hoogeveen. (2012). *Introduction to the Legal Framework for Mining in Canada.* Ottawa: MiningWatch Canada.

Interview, S.-s. (2014, March 18). (M. A. Alam, Interviewer)

Jewiss, T. (1983). *The Mining History of the Sudbury Area.* Retrieved March 10, 2014, from https://uwaterloo.ca/earth-sciences-museum/resources/mining-canada/mining-history-sudbury-area

Jones, R., Fiore, L., Davis, K., & Eby, C. (2001). *City of Greater Sudbury 2001 Urban Soil Survey.* Toronto: Ontyario Ministry of Environment.

Kuyek, J. (2011). *The Theory and Practice of Perpetual Care of Contaminated Sites.* Northern Territories: Mackenzie Valley Environmental Impact Review Board as part of the Giant Mine environmental assessment.

Louiseize, K. (2008, January 14). *Cleaning up the Kam Kotia mine site*. Retrieved March 05, 2014, from http://www.northernontariobusiness.com: http://www.northernontariobusiness.com/Industry-News/mining/Cleaning-up-the-Kam-Kotia-mine-site.aspx

Louiseize, K. (2008, January 14). *Cleaning up the Kam Kotia mine site*. Retrieved February 11, 2014, from http://www.northernontariobusiness.com: http://www.northernontariobusiness.com/Industry-News/mining/Cleaning-up-the-Kam-Kotia-mine-site.aspx

Malque III, I. a. (2007). Urbanization Process and the Changing Agriculktural Landscapoe Pattern in the Urban Fringe of Meto Manila, Philipines. *Environment and Urbanization, 19*(1), 191-206.

Mining Watch. (2009). *Canadian Lakes and Streams at Risk of Being Converted to "Tailings Impoundment Areas".* Ottawa: Mining Watch. Retrieved March 20, 2014, from http://www.miningwatch.ca/Lakes_and_Streams_at_Risk

Mining Watch. (2012). *Troubled Water: How mine Waste dumping is Poisoning Our Oceans, Rivers, and Lakes.* Ottawa: Mining Watch Canada.

Miningwatch. (2009). *Canadian Lakes and Streams at Risk of Being Converted to "Tailings Impoundment Areas".* Ottawa: Mining Watch. Retrieved March 20, 2014, from http://www.miningwatch.ca/Lakes_and_Streams_at_Risk

MiningWatch, E. a. (2012). *Troubled Water: How mine Waste dumping is Poisoning Our Oceans, Rivers, and Lakes.* Ottawa: Mining Watch Canada.

Mitchell, A. (2002). *Sudbury leads push to save planet.* Retrieved March 10, 2014, from http://ezproxy.lib.ryerson.ca/login?url=http://search.proquest.com/docview/383960691?accountid=13631

MNDM, M. o. (2009). *Ontario Mining Act Moderinization*. Retrieved February 10, 2014, from http://www.mndm.gov.on.ca/mines/mining_act_e.asp: http://www.mndm.gov.on.ca/mines/mining_act_e.asp

MNDM, M. o. (2014). *All Mining Claim Data.* Retrieved from http://www.mndm.gov.on.ca/en/mines-and-minerals/applications/claimaps.

Moncur, M. C. (2006, March 1). *Acid mine drainage: past, present...future?* Retrieved March 24, 2014, from https://uwaterloo.ca/wat-on-earth/news/acid-mine-drainage-past-presentfuture

Mudd, G. M. (2009). Historical Trends in Base Metal Mining: Backcasting to Understand the Sustainability of Mining. *48th Annual Conference of Metallurgists, Canadian Metallurgical Society.* Sudbury, Ontario: Monash University, CLAYTON.

Ontario Mining Association, O. (2013). *Economic Contribution*. Retrieved January 22, 2014, from http://www.oma.on.ca/en/ontariomining/EconomicContribution.asp

Ontario Nature. (2012). *Mining in Ontario: A Deeper Look.* Ontario. Retrieved November 12, 2013, from http://www.ontarionature.org/discover/resources/PDFs/reports/mining-in-ontario-web.pdf

Ramsey Hart, D. H. (2012). *Introduction to the Legal Framework for Mining in Canada.* Ottawa: MiningWatch Canada .

Randall Jones, L. F. (2001). *City of Greater Sudbury 2001 Urban Soil Survey.* Toronto: Ontyario Ministry of Environment.

Regional Municipality of Sudbury. (1977). *Official Plan.* Sudbury: Regional Municipality of Sudbury.

Republic of Mining. (2010, July 23). *A Brief History of Ontario Mining*. Retrieved March 02, 2014, from http://www.republicofmining.com: http://www.republicofmining.com/2010/07/23/brief-history-of-ontario-mining/

Reynolds, G. (2002, Fall). The Kam Kotia Mine Disaster: Ontario's most notorious mine waste problem. *HighGrader Magazine*. Retrieved March 10, 2014, from http://www.miningwatch.ca/kam-kotia-mine-disaster-ontarios-most-notorious-mine-waste-problem

Semi-structured Interview. (2014, March 18). Urnderstanding the Mining Process and Its Impact in Northern Ontario. (M. A. Alam, Interviewer)

Stothart, P. (2011). *Facts and Figures of the Canadian Mining Industry.* The Mining Association of Canada (MAC). Retrieved April 02, 2014, from http://www.miningnorth.com/wp-content/uploads/2012/04/MAC-FactsFigures-2011-English-small.pdf

Strauss, S. (1992, 11 17). Sudbury helps nature heal itself. *The Globe and Mail*, p. A1.

Sudbury, R. M. (1977). *Official Plan.* Sudbury: Regional Municipality of Sudbury.

Sudbury, T. C. (2012). *About Greater Sudbury.* Sudbury.

Survey, T. U. (2013). Landsat - A Global Land-Imaging Mission. Retrieved April 02, 2014, from http://pubs.usgs.gov/fs/2012/3072/fs2012-3072.pdf

The City of Greater Sudbury. (2013). *Population, Household and Employment Land: Projections for the City of Greater Sudbury.* Sudbury: The City of Greater Sudbury. Retrieved March 26, 2014, from http://www.greatersudbury.ca/linkservid/07D7FA34-D04A-0498-B7F43000A42EFAAC/showMeta/0/

The City of Sudbury. (2006). *Official Plan 2006.* Sudbury: The City of Sudbury.

Travis L. Hudson, F. D. (1999). *Metal Mine and the Environment.* Virginia: American Geological Institute. Retrieved March 20, 2014, from http://www.agiweb.org/environment/publications/metalsfull.pdf

U.S. Geological Survey, U. (2013, 09 24). *Remote-Sensing Data, Landsat-8.* Retrieved March 12, 2014, from http://earthexplorer.usgs.gov/: http://earthexplorer.usgs.gov/

U.S. Geological Survey, U. (2013). *Landsat—A Global Land-Imaging Mission.* Retrieved on 09 April 2014 from http://pubs.usgs.gov/fs/2012/3072/fs2012-3072.pdf

VETAC. (2014). *Regreening Program*. Retrieved March 19, 2014, from http://www.greatersudbury.ca: http://www.greatersudbury.ca/living/environmental-initiatives/regreening-program/vetac/present/

Wallace, C. &. (1996). *Sudbury: Rail Town to Regional Capital.* Toronto: Dundum.

Winterhalder, K. (1996). Environmental degradation and rehabilitation. *Environniental Reviews, 1*. Retrieved March 06, 2014

Wren, C. (2012). *Risk Assessment and Environmental Management: A Case Study in Sudbury, Ontario, Canada.* Netherlands: Maralte. Retrieved from http://www.sudburysoilsstudy.com/EN/overview/reports/SSS_ERA_ENG_Final.pdf

WU Wen-bo, Y. J.-j. (2008). Study on land use changes of the coal mining area based on TM image. *JOURNAL OF COAL SCIENCE & ENGINEERING, 14*(2), 287–290.

Wu, W.-b., Yao, J., & Kang, T.-j. (2008). Study on land use changes of the coal mining area based on TM image. *JOURNAL OF COAL SCIENCE & ENGINEERING, 14*(2), 287–290.