

**Assessing Deposition Of Airborne Particulates and Gases
In The Selkirk Area
Using Lichens Growing On Tree Trunks:
Non-Technical Summary**



Prepared For:
Manitoba Conservation,
Environmental Approvals Branch

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Notice

This document uses non-technical language to summarize a technical report entitled Assessing Deposition Of Airborne particulates and Gases In The Selkirk Area Using Lichens Growing On Tree Trunks. Some important nuances will be unavoidably lost when scientific jargon is translated into everyday language and when a lengthy scientific report is summarized. Consequently, all citations and uses of the results and information generated by this study must be based on the technical report alone.

Except as required by law, this report and the information and data contained herein may be used and relied upon only by the Client and its officers and employees, in their capacity of officer or employee.

Introduction

Residents in the Selkirk area are concerned that deposition of airborne emissions from the Manitoba Hydro coal-fired electricity generating station located in Selkirk may be adversely affecting plant, animal and human health. Manitoba Hydro requested that Manitoba Conservation undertake an independent, scientifically credible study to address this concern. Manitoba Conservation contracted ECOSTEM Ltd. to undertake such a study.

This document uses non-technical language to summarize the results of ECOSTEM's study of lichens as biological indicators of historical deposition of airborne dust and gases in the "Selkirk study area". Included in the "Selkirk study area" are the lands found within about 18 km of the Selkirk coal-fired generating station (Figure 1). The Selkirk study area is over 1,000 km² and includes the Towns of Selkirk and East Selkirk at its center.

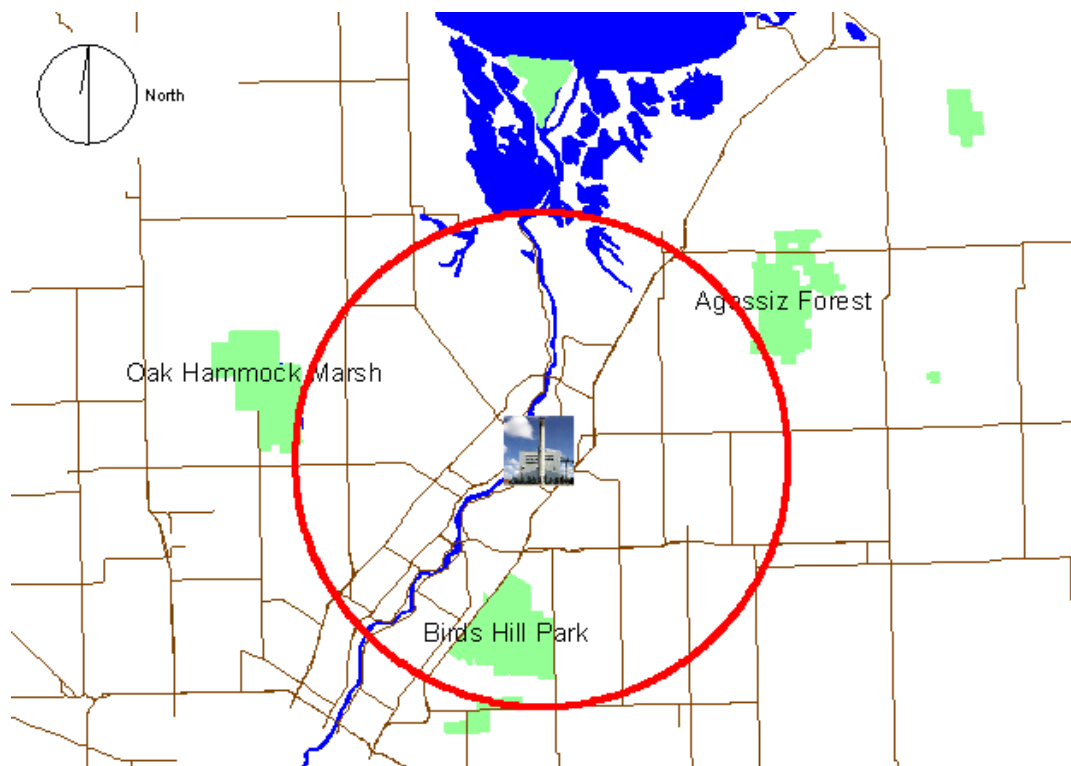


Figure 1. Location of Selkirk study area. Selkirk generating station shown as icon. Circle is 16 km radius around generating station.

There are many potential sources of airborne dust and gases in the Selkirk study area. Urban centers such as Winnipeg and Selkirk are home to many sources of airborne particulates and gases. Agriculture is the dominant land use in the Selkirk study area. Agriculture exposes soil to wind and sometimes uses pesticides and fertilizers to control insects, diseases and weeds. Pesticides are sometimes used by individuals, municipalities and the Province. Waste burning, vehicle use and manufacturing are other common sources of airborne dust and gases.

There are no air quality monitoring stations in the Selkirk study area which could indicate how air quality was affected by these sources or the Manitoba Hydro coal-fired generating station. Therefore, other indicators of past airborne deposition are required.

Lichens growing on tree trunks are well established as good indicators of past deposition of airborne dust and gases. Lichens have been used as bio-indicators of air pollution since 1866. The relationship between lichens and air quality has been reported in over 1,500 scientific papers.

Lichens work well as indicators of airborne deposition because they are widespread in most areas, are long-lived, do not move around, acquire most of their nutrients from the atmosphere, retain most of the airborne deposition that they initially trap and can accumulate airborne deposition year round. Whatever lichens take in from the air over the years is accumulated in their tissue. Chemical analysis of lichen tissue provides us with a record of the chemicals that have been present in the air. In contrast, plants and animals can be poorer indicators as they excrete some of the elements that they take in (e.g. shedding leaves for plants, bodily functions for animals) and they also take up elements found in the soil and water.

Study Objectives

The objectives of this study were to use the concentrations of various chemical elements in lichen tissue and the distribution and abundance of lichen species to:

- (1) Determine whether there is evidence that deposition of airborne chemical elements was substantially elevated in all or portions of the Selkirk study area, and
- (2) In the event that there is evidence of elevated airborne deposition, assess whether the Selkirk coal-fired generating station is the apparent source of airborne deposition.

Background

Fingerprint Elements

Dust and gases are emitted by many point sources and open sources. Essentially, a point source is a single stationary source such as a smoke stack, while an open source is a widespread or mobile source such as cars burning gasoline or exposed soil picked up by wind. Each source of airborne dust and gases contains different amounts of various elements. Relative to the total concentrations of all elements, some sources contain high percentages of some elements and low percentages of other elements. These between source differences can be used to identify chemical elements that could be used to “trace” or “fingerprint” the sources of airborne deposition. That is, if one industry or plant emits a chemical element in a substantially higher amount relative to all other sources in the area then we expect to find much higher concentrations of this element in lichen tissue at locations near this point source. This element can be a “fingerprint” for emissions from this particular industry or plant.

Concentrations of a fingerprint element in lichen tissue can be mapped and then converted into concentration contours. If we measured tissue concentrations at all locations in an area we could map those concentrations as colors (Figure 2 {A}). This is referred to as a tissue concentration surface map because it would look like the surface of a hilly area if the measurements were displayed as a 3-D graph (Figure 2 {B}). Lines

that follow the same tissue concentration are drawn on the tissue concentration surface map. These are known as tissue concentration contours. In theory, every point along each line has the same concentration in the same way that every point along a contour on a topographic map has the same elevation. In practice, no study measures concentrations or elevations at every point in an area. Instead, concentrations are measured at selected points in the area. Values between the selected points are estimated based on the values at surrounding sample locations.

Like contours on a topographic map, lichen tissue concentration surface maps and contours show areas where deposition of airborne deposition of dust and gases was elevated. Areas where concentration contours appear to form ridges or peaks are referred to as hotspots, or areas of the highest concentration for the fingerprint element.

Mapping tissue concentration hotspots and contours is one way of showing how airborne deposition changes with distance from a major point source. By combining local wind information with the shape and location of fingerprint element hotspots, we can trace deposition of fingerprint elements back to their source. Fingerprint elements in lichen tissue will have hotspots downwind of the point source in the directions that winds blow most frequently.

The ideal situation for interpreting concentration contour maps for fingerprint elements is in an area where:

- (1) There is only one substantial point source;
- (2) Airborne deposition of fingerprint elements from other sources is either very low or occurs at a similar level everywhere;
- (3) Local information on the chemical composition of airborne emissions for all of the major point and open sources is available so that fingerprint elements can be selected;
- (4) There is an understanding of how fingerprint elements are deposited from the point sources of interest;
- (5) Local wind direction and speed information is available.

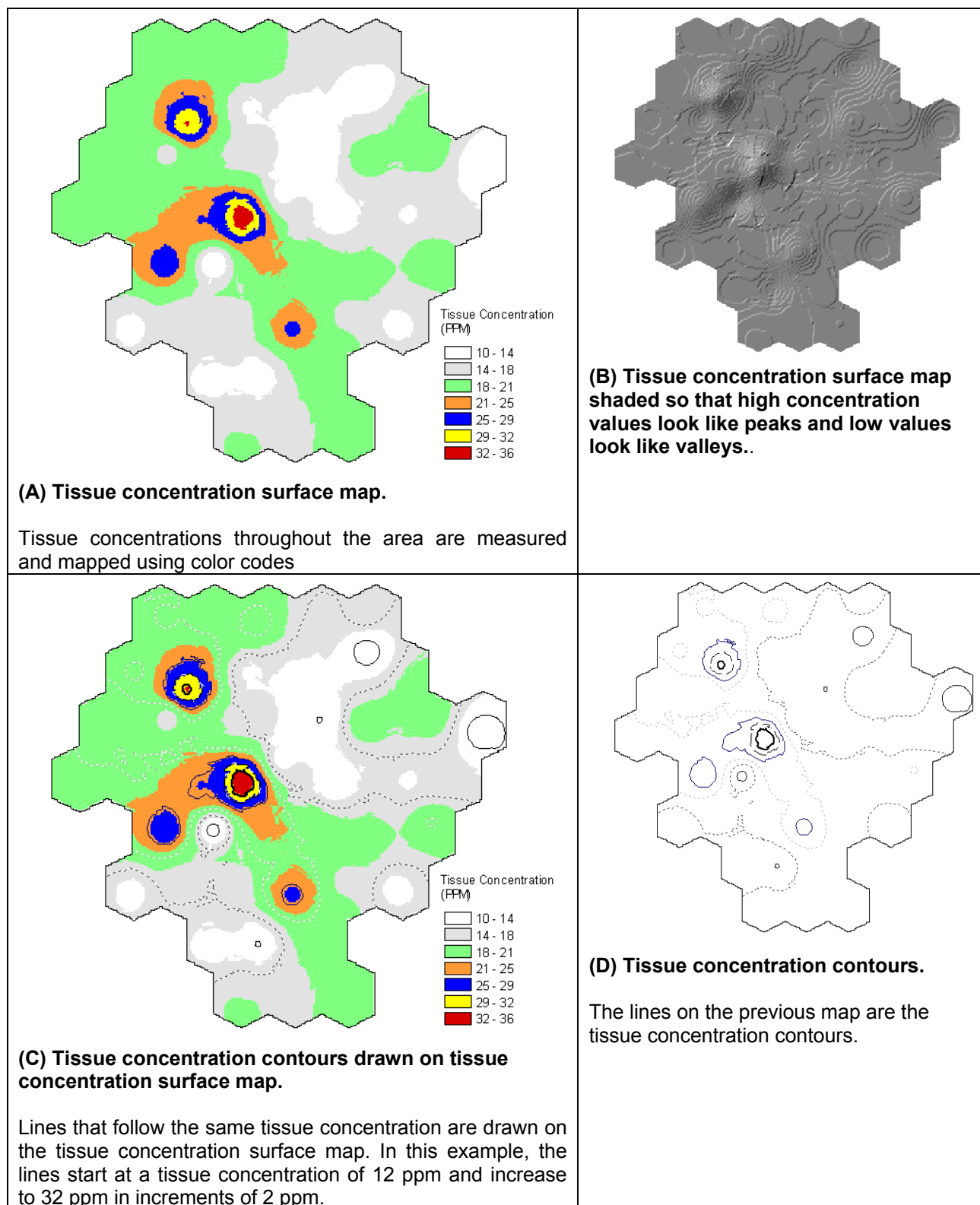


Figure 2. Overview of procedure used to generate tissue concentration contours from a tissue concentration surface map.

Chemical Composition Of Airborne Emissions In Selkirk Area

Airborne emissions data by point source and by element were not available for the Selkirk study area. Fingerprint elements for the Selkirk generating station were selected using seven information sources that ranged from very general to very specific. Two of the information sources covered large geographic areas that included Selkirk, the third was the US Agency for Toxic Substances and Disease Registry, U.S. Department Of Health And Human Services toxic materials reports, the fourth was the Environment Canada National Pollution Release Inventory (NPRI) data for the Selkirk study area, the fifth was a case study of four Canadian coal-fired power plants, the sixth was emissions estimates based on Selkirk generating station stack sampling conducted between February 5-7, 2001 by Maxxam Analytics Inc. and the seventh was a scientific journal article which estimated the chemical composition of different types of crustal material (the source of soil dust).

Gerdau MRM Steel was the only substantial point source other than the Selkirk generating station that reported emissions to the NPRI. Gerdau MRM Steel estimated that 1999 emissions of chromium, copper, lead, manganese and zinc and their compounds were 0.234, 0.063, 0.424, 2.862 and 5.624 tonnes, respectively. Deposition of Gerdau MRM Steel emissions could be confused with deposition from the generating station because Gerdau MRM Steel is only about 3 km to the west-southwest of the generating station. This information was used when generating station fingerprint elements were selected.

There were other emissions sources in the Selkirk area that did not report to the NPRI. In describing the limitations of its database, the NPRI notes that the combined emissions from businesses not required to report to the NPRI “may account for the majority of releases of some pollutants”. Since the Selkirk generating station was not the only emission sources in the Selkirk area, fingerprint elements for the Selkirk Developed Area as a whole (area in and between the Towns of Selkirk and East Selkirk and including the generating station) were also selected. This list of elements consisted of the generating station fingerprint elements plus some other elements emitted by burning coal or smelting metal according to information sources. We could not pre-select all of

the actual fingerprint elements for the Selkirk Developed Area because stack sampling measurements were only available for the Selkirk generating station.

Based on the information above, fingerprint elements were selected for the Selkirk generating station and the Selkirk Developed Area. Barium, boron and strontium were selected as dust fingerprint elements and sulfur as a gaseous fingerprint element for the Selkirk generating station. They were not expected to be crystal clear fingerprints of the Selkirk generating station because there probably were other local emission sources that did not report to the NPRI. Selenium was also initially selected as a generating station fingerprint but was dropped when lab results indicated that its concentration in lichen tissue was below the chemical detection limit (0.2 ppm) at 15 of the 48 Selkirk stations. Even though arsenic, molybdenum and silver were much more abundant in generating station emissions than in crustal material, they were not selected as generating station tracers because their total emission amounts were low and could be confused with other local sources.

Instead, arsenic, molybdenum and silver along with cadmium and zinc were selected to supplement the generating station fingerprints to trace deposition from the Selkirk Developed Area (area in and between the Towns of Selkirk and East Selkirk). That is, arsenic, barium, boron, cadmium, molybdenum, silver, strontium, sulfur and zinc were selected as fingerprints of all emissions sources in the Selkirk Developed Area (includes the generating station). Even though manganese was emitted by Gerdau MRM Steel, it was an ambiguous Selkirk Developed Area fingerprint because it was relatively abundant in soil dust. Mercury, sodium and silicon were selected as fingerprints of windblown soil dust in areas not receiving substantially elevated airborne deposition from the Selkirk Developed Area.

Local Wind Information

Wind data from a Manitoba Agriculture station located about 9 km northeast of the generating station became available after the field work for this project was completed. Although these wind data only covered a 10 month period, this source seemed more appropriate than data from the Winnipeg airport.

Local weather data suggested that the deposition contours produced by Manitoba Hydro's 1992 dispersion modeling should be rotated about 23° to the west to more accurately show where airborne deposition from the generating station would be elevated (deposition was reported as maximum ground level concentration). To facilitate the interpretation of results in this study, initially the dust and SO₂ concentration contours provided in Manitoba Hydro's environmental impact statement were rotated about 23° to the west. Shortly after a draft of this report was submitted to Manitoba Conservation, Manitoba Hydro released an updated environmental impact statement which, among other things, updated the predicted concentration contours and provided dust deposition contours based on local wind data. The amounts of airborne deposition indicated by lichen tissue concentrations with the Manitoba Hydro predictions provided in both the 1992 and 2001 environmental impact statements¹.

Methods

The ideal conditions for using fingerprint elements to trace point source emissions often do not occur. Some of the factors which made this a complex study to design were:

- (1) Reliable wind frequency and direction data was not available. Short term local wind data became available after the sampling was completed. This had a minor effect on how the samples stations were located. Ultimately, it would have been difficult to trace deposition back to apparent emissions sources had the local data not become available.
- (2) The area of potential impact was at least 300 km² based on Manitoba Hydro's model predictions which indicated that deposition from stack emissions would be highest between 4 and 10 km north of the generating station.

¹ References for Manitoba Hydro 1992 and 2001 environmental impacts statements are:
SENES Consultants Limited. 1992. Environmental impact assessment, thermal life assurance program, Selkirk Generating Station, Volume I: Summary & Main Report. Prepared for Manitoba Hydro.
SENES Consultants Limited. 2001. Environmental impact assessment 1993 - 2000. Prepared for Manitoba Hydro.

- (3) Estimates of generating station stack emission rates for various elements did not become available until after most of the field work was completed. This complicated the task of selecting fingerprint elements for the generating station and determining whether more sample stations were required.
- (4) There was at least one other major point source of airborne emissions near the generating station but stack emissions data were only available for the generating station. This also complicated the task of selecting fingerprint elements for the generating station.
- (5) There were other open sources of airborne elements that could not be assumed to be deposited at consistent rates or with consistent chemical composition throughout the study area. Soil and parent material exposed by cultivation and borrow pits was presumed to be the most substantial open source. Again, this complicated the task of selecting fingerprint elements for the generating station and interpreting the results.

The most appropriate way to meet the study objectives given the complicated background conditions was to sample lichens at locations on a grid centered on the Selkirk generating station and compare Selkirk tissue concentrations with those from a control area. Selkirk sample stations were located on a 4 km triangular sampling grid centered about 2 km west of the Selkirk generating station. In theory, this sampling grid had a 99% probability of detecting a “hotspot” that was (1) double the background concentration and (2) at least 3,600 m wide and 7,200 m long. Two additional sample stations were added near the Selkirk generating station where the probability of missing a hotspot could be substantially higher if winds blew frequently in that direction.

An area receiving virtually no airborne deposition from human sources was used as a control for lichen results from the Selkirk area. A relatively pristine area was chosen because there was no scientific evidence establishing how the levels of various elements in lichen tissue correlated with human, animal or tree health. If Selkirk tissue concentrations were not higher than in a relatively pristine control area then it seems reasonable to assume that airborne deposition in the Selkirk area was too low to affect human, animal or tree health.

A control area could not be selected before sampling started because there was no air quality monitoring information available to identify which areas received virtually no airborne deposition from human sources. Three candidate control areas were sampled- Spruce Woods Provincial Park, Sandilands Provincial Forest and Whiteshell Provincial Park. The area which had the lowest tissue concentrations of elements from human sources was selected as the control area.

A sample station, which consisted of six suitable trees (oak at all but two stations where ash were sampled), was located as close as possible to each target location on the sampling grid. All species of lichens and mosses growing between 0.5 and 2.0 m high on each tree were collected and taken back to the lab to determine species composition. *Xanthoria* lichens were selected as the group of species to use for chemical analysis. *Xanthoria* was the only group of closely related species which was both widespread in all of the areas and large enough to be collected in adequate amounts for chemical analysis. *Xanthoria* lichens and bark samples were collected from each sample tree, taken back to the lab and dried. *Xanthoria* tissue was cleaned of bark and other lichen species in a clean room using low contaminant tools by people wearing low contaminant clothing. Processed tissue samples were sent to Enviro-Test Labs in Edmonton, Alberta for chemical analysis. Chemical analysis reported concentrations of 33 elements: aluminum, antimony, arsenic, barium, beryllium, boron, cadmium, calcium, chromium, copper, gallium, iron, lead, lithium, magnesium, manganese, mercury, molybdenum, nickel, phosphorus, potassium, scandium, selenium, silicon, silver, sodium, strontium, sulfur, thallium, tin, titanium, vanadium and zinc.

Information about each sample station and the sample trees was also collected at each station. Information collected included such things as geographic coordinates of station, land use surrounding the station (park, woodlot, agricultural forage, agricultural pasture, agricultural cultivated, industrial/ urban), land use at the station (woods, yard, pasture, picnic/ playground area), tree species, tree circumference and distance of tree from nearest road.

For statistical analysis, the Selkirk study area was sub-divided into nine zones based on distance and direction from the generating station (Figure 3). Manitoba Hydro dispersion modeling predicted that concentrations of some elements would be maximal

4.1 – 10 km north of the generating station. Because there were conflicts between the wind information used in the concentration predictions (wind information recorded at Winnipeg airport) and the wind information available for other places in southern Manitoba, it was possible that maximum deposition occurred in a direction other than north.

Tissue concentrations from each distance and direction zone were compared with each other. Among other things, these comparisons identified the distance and direction zone which had the lowest deposition from human sources. The zone with the highest tissue concentrations was compared with the relatively pristine control area and with the Selkirk zone with the lowest concentrations. These two comparisons provided two benchmarks for any elevated tissue concentrations ranging from virtually no deposition to “background” deposition for the Selkirk area. Most people, including those living in agricultural areas, are exposed to more deposition than a pristine area even if there is no major point source in the area.

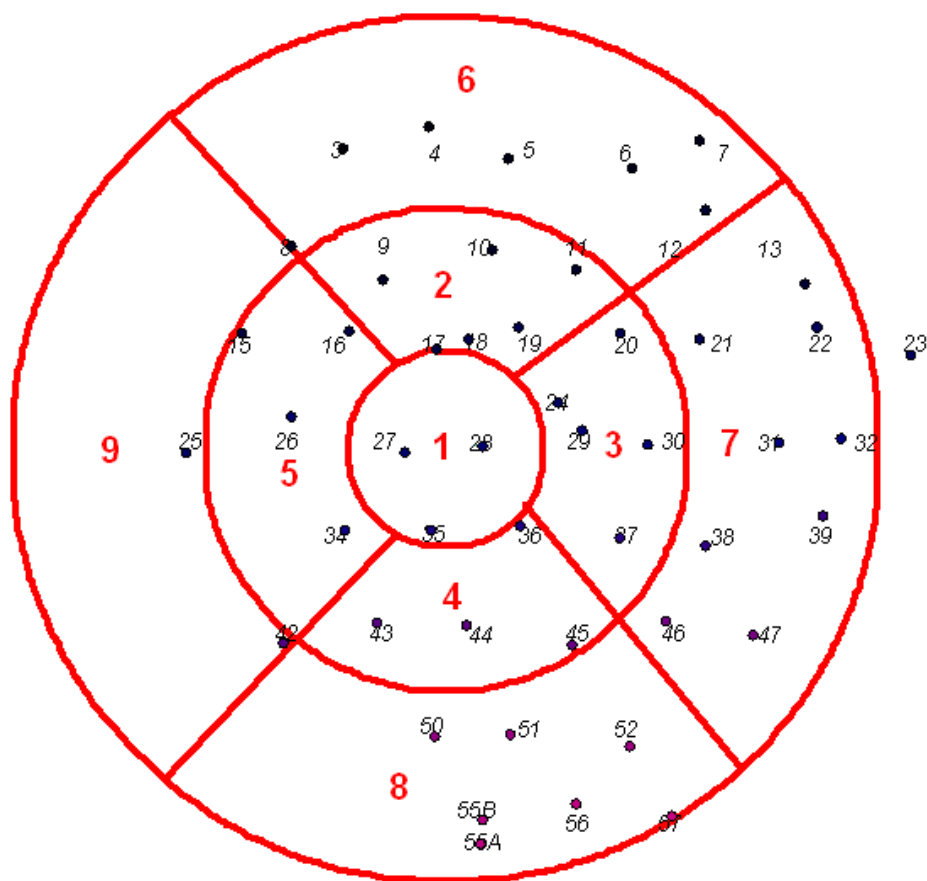


Figure 3. Location of stations relative to distance and direction from center of Selkirk developed. Stations numbers in small type, distance & direction zones in large type. S23 was included in Zone 7, S17 in Zone 1 and S15 in Zone 9.

It was recognized that the crude subdivision of the Selkirk study area into nine distance and direction zones might not detect the complexity of the actual deposition patterns of many elements. Tissue concentration surface maps for fingerprint elements for the generating station and the Selkirk Developed Area (area in and between the Towns of Selkirk and East Selkirk) were used to identify areas that appeared to receive elevated levels of airborne deposition relative to other areas within the Selkirk study area. Fingerprint element tissue concentration maps were compared with Manitoba Hydro's SO₂ concentration and dust deposition predictions. Only those hotspots that incorporated more than one sample station were used in these comparisons because it was more likely that a single station hotspot was created by a small local source rather than a substantial point source.

Fingerprint elements were selected prior to fieldwork based on general information and results from generating station stack sampling. Tissue concentration surface maps were examined together with statistical results (correlations, principal components analysis) to determine whether the pre-selected fingerprint elements actually separated generating station deposition from other known and unknown sources of airborne emissions in the area.

Generating station deposition contours based on fingerprint element tissue concentrations were outlined essentially by superimposing fingerprint element tissue concentration surface maps on each other. Hotspots found only on one fingerprint element concentration surface map were ignored. Selkirk Developed Area and windblown soil dust deposition contour maps were also created in the same way using Selkirk Developed Area and soil fingerprint elements, respectively. Each station was assigned an implied airborne deposition index value based on its location within the Selkirk Developed Area deposition contours and other information gathered by the study.

The deposition contours generated from fingerprint element concentration surface maps show relative differences in deposition but do not have a one-to-one relationship with actual airborne deposition levels. This is because different elements are deposited at different rates and because lichens bio-accumulate different elements at different rates. The locations of the contours shown in all of the contour maps are approximate and cannot be used to determine airborne deposition at a particular location. The locations of the lichen implied deposition contours are accurate to within about 1 km. That is, the actual location of the contour could be anywhere within a band of up to 2 km centered on the contour. This was considered adequate to meet the study objectives. The purpose of these maps was to identify the broad patterns of deposition implied by lichen tissue concentrations so that we could assess whether it appeared that the Selkirk generating station was depositing airborne elements beyond its immediate vicinity in general and in the Birds Hill area in particular.

In addition to chemical analysis of lichen tissue, the relationship between implied airborne deposition and lichen species composition was examined. Various measures of species composition such as percent cover, average number of species at a station,

station frequency, tree frequency, index of atmospheric purity, ordination and classification were used for these comparisons.

Findings

A total of 62 stations and lichens on over 400 trees were sampled in Spruce Woods Provincial Park, Sandilands Provincial Forest, Whiteshell Provincial Park and the Selkirk study area. Whiteshell was selected as the control area for this study because Spruce Woods and Sandilands appeared to receive much higher deposition of airborne elements from human sources. For Sandilands, the sources of airborne elements appeared to be a combination of windblown soil dust from the cultivated agricultural zone located between 2 and 20 km to the west of the sample stations and emissions from the City of Winnipeg about 60 km to the northwest. For Spruce Woods, the sources of airborne elements appeared to be a combination of windblown soil dust from cultivated agricultural lands surrounding and within Spruce Woods Park and exposed sand dunes to the west and emissions from the Canadian military Shilo test range to the north and the City of Brandon to the west. The Whiteshell control area was furthest from major point and/ or open sources (nearest source to Whiteshell is located in Kenora about 60 km to the east), none of the Whiteshell stations were near a gravel road, all of the Whiteshell stations were at least 20 km away from a cultivated agricultural field. Whiteshell tissue concentrations for most elements were within background ranges reported for other lichen species in the scientific literature.

Selkirk Study Area- Deposition Patterns Implied By Lichen Tissue Concentrations

Within 10 Kilometers Of The Generating Station

Lichens were good bio-indicators of airborne deposition of dust emissions from the Selkirk generating station and the Selkirk Developed Area (area in and between the Towns of Selkirk and East Selkirk). There was a striking similarity between (1) the results of statistical tests for differences in concentrations based on distance and

direction from the Selkirk Developed Area, (2) results from statistical and mapping methods, and (3) Manitoba Hydro dust deposition predictions.

Concentrations of generating station fingerprint elements in lichen tissue were compared by distance and direction zone within the Selkirk study area. Zone 1 included the four stations found in and around the Selkirk Developed Area (Figure 3). Fingerprint element tissue concentrations indicated that airborne deposition was highest in Zone 1 and lowest in Zone 7 not including Station 13 (S13 had high tissue concentrations of some elements from a local source).

Sulfur, a fingerprint for gaseous emissions from the generating station, had tissue concentrations that were 1.32 times higher in Zone 1 than in Zone 7 or 1.84 times higher than the relatively pristine control area. Comparison of the nine distance and direction zones did not reveal significantly different tissue concentrations for the three remaining generating station fingerprint elements. This was probably because (1) Zone 1 had a large range of tissue concentrations, and (2) the deposition patterns of these elements were more refined than the crude subdivision of the Selkirk study area into nine zones. An examination of the Selkirk Developed Area portion of Zone 1 indicated that barium and boron tissue concentrations in the Selkirk Developed Area (average of Stations 27 and 28 {S27, S28}) were significantly higher than in Zone 7 by 1.6 and 1.4 times, respectively.

Statistical analysis of the study data indicated that barium, boron and strontium were in fact the clearest fingerprint elements for generating station emissions. A comparison of tissue concentration surface maps and Manitoba Hydro dust deposition modeling showed that barium, boron and strontium concentrations in lichen tissue were substantially higher in the same general locations as predicted by the deposition modeling (Figure 4). Some minor differences between the dust fingerprint tissue concentration surface maps and the Manitoba Hydro dust deposition predictions were expected because (1) the latter are predictions based on modeling, (2) different elements are deposited in different ways depending on whether they are emitted predominantly as dust or gas and whether their subsequent deposition is dominated by wet or dry processes, (3) the generating station was not the only source of airborne dust, (4) highly localized factors were present (elevated windblown soil dust, fertilizer

application, etc.), (5) the Manitoba Hydro dispersion model provided predictions for a much finer grid, and (6) the precision of the lichen tissue concentration surface maps is about 1 km.

Generating station dust deposition contours as implied by lichen tissue concentrations were generated by overlaying tissue concentration surface maps for barium, boron and strontium (Figure 5). The only major difference between the generating station dust deposition contours implied by lichen tissue concentrations and the Manitoba Hydro dust deposition predictions was the location of the hotspot northwest of the generating station (Figure 6). Lichen tissue concentrations located the peak of the northwest hotspot between 2.5 and 4.5 km further northwest of the generating station than shown in the Manitoba Hydro dust deposition predictions (range of distances due to resolution of the sampling grid). The peak of the hotspot was centered at S9.

The possibility that some factor other than the generating station was responsible for substantially higher tissue concentrations at S9 was explored. Because there was no evidence that another factor was responsible and because tissue concentrations of fingerprint elements at adjacent stations were also elevated, it was concluded that the high peak in the northwest hotspot was primarily the result of deposition from the Selkirk Developed Area.

The reliability of the location of the northwest deposition hotspot as implied by lichen tissue concentrations was corroborated by the fact that the Manitoba Hydro dispersion modeling predicted that aluminum deposition would be highest in a hotspot northwest of the generating station. The highest aluminum concentration in lichen tissue was found at the hotspot peak located at S9. Another corroboration was that our Station 9 was located within the northwest end of the highest 24 hour average coarse dust (PM₁₀) concentration contour in the Manitoba Hydro 2001 predictions.

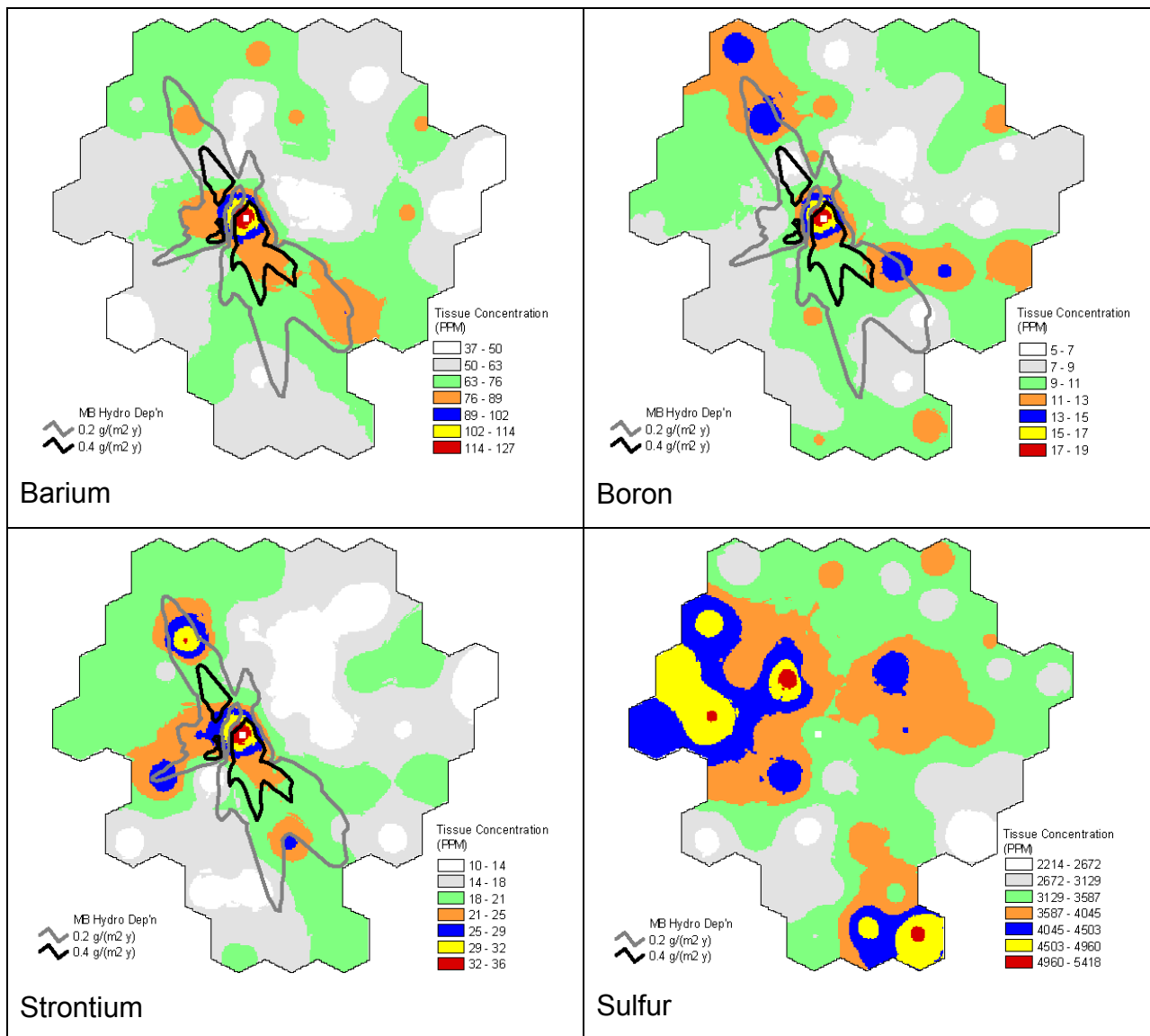


Figure 4. Tissue concentration surface maps for tracers of the Selkirk generating station with Manitoba Hydro dust deposition contours superimposed. Generating station is white square.

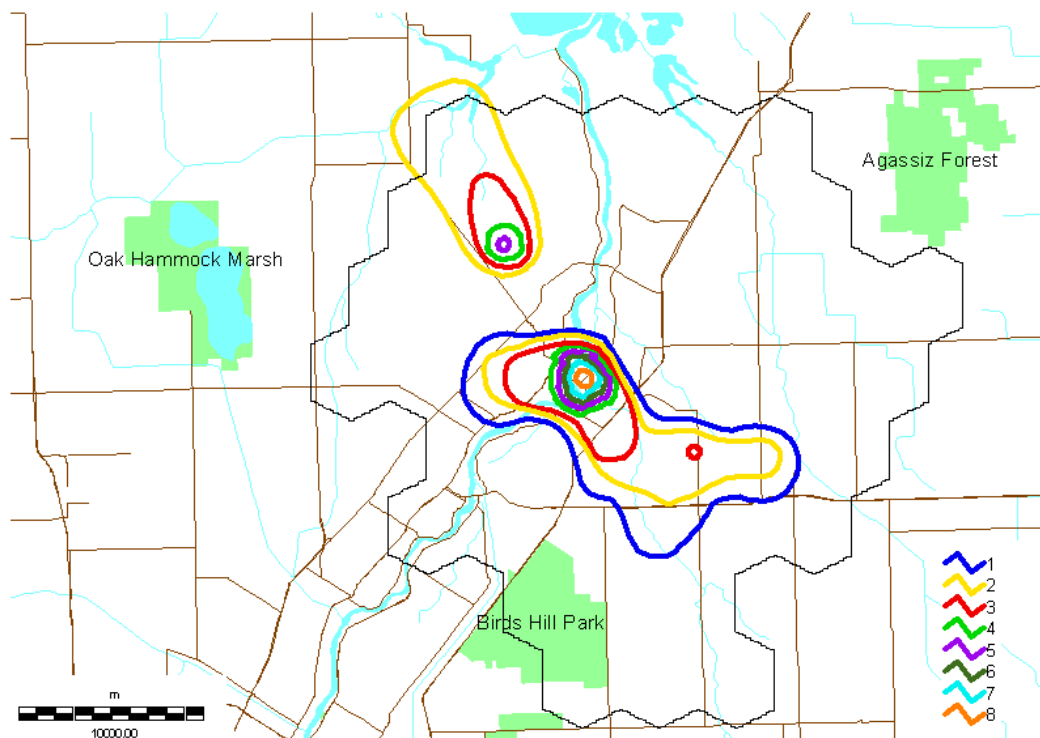


Figure 5. Generating station dust deposition contours implied by barium, boron and strontium lichen tissue concentrations. Generating station is at center of contour 8. Contours show increasing tissue concentrations and are not directly proportional to actual deposition. Black line shows boundary of study area.

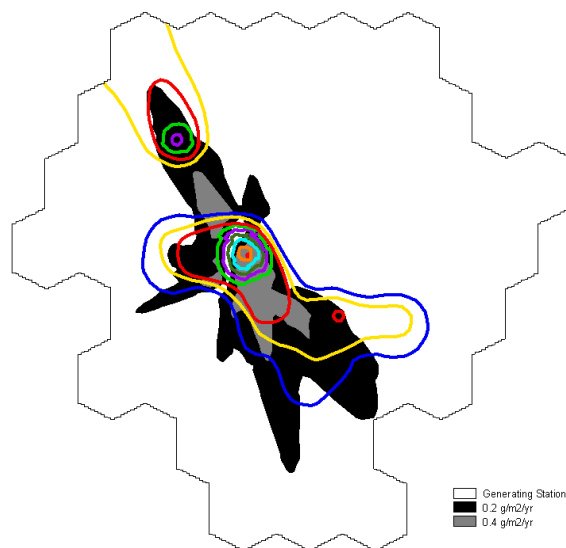


Figure 6. Generating station dust deposition contours implied by concentrations of barium, boron and strontium in lichen tissue (lines) superimposed on Manitoba Hydro dust deposition predictions (solid colors). Contours increase in value from the outside in and are not directly proportional to actual deposition. Black line shows boundary of study area.

Barium and strontium tissue concentrations at many stations outside of the areas of elevated generating station dust deposition were lower than in the Whiteshell. Nevertheless, it did not appear that the rate of bio-accumulation was substantially lower near the generating station than further away from it. The similarity of tissue surface concentration maps for these elements and the Manitoba Hydro dust deposition predictions indicated that barium and strontium bio-accumulation still increased with increasing airborne deposition. A comparison of the candidate control areas suggested that areas with elevated deposition of trace metals had lower overall barium and strontium tissue concentrations.

Sulfur was pre-selected as the element with the best potential as a fingerprint of gaseous emissions from the generating station. Relative to the generating station, sulfur tissue concentrations were lowest nearby, highest about 5 km northwest and high to the northwest, west and east-northeast. The sulfur tissue concentration surface map was generally similar to the relevant Manitoba Hydro concentration predictions of areas of elevated sulfur deposition. It was also consistent with overlapping emissions from burning fossil fuels in vehicles and home heating in the Town of Selkirk.

Arsenic, cadmium, molybdenum, silver and zinc were also pre-selected as additional fingerprint elements that could identify deposition from the Selkirk Developed Area as a whole. There were likely additional fingerprint elements for the Selkirk Developed Area but we could not identify them with certainty since we knew that there was at least one other source of airborne emissions near the Selkirk generating station and stack emissions data were available only for the generating station.

Tissue concentration surface maps for all of the Selkirk Developed Area dust fingerprint elements suggested that these elements were emitted from the generating station and/ or the west side of the Selkirk Developed Area. The dominant sources of cadmium and zinc emissions also appeared to be in the west side of the Selkirk Developed Area (Figure 7). There also appeared to be at least one other source of airborne molybdenum and silver in the west side of the Selkirk Developed Area (Figure 7). In its report to the National Pollution Release Inventory, Gerdau MRM Steel did not report emissions of molybdenum and silver. Tissue concentration surface maps for other

elements indicated that it was unlikely that molybdenum and silver were deposited from the generating station in a different pattern than the other elements.

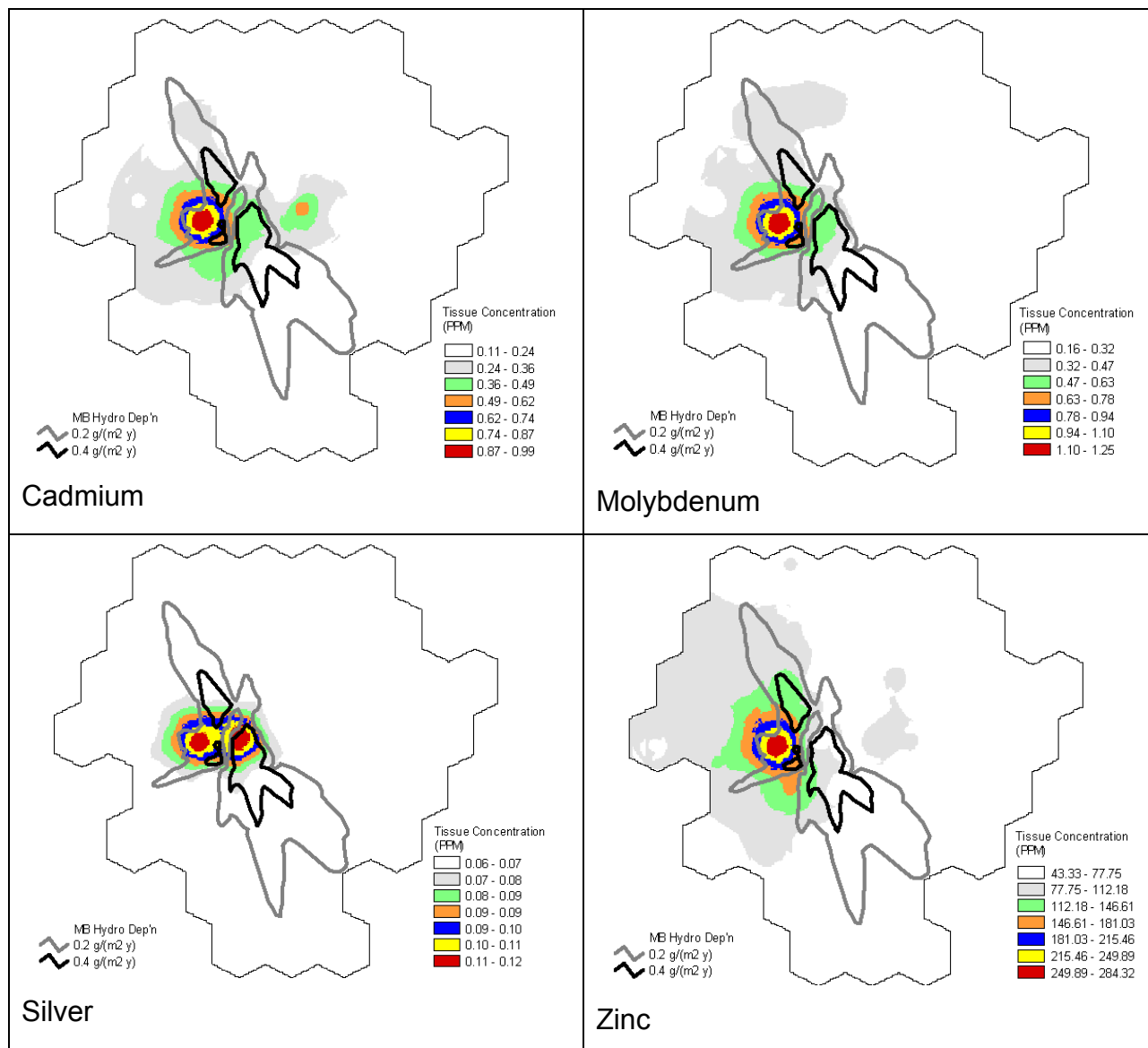


Figure 7. Tissue concentration surface maps for tracers of the Selkirk generating station with Manitoba Hydro dust deposition contours superimposed.

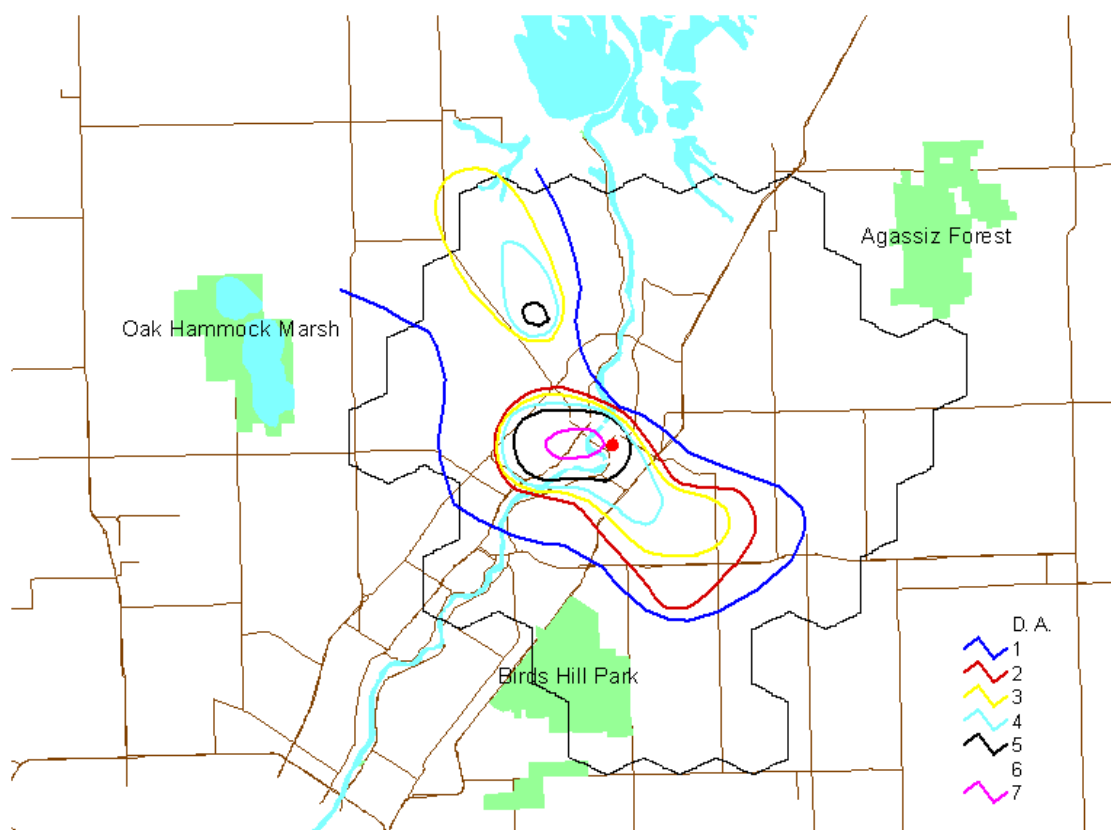


Figure 8. Contours for airborne dust deposition from the Selkirk Developed Area implied by lichen tissue concentrations. Generating station is red dot. Contour values have no units because they are relative. Black line shows boundary of study area.

Although not pre-selected as Selkirk Developed Area tracers, antimony, chromium, lead and tin tissue concentration maps were quite similar to that of zinc which suggested that these elements were emitted in relatively large amounts from the west side of the Selkirk Developed Area. Dust deposition contours for emissions from all sources in the Selkirk Developed Area were generated by overlaying tissue concentration surface maps for generating station and Selkirk Developed Area tracers (antimony, barium, boron, cadmium, copper, lead, molybdenum, strontium and zinc; Figure 8).

Fingerprint element tissue concentrations suggested that deposition of emissions from the Selkirk Developed Area was highly elevated within the Selkirk Developed Area, moderately elevated in a small hotspot about 8 km northwest of the center of the Selkirk Developed Area and slightly elevated up to 12 km to the northwest, 9 km to the southeast and 5 km to the west. This was similar to the overall pattern shown in the Manitoba Hydro dust deposition predictions.

It must be re-emphasized that the locations of the contours shown in all of the lichen implied dust deposition maps were approximate and cannot be used to determine airborne deposition at a particular location. The precision of the implied deposition contours was about 1 km which was considered adequate to meet the study objectives. It must also be emphasized that the lichen implied generating station deposition contours measure relative rather than absolute differences in airborne deposition within the Selkirk study area.

Although theoretically possible, it was unlikely that fertilizers, pesticides, soil dust or road dust caused the fingerprint element tissue concentration patterns observed within an 8 km radius of the center of the Selkirk Developed Area. A review of all of the data collected in this study provided no evidence that deposition from agricultural activities or road dust had a major influence on the tissue concentration surface or contour maps within the 8 km radius.

Within the areas where lichens implied deposition from the Selkirk Developed Area was elevated, arsenic had a tissue concentration surface map that was generally similar to the other fingerprint elements with one exception. Unlike the other elements, arsenic tissue concentrations were also elevated in a large patch southeast of the Selkirk Developed Area. It was possible that this arsenic hotspot was due to overlapping deposition from the generating station and other sources in the Selkirk Developed Area. This area was within the area of elevated deposition as implied by fingerprint element tissue concentrations and as predicted by Manitoba Hydro modeling. However, none of the other generating station or west side of the Selkirk Developed Area fingerprint elements had a hotspot in this area. Because four stations to the southeast had substantially elevated arsenic concentrations it was unlikely that the elevated tissue concentrations were the result of sampling variability, normal variability in the chemical tests or a small local point source. Two of the possible explanations for elevated arsenic concentrations southeast of the Selkirk Developed Area were (1) there was another point source of airborne arsenic, or (2) arsenic concentrations in soils were naturally high.

Further Than 10 Kilometers From The Generating Station

Selkirk Developed Area fingerprint element tissue concentrations outside the area that Manitoba Hydro predicted would receive elevated dust deposition were also examined. Concentrations of these elements should be relatively low there if the model predictions are generally accurate and if there are no other sources of fingerprint elements.

Windblown soil and road dust can be a major open source of airborne elements. Soil dust deposition occurs even in relatively undeveloped regions because soil dust is transported over great distance in high altitude air currents. Cultivated agricultural fields comprise a large percentage of the Selkirk study area. This naturally leads to elevated soil dust deposition when compared with an undeveloped region such as the Whiteshell. If the amount and chemical composition of soil dust was constant throughout the Selkirk study area then there would be little need to consider this issue. Soil samples were not collected as part of this study so we cannot assume that soil dust deposition was similar throughout the Selkirk study area.

Soil dust forms when the earth's crustal material is broken down by various weathering processes. In the absence of soil samples from each sample station, the average chemical composition of soil was estimated using the concentrations of elements in crustal material. Soil dust fingerprint elements were selected based on crustal material concentrations and used to identify areas that appeared to receive windblown soil and/ or road dust deposition in higher amounts and/ or of different chemical composition.

Crustal material fingerprint elements (mercury, silicon and sodium) suggested that deposition of windblown soil and road dust was substantially higher in two bands along the northeastern and southeastern edges of the Selkirk study area. It appeared that there were additional local point sources of some elements at one sample station in each of these bands (S13 and S57).

Several elements had hotspots outside the lichen implied zone of elevated deposition from the Selkirk Developed Area (outside of contour 1 in Figure 8). A review of the data available and a comparison with lichen implied soil dust deposition contours

did not indicate that any of these hotspots were due to deposition of emissions from the Selkirk generating station.

Lichen Tissue Concentrations For Elements Of Concern In The Selkirk Study Area

Tissue concentrations for some elements were examined further because they are considered toxic by some sources. Elements of concern included antimony, arsenic, barium, boron, cadmium, chromium, copper, iron, lead, manganese, mercury, molybdenum, nickel, selenium, silver, sulfur, thallium, tin, vanadium and zinc.

Tissue concentrations for most of the elements of concern were substantially higher in the Selkirk Developed Area than in the relatively “pristine” control area (the Whiteshell) or in the portion of the Selkirk study area where implied deposition was lowest (Zone 7 not including S13). Tissue concentrations for elements with substantially higher tissue concentrations in the Selkirk Developed Area declined rapidly as distance from Selkirk Developed Area increased (sulfur was the exception). Concentration declines were generally least rapid to the northwest and southeast. At distances greater than about 8 km from the center of the Selkirk Developed Area, tissue concentrations for most of these elements were less than double Whiteshell concentrations. Mercury tissue concentrations exhibited the same pattern although they were not substantially elevated relative to the Whiteshell.

It should be re-emphasized that the precision of the lichen implied deposition contours is about 1 km. Therefore, it is possible that the actual declines in tissue concentrations as one moves away from S27 or S28 were more rapid than shown by the method used to estimate concentrations between sample stations.

Most elements of concern had tissue concentrations at S27 and/ or S28 that were at least double those in the Whiteshell (barium, mercury, manganese, thallium and sulfur were the exceptions). Antimony, molybdenum, tin and zinc had the highest degrees of accumulation in Selkirk Developed Area lichen tissue (concentrations at either S27 or S28 were 8.9, 9.0, 18.8 and 7.6 times those in the Whiteshell, respectively). Most elements of concern also had significantly higher tissue concentrations in the Selkirk Developed Area than in Zone 7 (arsenic, boron, nickel, sulfur, thallium and vanadium

were the exceptions). Mean Selkirk Developed Area antimony, molybdenum, tin and zinc tissue concentrations were 4.7, 4.3, 10.0 and 3.3 times higher than in Zone 7, respectively.

Relative to the Whiteshell control area, molybdenum and sulfur had slightly to highly elevated lichen tissue concentrations at many stations in the Selkirk study area. Both of these elements comprise a very low percentage of crustal material. Molybdenum and sulfur are emitted by fuel combustion from many sources. Widespread elevation of molybdenum and sulfur concentrations was attributed to the combined effects of deposition from point and open sources including motor vehicle use and combustion of home heating fuels in the Selkirk Developed Area and the City of Winnipeg.

Birds Hill area lichen tissue concentrations for elements of concern were not substantially higher than in the Whiteshell. None of the elements of high concern had tissue concentrations that were more than 2.0 times the concentrations found in the Whiteshell. Statistical tests found that chromium, lead and zinc were the only elements of moderate concern where the difference between Birds Hill area and Zone 7 (excluding S13) tissue concentrations were statistically significant. Only lead and zinc had concentrations that were up to 2.25 times those of the Whiteshell at a couple of stations in this area.

The results of this study are strongly suggestive but they are not definitive. Some factors which affect the accumulation of elements in lichen tissue (e.g. precipitation, chemical composition of windblown soil dust) were not directly measured. Nevertheless, we do not expect that measuring these other factors would change the conclusion that deposition of elements of concern was substantially elevated in the Selkirk Developed Area and that tissue concentrations for most elements declined rapidly with distance from the generating station. Measuring additional factors might somewhat change the shape of the lichen implied Selkirk Developed Area deposition contours and/ or provide an explanation for anomalies such as the patch of elevated arsenic tissue concentrations located southeast of the Selkirk Developed Area.

More refined allocation of deposition to sources in the Selkirk Developed Area requires identification of all point sources in the area and stack sampling of those sources. In addition, because the study area borders Winnipeg we expect there

probably was some overlap of airborne emissions from sources in Winnipeg and the Selkirk study area.

Implications For Human Health

The highly elevated lichen tissue concentrations in the Selkirk Developed Area will prompt some to ask: what are the implications for human health? To date the Canadian Council of Ministers of the Environment (CCME) has not developed guidelines for acceptable levels of toxic elements as indicated by lichen tissue. There are CCME guidelines that relate to elemental concentrations in soils but these cannot be applied to lichens since (1) the natural or baseline total concentrations of toxic elements in lichens and soils are different, and (2) lichens accumulate elements at different rates than soils. A comparison of total elemental concentrations in crustal material and Whiteshell lichen tissue showed that most elements of concern have much lower baseline concentrations in *Xanthoria* tissue.

Lichen Species Composition

Lichen species composition was related to implied airborne deposition from the Selkirk Developed Area but was a less reliable indicator than tissue concentrations. Other studies have reached a similar conclusion. It was not surprising that species composition measures were less reliable indicators of airborne deposition than elemental tissue concentrations. There are factors beyond airborne deposition which affect lichen species composition and these factors have a greater impact on lichen species composition than on the bio-accumulation of elements in a single species of lichen.

Conclusions

- (1) Lichens were good bio-indicators of deposition of airborne emissions from the Selkirk Developed Area (area located in and between the Towns of Selkirk and East Selkirk).
- (2) A combination of barium, boron and strontium was the best fingerprint of Selkirk generating station dust emissions.
- (3) Nine elements of concern had lichen tissue concentrations that were substantially higher in the Selkirk Developed Area than in the Whiteshell and Zone 7 (a relatively pristine control area compared with the portion of the Selkirk study area with the lowest implied level of airborne deposition). Antimony, molybdenum, tin and zinc tissue concentrations were 4.7, 4.3, 10.0 and 3.3 times higher in the Selkirk Developed Area than in Zone 7.
- (4) Lichen tissue concentrations for elements of concern declined rapidly as distance from the Selkirk Developed Area increased. Concentration declines were generally least rapid to the northwest and southeast. At distances greater than about 6 km from the center of the Selkirk Developed Area, tissue concentrations for most elements of concern were not substantially higher than Whiteshell concentrations. Note that the decline of tissue concentrations within the Selkirk Developed Area may be greater than shown on the deposition contours implied by lichen tissue concentrations because the precision of the contours was about 1 km.
- (5) Although the differences in Birds Hill area and Zone 7 chromium, lead and zinc tissue concentrations were statistically significant, Birds Hill area chromium, lead and zinc tissue concentrations were not substantially higher than in the Whiteshell.
- (6) Arsenic, barium, boron and manganese were bio-accumulated at lower rates than other elements of concern. Arsenic, barium and boron tissue concentrations were highest and manganese was second highest in the Selkirk Developed Area.
- (7) A conclusion regarding human health cannot be drawn from this study as a scientific relationship between lichen tissue concentrations and human health has not been established.

- (8) Measures of lichen species composition reflected the degree of implied airborne deposition at high and low levels of implied airborne deposition but were a less sensitive indicator than elemental tissue concentrations at intermediate degrees of implied airborne deposition.

The following additional conclusions were based on the assumptions that (1) the ten months of local wind data collected by the Agrometeorological Centre of Excellence, Manitoba Agriculture accurately reflected historical wind direction and speed, and (2) deposition of dust and gases emitted by the generating station followed the overall patterns predicted by the Manitoba Hydro dispersion modeling (SENES 2001).

- (9) There appeared to be at least one other substantial source of airborne emissions in the Selkirk Developed Area.
- (10) It appeared unlikely that the Selkirk generating station was the primary source of airborne antimony, lead, tin and zinc deposition.
- (11) More refined source apportioning of airborne deposition from the Selkirk Developed Area requires identification of all point sources in the area and stack sampling of those sources.