Phillips, Floyd and Vicki Henderson. 2000. Vegetation and Soil Monitoring Study in the Vicinity of 8 - 8 Battery, Tilston, Manitoba, 1999. Terrestrial Quality Management Section, Manitoba Conservation. Manitoba Conservation Report 2000-05 iv + 22 pp.

Executive Summary

The Tilston area is the site of oil extraction from underground reserves in the southwest corner of Manitoba. A vegetation and soil monitoring study was carried out during the summer of 1999 in response to concerns of rural residents near the 8-8 oil processing battery (SE8-6-29). The objective of the study was to determine if there were any observable effects caused by the sulphur compounds present in the air emissions from the battery.

Ten monitoring sites were selected, 5 along each of two 2 km transects running SE and W of the battery. Aspen leaves were collected from each of the sites in May, July and August, and soil samples were collected in July. Aspen leaves were analyzed for sulphur and soil samples were analyzed for sulphur and sulphate. The condition of plant leaves was observed several times during the summer, at the monitoring stations, at the aspen bluffs close to the battery, and at farmyards within 2.5 km of the battery. Samples of unhealthy or injured leaves were collected and sent to the Crop Diagnostic Centre, Manitoba Agriculture where plant pathologists diagnosed the cause.

Although many plants in the study area and the control farm showed injury symptoms, disease (mostly fungus) or insects caused them all. There was no visible SO_2 injury to plants in the study area. The relatively high incidence of fungal infection and other plant diseases was probably a product of the abnormally wet conditions during the spring and summer of 1999.

The sulphur content of aspen leaves suggested that there may have been some effect from the battery emissions at one close-in site, although the data were too variable to reach a definitive conclusion.

Available sulphate in the surface soil was slightly elevated at locations within 500m of the 8-8 battery, but due to the high variability, there was no conclusive evidence that emissions of sulphur compounds may have been a contributing factor. Total sulphur in the soil was also variable but there was no pattern that suggested that this parameter might have been affected by sulphur compounds emitted from the 8-8 oil processing battery.

In summary, emissions of sulphur compounds in the study area did not injure vegetation. There was no conclusive evidence that sulphur compounds in the air of the study area affected sulphur levels in aspen leaves or sulphate or sulphur in the soil. The levels of sulphur found in the aspen leaves were within the normal range and would not be detrimental to plant health. The sulphate levels in the soil were lower than or in the low part of the range reported in the Soil Survey Report for the area.

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The authors wish to thank the local residents of the study area for their cooperation in providing access to their property and for agreeing to allow the sampling of soils and vegetation. The authors also acknowledge the assistance of Mr. D. Bezak who provided comments on an earlier draft of the report and Mr. G. Jones for preparing the figure showing the study area.

Vegetation and Soil Monitoring Study in the Vicinity of 8 - 8 Battery, Tilston, Manitoba, 1999

Introduction and Background

Oil reserves are present in the southwest corner of Manitoba, and oil extraction has been occurring in the Tilston area since the early 1950s.

The Terrestrial Quality Section of Manitoba Conservation conducted a vegetation and soil monitoring program in the vicinity of the 8-8 oil processing battery during the summer of 1999. The 8-8 battery is located north of Tilston, in the southeast quarter of Section 8 Township 6 Range 29. This is one of the larger processing batteries in the area and has operated since 1985. Rural residents living within a few kilometres of the 8-8 battery have complained about odours and are concerned that air pollutants may be causing health effects to both humans and livestock.

The product pumped from the oil wells in the area is approximately 10 percent oil and 90 percent salt water. The oil contains solution gases, including hydrocarbon components of natural gas and hydrogen sulphide (H_2S). Oil processing batteries perform two initial treating steps: (i) separation of the crude oil from the salt water during which some of the solution gases are released, and (ii) heating the oil to drive off more of the solution gases. Some of the solution gases is burned as fuel in the oil treater, and the past practice, was to direct the excess gas to a flare stack where it was partially burned. A more recent technology used at Tundra's 8-8 battery since November 1999, is to burn the excess gas in an incinerator to effect more complete combustion. Since the combustion of H_2S produces sulphur dioxide (SO_2), the air emissions from a processing battery can contain both H_2S and SO_2.

Although air quality monitoring was being conducted at two fixed locations, plus some spot monitoring with a portable monitor, there was interest in using other monitoring tools to provide further information about the levels of sulphur gases and their distribution in the area. If the sulphur dioxide dose (concentration x duration) is high enough it can cause visible injury symptoms to the leaves of susceptible plants or to the needles of conifers. Plants, including some that are native to the area (e.g. aspen, rose, wild pea), are susceptible to SO_2 injury. There is a potential that these plants may be injured if doses are above a critical minimum. Dreisinger and McGovern (1970) reported injury to aspen leaves after a one hour exposure to 0.42 ppm SO_2, but usually did not observe damage until exposures were in the range of 0.95 ppm for one hour. If the relative humidity is high, SO_2 exposures that may cause acute damage are typically lower, for instance in the 70 ppm range (Dreisinger and McGovern, 1970). Acute SO_2 damage (brown tissue) typically occurs on the leaf margins and between the veins of the leaves in broad leaf plants and on the tips of needles in conifer trees.

The purpose of this study was to determine if sulphur compounds, released into the air from oil processing at the 8-8 battery, were affecting local vegetation or soils. The study was conducted during the 1999 growing season and had the following objectives:

1. examine plants in the vicinity of 8-8 battery for visible signs of leaf injury and diagnose the cause;
2. determine if there were differences in the concentration of sulphur in the vegetation of the area and if so, was there a pattern that might suggest the likely source of the sulphur; and
3. determine if there were differences in the concentration of sulphur in the soil of the area and if so, was there a pattern that might suggest the likely source of the sulphur.

Methods

Vegetation Health

During the course of the study, the leaves of plants were examined to see if there were any visible signs of injury. Native plants including trees, shrubs, and herbaceous species, which grow along the edges of poplar bluffs in the area, were the main focus of this investigation. All poplar bluffs growing within 200m of the 8-8 battery were examined as well as the bluffs selected for soil and vegetation (aspen) sampling. Local species considered to be most susceptible to SO_2 injury included members of the pea family, rose family and trembling aspen (*Populus tremuloides*).

During the summer, several species of trees and shrubs in shelterbelts or gardens at three farmyards within 2.5 km of the battery were periodically examined for leaf or needle injury (Figure 1). On September 1, 1999, trees and shrubs in a farmyard northeast of Sinclair, were examined as a control. If vegetation was injured or appeared to be in poor health, samples were taken, placed in sealed plastic bags, refrigerated, and taken to the Crop Diagnostic Centre, Manitoba Agriculture, for a determination of the cause.

Table 1. Farmyards where vegetation health was examined

Farmyard	Legal Description	Direction	Distance (km)
Yard 1	SE 9-6-29	E	1.5
Yard 2	NE 4-6-29	SE	2.1
Yard 3	SE 5-6-29	SSW	2.2
Control	NE 22-7-28	NE	21.9

Trembling Aspen Monitoring

Ten sites were selected to collect leaves of trembling aspen trees to determine the concentration of sulphur in the foliage. Five sites were selected along each of two transects, one running southeast of the battery and one running west of the battery. The study design called for sites to be spaced along each transect at distances of 125m, 250m, 500m, 1km, and 2km from the battery. Although suitable natural vegetation was not available at the precise distances and directions identified in the study design, poplar bluffs that matched the distance and direction criteria as closely as possible were selected (Figure 1).

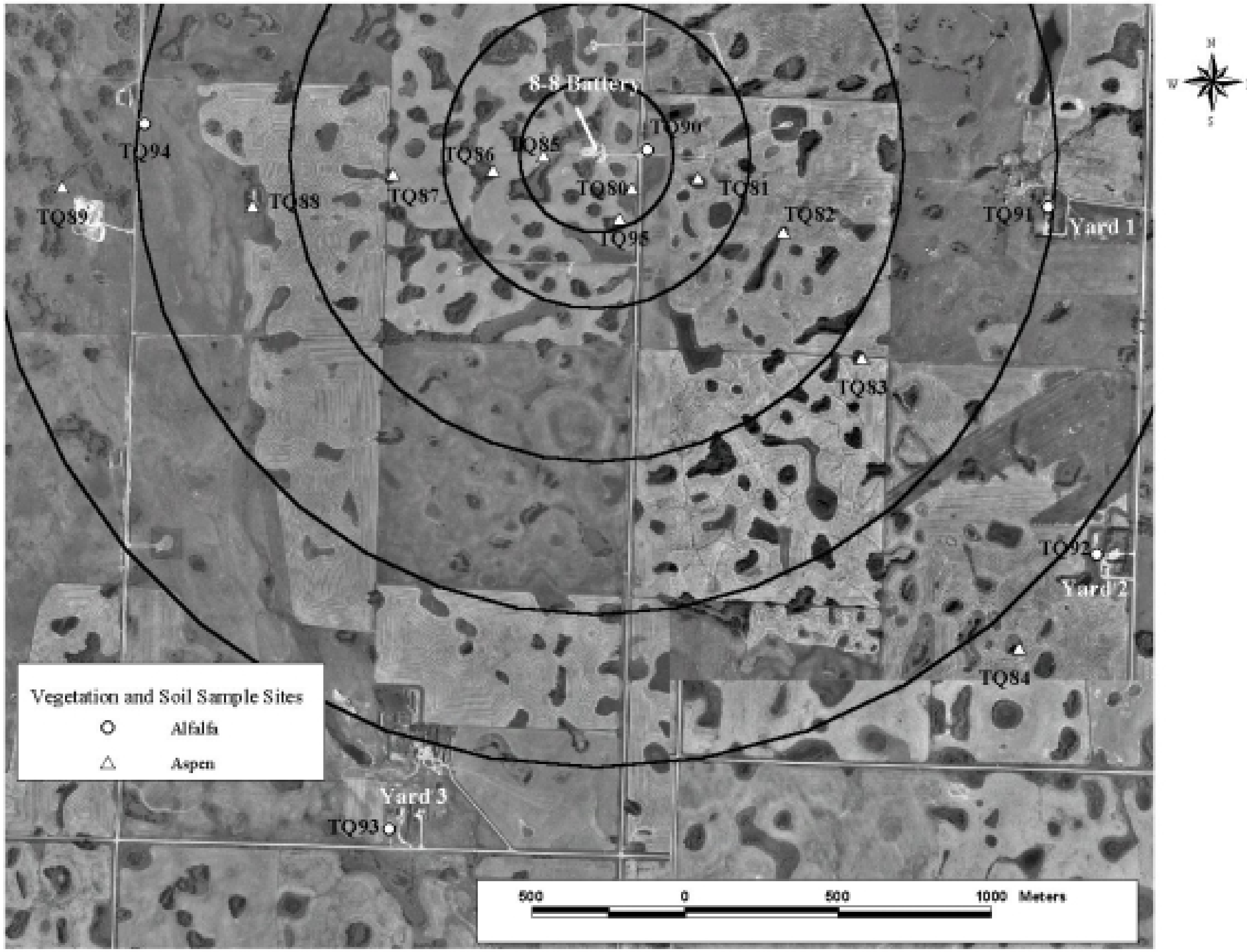

Figure 1. Orthophoto of Tilston 8-8 Study area.

Three replicate samples of aspen leaves were obtained at each site by stripping leaves by hand from branches that could be reached from the ground. The samples were stored in paper bags and frozen within a few hours of sampling. Frozen samples were submitted to the Enviro-Test Laboratory for tissue analysis. Each sample was dried, ground and homogenized and subsampled for each analysis. Leaf samples were analyzed for total sulphur (S), iron (Fe), nitrogen (N), phosphorous (P), and potassium (K).

Alfalfa Monitoring

Four replicate samples of alfalfa were collected from fields and roadsides within 2.2 km of the 8-8 battery (August). The stems and leaves were dried, ground and analyzed for total S, Fe, P, K, and selenium (Se).

Soil Monitoring - Surface Organic Soils

Three replicate samples of the surface organic layer of soils were obtained from each of the five sites along the southeast and west transects. At each sample location, the vegetation was removed from an area approximately 15cm by 30cm. Using a plastic template as a guide, a sharp knife was used to cut out two 10cm by 10cm squares. A flat 10cm wide plastering trowel was used to help lift out each square of the organic layer. The depth of the organic layer (usually approximately 5 cm thick) was recorded to enable calculation of the total volume of the sample. Each replicate sample was comprised of two 10cm by 10cm squares of organic material.

Soil Monitoring - Mineral Soils

Fifteen-centimetre deep samples of the mineral soil were obtained with a 5cm diameter by 15cm long soil core sampler. Using its pile-driver handle, the sampling tube was driven into the ground in the area where the surface organic sample had been removed. Two 5cm by 15cm samples comprised each replicate sample and three replicate samples were collected at each site along each transect. The sampler was disassembled to remove each core sample, and soil adhering to the sampler was cleaned off prior to taking the next sample.

Soil Monitoring - Deeper Mineral Soils

Deeper soil samples (15 to 30 cm, 30 to 60 cm, 60 to 90 cm and 90 to 120 cm, provided rocks were not encountered) were collected from three locations to provide data on the baseline chemistry of the soil parent materials. A Dutch auger was used to collect the samples. After each bit full of soil was brought to the surface, the outer edges were pared off to remove any contamination that might have been picked up as it rubbed the wall of the hole while being removed. The remainder was then removed from the auger bit and placed in a sealed plastic bag.

Soil Handling and Analysis

The soil samples were frozen within a few hours. The frozen samples were submitted to Enviro-Test Laboratories for analyses including total S, and available sulphate (SO_4), nitrate-nitrite (NO_3-NO_2), phosphate (PO4) and K.

Monitoring Schedule

Table 2. Sampling dates.

Date	Vegetation Health		Aspen Samples	Alfalfa Samples	Soil Samples
	Farmyards	Aspen Bluffs			
May 31/99	✓	✓	✓		
June 30/99	✓	✓			
July 14/99	✓	✓	✓		✓
Aug. 11/99	✓	✓			
Aug. 25/99	✓	✓	✓	✓	
Sept. 1/99	*	*	*		*

* Control farm NE of Sinclair NE22-7-28

Results and Discussion

Vegetation Condition

- Poplar bluffs within 200m of the battery in any direction:

  Several aspen trees showed signs of insect damage, including rolled leaves and leaves that had been partially eaten.

  Some aspen trees in the S and SW directions had interveinal chlorosis (yellow-green tissue between the veins of the leaves), a symptom that is sometimes indicative of chronic SO_2 injury. However, the Crop Diagnostic Centre (MB Agriculture) determined this to be an iron deficiency symptom.

  By June 30, a few aspen trees in each bluff (especially smaller trees along the edge) had developed brown areas along the leaf margins and between the veins. Although this resembled acute SO_2 injury symptoms, the Crop Diagnostic Centre determined it to be a shoot blight fungal disease (Table 3). By August 11, leaves at the ends of affected branches had died and the stem had turned black, which is consistent with the development of the shoot blight disease.

  The shoot blight fungal disease was also observed in the aspen bluff from the control farm (Table 4), indicating that the disease was not correlated in any way with the emissions of sulphur compounds.

  No symptoms that resembled SO_2 injury were observed on any plant species.

- Monitoring sites

  A few aspen trees at each location showed iron deficiency symptoms, and there was sporadic occurrence of the shoot blight disease at all sample locations. The occurrence of a similar level of shoot blight infection at the control farm confirmed that it was not related in any way to emissions in the study area.

  No SO_2 injury symptoms or injury that might have been caused by other pollutants were observed on any plant species in the poplar bluffs.

- Alfalfa

  No leaf damage from insects, disease or SO_2 injury was observed on alfalfa in the study area or at the control farm.
- Farmyards

  Several species of trees, shrubs and flowers in the farmyards had injury symptoms or unhealthy appearance and were collected for further diagnosis. The Crop Diagnostic Centre determined the cause of the symptoms, and the results are presented in Tables 3 and 4. It is noteworthy that some of the same fungal infections were found in both the study area and the control farmyard, although there did seem to be a higher proportion of foliage affected in the study area. This was probably a result of natural variability in an abnormally wet year although the study was not able to rule out the remote chance that sulphur compounds in the air may have made the plants more susceptible to disease.

Table 3. Cause of leaf tissue damage within the study area as determined by the Crop Diagnostic Centre, Manitoba Agriculture.

Location / Date	**Plant**	**Symptoms**	**Disease Name / Type**
Yard 3 99/06/15*	Blue spruce	Brown needles & needle tips	Resembled SO_2 injury but needle cast disease was confirmed in later samples
SE8-6-29 99/06/30	Aspen poplar	Chlorosis (yellowing) between veins	Iron deficiency
SE8-6-29 99/06/30	Aspen poplar	Brown lesions on the margins of leaves and between veins	Pollacia shoot blight / fungus
Yard 3 99/07/14	Blue spruce	Brown needle tips and brown needles on previous years growth	Winter injury Needle cast disease / fungus
Yard 3 99/07/14	Green ash	White flecks on leaves	Ash plant bugs / insects
Yard 3 99/07/14	Green ash	Leaf curling	Uncertain, possibly herbicide drift / herbicide such as 2-4D
Yard 3 99/07/14	Lilac	Brown lesions on the margins of the leaves	Leaf scorch / saline soils or stem injury from an unknown cause
Yard 3 99/07/14	Amur maple	Black spots on leaves	Tar spot / fungus
Yard 3 99/07/14	Manitoba maple	Leaves curled and light green colour	Herbicide drift / group 4 growth regulator herbicide, e.g. 2-4D
Yard 3 99/07/14	Apple	Chlorosis (yellowing) between veins	Iron deficiency
Yard 3 99/07/14	Apple	Brown spots or areas on the leaves	Frogeye leaf spot / fungus

Table 3. (continued)

Location / Date	Plant	Symptoms	Disease Name / Type
Yard 3 99/07/14	Chokecherry	Spots on leaves and holes in the leaves	Shot hole / fungus
Yard 3 99/07/14	Petunia	Extremely chlorotic (yellow)	Nutrient deficiency
SW4-6-29 99/08/11	Aspen	Brown areas on the leaf margins and between the veins	Marssonina leaf spot / fungus Leaf rust / fungus
Yard 3 99/08/11	Blue spruce	Brown needle tips and brown needles on previous years growth	Rhizosphaera needle cast disease / fungus
Yard 3 99/08/11	Saskatoon	Chlorosis (yellow) between the veins & poor leaf colour	Iron deficiency + insect injury (aphids, leaf hoppers)
Yard 2 99/08/11	Caragana	Yellow leaves and some brown areas on the leaves	Septoria leaf spot / fungus
Yard 2 99/08/11	Lilac	Yellowing leaves and brown areas especially on the leaf margins	Nutritional deficiency with browning caused by dehydration of the stressed leaf tissues
Yard 2 99/08/11	Apple	Chlorosis and development of dry brown areas	Iron deficiency & stressed tissue is dehydrated
Yard 2 99/08/11	Ash	Chlorosis between veins	Iron deficiency
Yard 2 99/08/11	Raspberry	Yellowish leaves with some browning on the margins	Anthracnose / fungus
Yard 1 99/08/11	Elm	Yellowing areas on the leaves	Lace bugs which suck juices from the leaves
Yard 1 99/08/11	Cotoneaster	Shoot dieback with all leaves turning a reddish brown	Fire blight / bacterial disease
Yard 1 99/08/11	Cotoneaster	Brown spotted areas on the leaves	Larvae of the pear sawfly (pear slug) feeding damage
Yard 1 99/08/11	Chokecherry	Shot hole damage to leaves & some brown spots	Shothole (leaf spot) disease / fungus
Yard 1 99/08/11	Ash	Small white marks on the leaves & some areas brown	Insect feeding damage Anthracnose / fungus
Yard 1 99/08/11	Manitoba maple	Leaf curling on new growth, yellowing between the veins and occasional brown areas on the leaf margins	Stress symptoms, possibly caused by twig or branch canker diseases.
Yard 1 99/08/11	Saskatoon	Brown areas on the leaves	Entomosporium leaf spot / fungus

*Collected by Glen Robertson, Environment Officer, Park-West Region

Table 4. Cause of leaf tissue damage at the control farm as determined by the Crop Diagnostic Centre, Manitoba Agriculture.

Location / Date	Plant	Symptoms	Disease Name / Type
Control Yard 99/09/01	Lilac	White powdery material on the leaves	Powdery mildew / fungus
Control Yard 99/09/01	Chokecherry	Brown dry spots on leaves and some holes in leaves	Shot hole / fungus
Control Yard 99/09/01	Raspberry	Leaves drying and turning yellow and red	May be nutrient deficiency
Control Yard 99/09/01	Cotoneaster	Brown spotted areas on the leaves	This sample was lost in transit, but it resembled the sample from Yard 1. The diagnosis of the latter was feeding by pear sawfly larvae.
Control Yard 99/09/01	Manitoba Maple	Misshapen leaves with light green colour	Leaf galls / Eriophyid mites Leaf spot disease (unidentified) / fungus
Control Yard 99/09/01	Apple	Brown areas along leaf margins Some areas on the leaves turning yellow or reddish brown	Marginal leaf scorch / unknown Insect feeding damage Unidentified virus disease
NE22-7-28 99/09/01	Aspen	Brown necrotic areas on the leaves	Poplar rust
NE22-7-28 99/09/01	Aspen	Brown necrotic areas on the margins and between the veins of leaves	Marssonia leaf spot disease

Chemical Analysis of Aspen

Samples of trembling aspen leaves were analyzed for total sulphur (S), total iron (Fe), available nitrogen (N), total phosphorous (P), and total potassium (K). The NPK analyses were done to provide backup data in case it appeared that nutrient deficiencies may have been a factor in vegetation health. The nutrient data are included in the tables but since there was no evidence of nutrient deficiencies, the nutrient data are not discussed in this report.

The total S in aspen leaves ranged from 1040 to 3530 μg/g (Appendix, Tables 5 and 6) which is within the normal range of 500 to 14,000 μg/g depending on the species (Malhotra and Hocking. 1976). Freedman and Hutchinson (1980) reported concentrations of S in aspen of 2700 μg/g at control sites in the Sudbury area compared to 4900 μg/g at sites close to the smelter. Data from the SE transect show a trend of decreasing S with distance from the 8-8 battery (Figure 2).

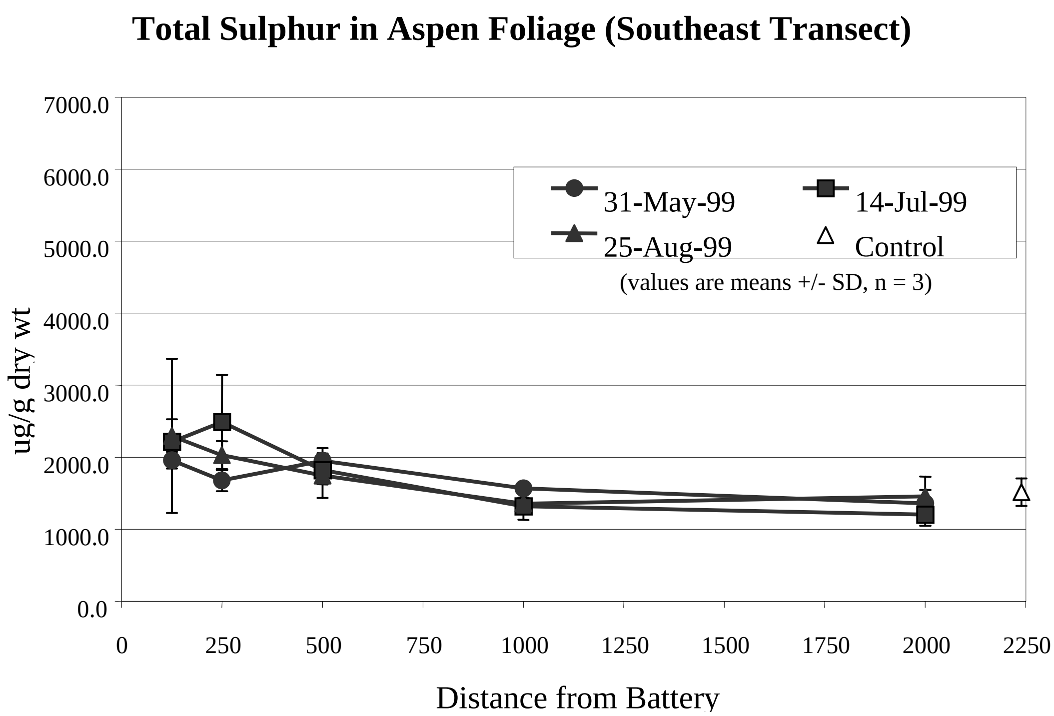

Figure 2. Mean concentration of total sulphur in leaves of trembling aspen along the SE transect from the 8-8 Battery.

The S in the aspen from the control site was slightly lower than at a few of the sites close to the battery. That suggests that there may have been some local effect from the S emissions, although it could also have been the result of variability in uptake of naturally occurring sulphur compounds. However, if the source of the S in the foliage had been the emissions from the 8-8 battery, the S content of the leaves from close-in sites should have increased markedly by August 25, 1999. Since that seasonal increase was not observed along the SE transect, sulphur compound emissions probably were not the cause of the slightly elevated S levels in the aspen leaves. At the site closest to the battery along the W transect, the S in the leaves did increase through the season (Figure 3). Based on these data, it appears that the average sulphur compound emissions may have had a very minor local effect on the S concentrations in aspen foliage but given the high variability in the data, the evidence is inconclusive. Sulphur is a necessary plant nutrient and the concentrations found in the aspen leaves of this study would not have a negative effect the growth and health of vegetation.

Chemical Analysis of Alfalfa

Samples of alfalfa were collected from four sites within 2.5 km of the 8-8 battery (Appendix Table 7). The concentrations of all chemical elements were highly variable. Unfortunately, no alfalfa samples could be found in close proximity to the 8-8 battery. The average total S in alfalfa collected from Yard 1 and Yard 2 was similar, but was lower in the samples collected near Yard 3. The alfalfa from the ditch 1.6 km west had the highest average S content. Since there is no other explanation for the differences, it appears that this can only be attributed to natural variability.

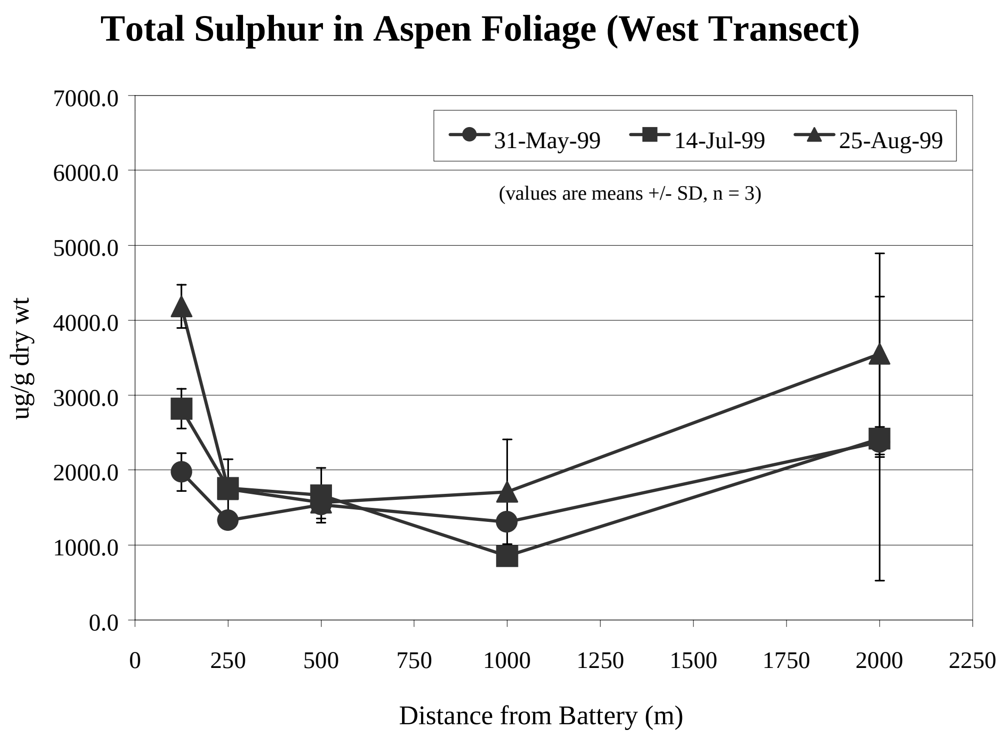

Figure 3. Mean concentration of total sulphur in leaves of trembling aspen along the W transect from the 8-8 Battery.

The alfalfa was also analyzed for total selenium in response to a concern expressed by a farmer in the study area. The levels are well below those that may be toxic to livestock, (5 μg/g) but within the range to provide adequate selenium nutrition (>0.2 μg/g) (Don Green pers.com.).

Chemical Analysis of Surface Organic and Shallow Mineral Soils

Soil chemical analyses were conducted to determine available nutrients as well as sulphur compounds (Appendix, Tables 8 & 9). The nutrient analyses were done in case there were vegetation health anomalies that might be related to the nutrient status. Available sulphate and total S analyses were done to determine if concentrations in the soil might be related to the impingement of sulphur compounds from flare gas emissions.

Available NO_3-NO_2, PO_4 and K in the soils were variable along both the SE and W transects, and there was no evident pattern to the nutrient amounts at the various sites. As expected, concentrations of nutrients were generally higher in the surface organic layer of soil than in the 15 cm mineral layer directly below the organic. The concentrations were never low enough to cause nutrient deficiency stresses in the natural vegetation.

Available SO_4 in the organic layer was highly variable with a range of 21 to 2100 μg/g, although the values of 1420 μg/g and 2100 μg/g along the SE transect appear to be anomalies. When those two values were ignored, the data indicated that within 500 m of the battery, there was a slight trend of decreasing SO_4 with distance compared with those further away (Figure 4). Sulphate levels in the west direction from the 8-8 battery are also somewhat higher in the first 500 m compared with the sites at 1 km and 2 km (Figure 5). Since the 504 μg/g value at 250 m W seemed to be unusually high, it too was removed before the data were averaged to produce the graph. Nevertheless, because differences in average available SO_4 are small and not statistically significant, no definitive statement can be made concerning a possible relationship between levels of SO_4 in the surface organic soil and emissions from the battery.

The concentration of available SO_4 in the mineral soil is generally lower than in the organic layer. It is also highly variable along both transects, but does follow a similar pattern to that in the organic layer. The value of 720 μg/g at the site 250m SE appeared to be an outlier and was ignored, resulting in an average SO_4 of 225 μg/g at that site. Again, although there was a slight trend of decreasing concentrations with distance, the data were too variable to conclude that emissions from the 8-8 battery were the cause. Some SO_4 data are available for this area in Manitoba Soil Survey Report No. 20 (Eilers *et al*, 1978). Although the soil samples for those analyses came from samples collected approximately 60 km SW of the study area, the were collected from the same soil series that is present in the study area. The results ranged from 41 meq/L in surface soil, to 160 meq/L in the deeper soil, which is roughly equivalent to 261 μg/g to 1280 μg/g. The results obtained in this study are at the low end of that range or below, and therefore there is no concern that the SO_4 content of soil in the study area is detrimental to soil quality.

Total S in the organic soil ranged from 517 to 1240 μg/g along the SE transect compared to a range of 467 to 1080 μg/g for the mineral soil. The S in the mineral soil was generally lower than in the surface organic, the exception being the site 2 km SE where two of the mineral replicates had unusually high S concentrations (>1000 μg/g). Since there was no trend of decreasing concentrations with distance, it is believed that the results merely represent the natural variability of S content in the soil (Figure 6). At the control site, the concentration of S in the organic soil was higher than any found in the study area, while the S in the mineral soil was in the same range as that of the study sites. Along the W transect, there was a trend of increasing concentrations of S with distance (Figure 7). The range in S was from 627 to 1390 μg/g in the organic soil and 530 to 1140 μg/g in the mineral. There is no evidence that the emissions from the 8-8 battery influenced the S concentrations in the soil of the study area.

In a study of the effects of sour gas emissions in the Whitecourt area of Alberta, Shipley (1975) also found that the differences in S in the soil were a function of the variability in the soil and not the proximity to the sour gas source. Hocking (1975) also reported that total S in the litter layer was highly variable (200 to 1700 μg/g) but found no evidence of a pattern related to the operation of the Windfall sulphur extraction plant around which the study was designed. Hocking (1975) did speculate that an overlap of

Windfall dispersion area with dispersion areas of other gas plants in the area might have been the reason for the lack of pattern.

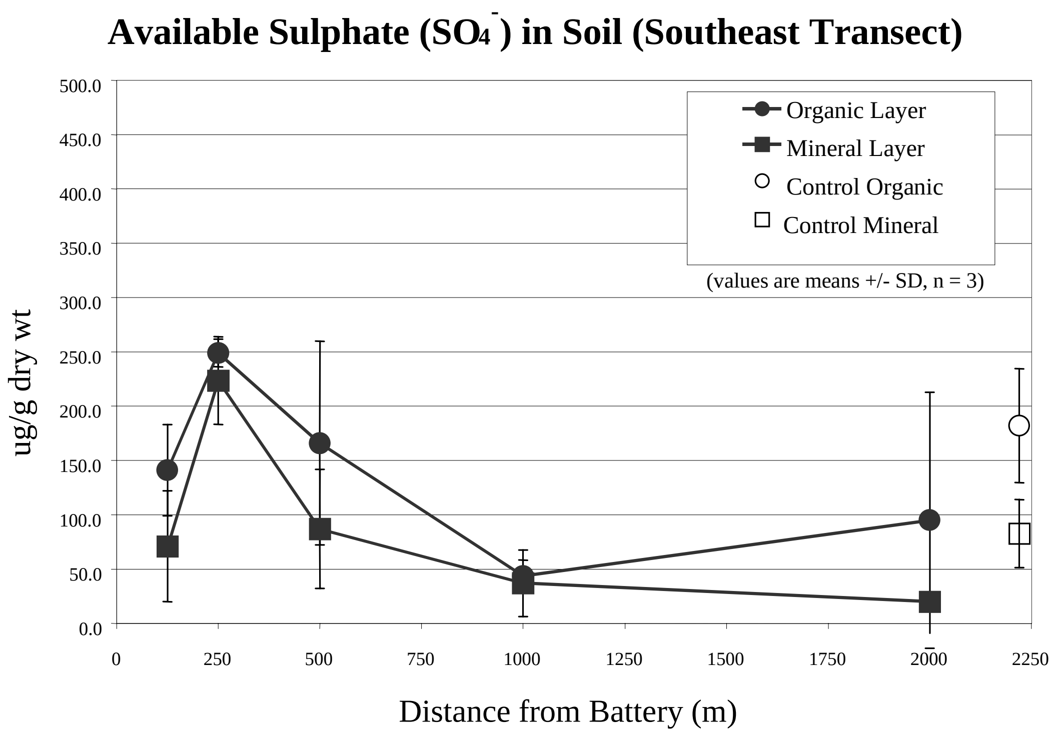

Figure 4. Mean concentration of available sulphate in surface organic and the mineral soil directly beneath it along the SE transect.

Chemical Analysis of Deeper Mineral Soils

Available SO_4 was generally low, ranging from 24 to 48 μg/g in the 15 cm to 60 cm zone of the soil at all three sites (Appendix Table 10). It continued to be low in the 60 to 90 cm zones at two of the sites, 1 km W and 2 km SE of the battery. The third site, 125 m from the battery, was the exception with levels of SO_4 increasing to 114 μg/g in the 60 to 90 cm zone and 132 μg/g in the 90 to 120 cm zone. It is unlikely that the SO_4 in the deeper soils at the closest site was caused by the operation of the battery. If the elevated SO_4 had originated from airborne deposition of sulphur compounds, the samples closer to the surface would also have been enriched. In any case, the concentration of SO_4 in the deeper soils is lower than the amounts reported in by Eilers *et al* (1978) which indicates that there has been no abnormal elevation of SO_4 in the soils of the study area.

The total S in the soil was highest at the surface and decreased with depth at all three sites. At first, one might wonder whether this was the result of the deposition of sulphur compounds at the surface. However, for this to be the case total S in the organic and near surface mineral layers close to the battery would have been elevated and that was not observed. Rather, the S appears to be from the decaying plant material at the soil surface which was to be expected given that S in aspen leaves was often in the 1000 to 3000 μg/g range.

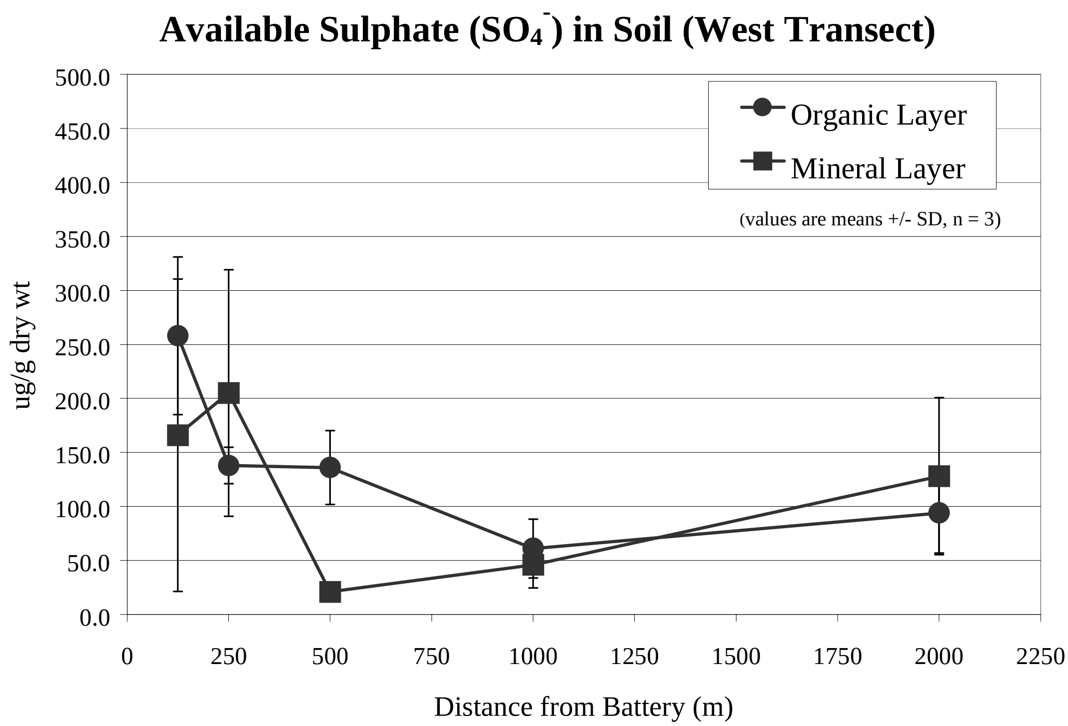

Figure 5. Mean concentration of available sulphate in surface organic and the mineral soil directly beneath it along the W transect.

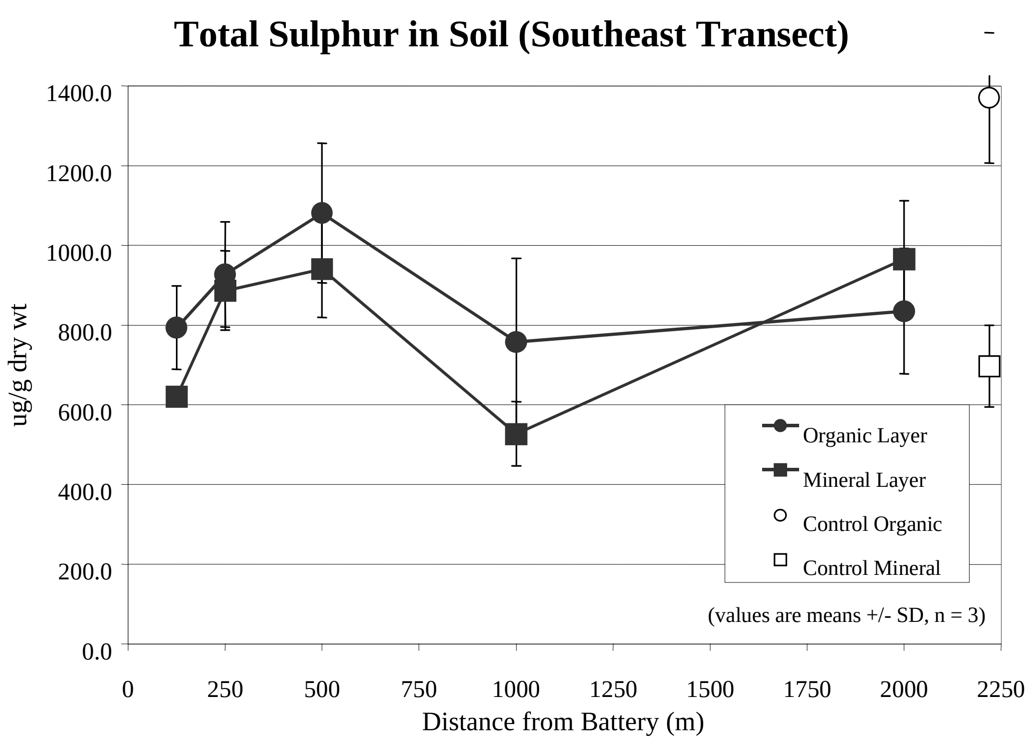

Figure 6. Mean concentration of total sulphur in surface organic and the mineral soil directly beneath it along the SE transect.

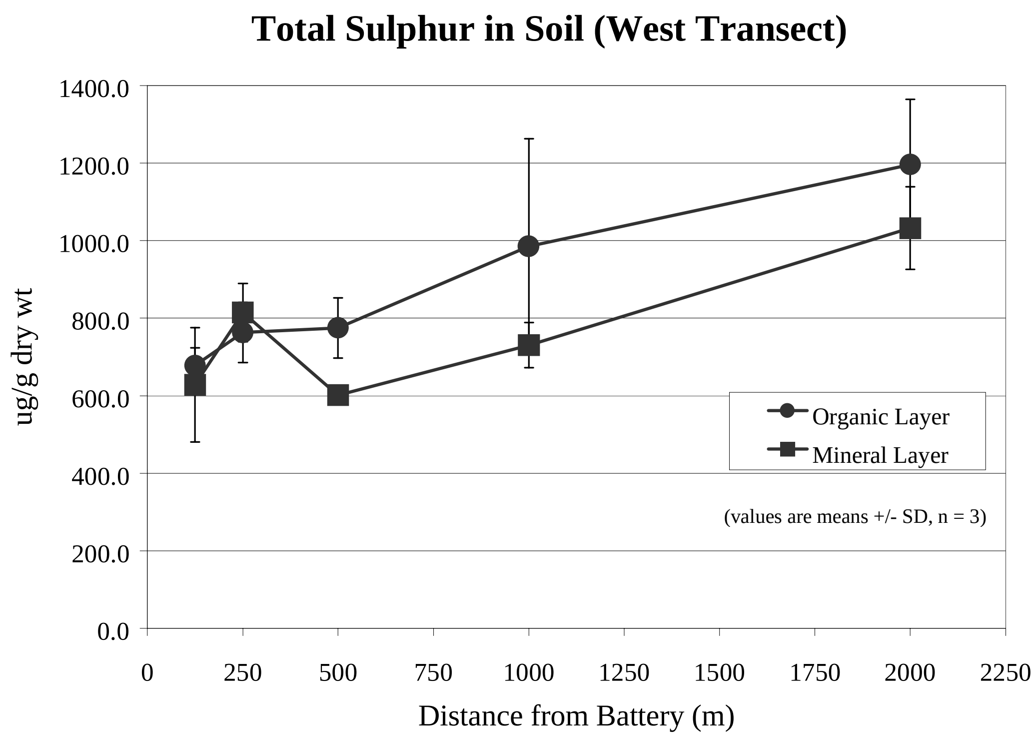

Figure 7. Mean concentration of total sulphur in surface organic and the mineral soil directly beneath it along the W transect.

Conclusions

1. Although several plants in the study area and control farm had leaf injury, disease (mostly fungus) or insects caused all the symptoms. There were no visible symptoms of SO_2 injury on plants in this study area and there were no plant injuries that might have been caused by other pollutants.
2. Although many of the same fungal diseases found in trees and shrubs of farmyards in the study area were also found in the control yard, there appeared to be more infected leaf tissue in the study area. This was probably a result of natural variability in such an abnormally wet year but the study was not able to rule out the remote chance that sulphur compounds in the air may have made the plants more susceptible to disease.
3. The sulphur content of aspen leaves suggested that there may have been some elevation caused by the battery emissions at one close-in site, but the data were too variable to reach a definitive conclusion. S in aspen leaves was in the normal range and would not be detrimental to plant health.
4. Available sulphate in the surface soil was slightly elevated at locations within 500m of the 8-8 battery. Considering the small data set and the variability in the data, there is no conclusive evidence that emissions of sulphur compounds were the cause. Sulphate content of soils was in the low part of the range or less than that reported for the same soil type at another location in the southwest corner of Manitoba.
5. Total sulphur in the soil was variable and the concentrations did not decrease with distance from the 8-8 battery, indicating that sulphur compounds emitted from the battery did not affect this parameter.

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Appendix

Data Tables

Table 5. Aspen tissue analysis data (µg/g except for N%) for sites SE of the 8-8 battery

			Distance					Control
Analyte	**Date**	**Rep**	**125 m SE**	**250 m SE**	**500 m SE**	**1000m SE**	**2000m SE**	**21 km NE**
Total S	May 31/99	1	2090	1740	2120	1570	1540	
		2	1870	1780	1770	1610	1170	
		3	1920	1510	1970	1530	1370	
	July 14/99	1	2520	2850	2020	1260	1360	
		2	1900	2890	1630	1530	1040	
		3	2230	1730	1810	1170	1220	
	Aug 25/99	1	1780	2250	1470	1450	1720	1710
		2	1580	1900	2080	1320	1480	1330
		3	3530	1940	1690	1300	1180	1510
Total Fe	May 31/99	1	69	49	54	56	72	
		2	62	44	138	60	62	
		3	56	46	56	69	78	
	July 14/99	1	122	68	90	78	130	
		2	86	44	93	83	100	
		3	106	89	93	68	113	
	Aug 25/99	1	149	122	114	95	223	122
		2	123	123	137	87	179	151
		3	244	113	120	131	127	162
Avail. N %	May 31/99	1	3.74	3.13	4.31	3.44	2.54	
		2	3.3	2.63	4.2	3.34	2.94	
		3	3	2.49	4.13	3.22	2.67	
	July 14/99	1	2.24	2.4	2.88	2.33	2.4	
		2	1.89	1.82	3.11	2.7	2.15	
		3	2.78	2.34	2.8	2.22	2.36	
	Aug 25/99	1	1.75	1.75	1.65	1.94	1.61	2.8
		2	1.75	2.06	1.99	1.92	1.95	2.8
		3	1.77	1.69	1.88	2.05	1.82	2.0
Total P	May 31/99	1	3160	2690	5630	3630	2620	
		2	3540	3080	5250	3670	2740	
		3	3060	2600	4980	3530	2300	
	July 14/99	1	1800	1500	2290	2020	1590	
		2	1460	1560	2220	2180	1610	
		3	1790	1610	1920	1810	1800	
	Aug 25/99	1	1600	1390	1580	1850	1540	2110
		2	1600	1710	1810	1820	1410	1960
		3	1600	1610	1850	1970	1630	1900
Total K	May 31/99	1	13500	10600	19300	14800	10400	
		2	12300	9910	16500	15000	10700	
		3	11300	9690	16200	13900	9730	
	July 14/99	1	5670	7160	8470	7750	9750	
		2	5240	7380	10200	8130	5350	
		3	5450	8340	7500	7180	7760	
	Aug 25/99	1	5110	4590	3300	6450	7030	6880
		2	5610	5830	4590	5610	6710	7490
		3	8790	5790	7110	6640	5170	8740

Table 6. Aspen tissue analysis data (μg/g except for N%) for sites W of the 8-8 battery.

			Distance				
Analyte	**Date**	**Rep**	**125 m W**	**250 m W**	**500 m W**	**1000m W**	**2000m W**
Total S	May 31/99	1	1700	1410	1330	1290	2570
		2	2200	1230	1670	1210	2170
		3	2020	1350	1620	1420	2380
	July 14/99	1	3050	2110	1590	846	1930
		2	2530	1820	1340	837	4510
		3	2880	1350	2060	881	820
	Aug 25/99	1	4390	1640	1660	1400	2600
		2	3980	1750	1450	2510	4500
		3	5530	1850	1590	1220	6750
Total Fe	May 31/99	1	43	56	63	99	84
		2	50	50	70	70	53
		3	57	49	64	76	79
	July 14/99	1	115	83	79	113	77
		2	72	83	66	105	69
		3	77	78	94	93	78
	Aug 25/99	1	167	131	130	145	176
		2	173	94	127	174	112
		3	174	120	112	117	110
Avail. N %	May 31/99	1	2.09	2.86	3.71	3.66	5.22
		2	2.19	2.92	3.65	3	3.59
		3	2.79	3.06	3.33	2.83	5.06
	July 14/99	1	2.46	2.98	2.2	3.27	3.17
		2	2.29	2.71	2.39	2.3	2.1
		3	2.4	2.6	3.51	1.87	2.22
	Aug 25/99	1	1.85	1.54	1.71	1.61	1.57
		2	1.86	1.67	1.78	1.63	2.04
		3	1.61	1.75	1.85	1.26	2.05
Total P	May 31/99	1	2280	2790	3570	4070	6340
		2	2220	2890	4770	3220	3170
		3	3020	3010	3720	3210	6080
	July 14/99	1	1650	1980	2170	2460	1880
		2	1650	1740	1820	1910	1570
		3	1880	2110	2420	1820	1740
	Aug 25/99	1	1500	1710	1680	1560	1510
		2	1700	1840	2000	1380	1580
		3	1650	1660	1770	1280	1640
Total K	May 31/99	1	10300	9940	14600	11400	21900
		2	10300	10100	17400	11100	13500
		3	12000	9500	13300	11400	20700
	July 14/99	1	12600	8670	10100	5540	11800
		2	9170	7700	9910	9390	10000
		3	8450	10200	10600	7590	11300
	Aug 25/99	1	7450	8080	8110	5520	4540
		2	8150	8230	12300	5820	6850
		3	7060	7400	7730	6570	7030

Table 7. Alfalfa tissue analysis data (μg/g) for sites in the vicinity of the 8-8 battery.

		Site, Distance and Direction			
Analyte	Rep	Yard 1 1.7 km E	Yard 2 2 km SE	Yard 3 2.4 km SSW	Ditch 1.6 km W
Total S	1	1730	3020	1200	3420
	2	2860	2190	1350	4050
	3	1600	2220	1510	2800
Total Fe	1	73	75	107	239
	2	96	84	140	231
	3	53	105	222	136
Total P	1	3340	2640	2520	1980
	2	4300	2710	2860	1990
	3	2910	2770	2930	1880
Total K	1	27200	31000	27600	14900
	2	47700	21500	28600	23100
	3	30000	24500	25100	14600
Total Se	1	0.57	0.43	0.46	0.25
	2	0.82	0.37	0.64	0.13
	3	0.6	0.35	0.82	0.08

Table 8. Soil analysis data (µg/g) for soil samples collected at sites SE of the 8-8 battery.

Analyte	**Soil Type**	**Replicate #**	**Distance from the 8-8 Battery**					**Control**
			125m SE	**250m SE**	**500m SE**	**1000m SE**	**2000m SE**	**21 km NE**
Avail. SO_4	Organic	1	171	258	66	33	33	168
		2	93	1420	180	54	21	138
		3	159	240	252	2100	231	240
	Mineral	1	18	195	51	24	18	96
		2	75	720	60	15	18	47
		3	120	252	150	72	24	105
Total S	Organic	1	857	925	893	517	818	1550
		2	673	1060	1240	844	687	1330
		3	851	796	1110	910	1000	1230
	Mineral	1	632	878	1080	496	1060	705
		2	628	990	892	467	797	591
		3	602	792	851	619	1040	796
NO_3-NO_2	Organic	1	27.9	41.9	16.6	28.4	18.9	10.4
		2	27.7	18.9	151	34.5	28.4	8.4
		3	33.4	40.2	42.6	53.2	48.5	10.4
	Mineral	1	14.8	16.1	21.6	10.8	24.5	6.4
		2	13.3	11.8	24.5	9.7	23.7	7.2
		3	9.5	14.2	22.4	10.8	19.9	7.6
Avail. PO_4	Organic	1	10.8	23.3	27.4	25.3	30	10.0
		2	12.2	16	63.6	25.8	20.6	19.0
		3	22	33.3	78.3	29.4	27.9	39.0
	Mineral	1	6.4	9.1	18.2	12.8	11.3	2.6
		2	7.4	10.8	16.9	4.4	25	13.0
		3	8.1	10.8	27.4	7.4	9.3	584
Avail. K	Organic	1	696	810	492	910	600	858
		2	668	468	548	755	725	1370
		3	912	975	660	750	615	1590
	Mineral	1	472	516	476	672	740	613
		2	488	392	548	512	1030	578
		3	504	448	572	584	592	584

Table 9. Soil analysis data (µg/g) for soil samples collected at sites W of the 8-8 battery.

Analyte	Soil Type	Replicate #	Distance from the 8-8 battery				
			125m W	250m W	500m W	1000 m W	2000 m W
Avail. SO_4	Organic	1	294	504	126	90	117
		2	306	126	108	57	51
		3	174	150	174	36	114
	Mineral	1	150	336	18	27	45
		2	318	153	21	69	180
		3	30	126	24	42	159
Total S	Organic	1	711	846	691	1300	1110
		2	697	752	790	883	1090
		3	627	692	844	774	1390
	Mineral	1	530	900	624	763	927
		2	798	785	599	766	1030
		3	558	759	582	664	1140
$N0_3$-NO_2	Organic	1	26	49.6	20.1	70.9	42.6
		2	28.4	96.9	70.9	6.9	42.3
		3	18.9	16.6	33.1	31.7	40.7
	Mineral	1	5.5	27.3	11.6	19.7	23.3
		2	8.5	28.8	12.3	17.8	25.4
		3	4.6	27.5	7.8	18	19.9
Avail. PO_4	Organic	1	33.3	36.2	44	73.4	28.4
		2	27.9	34.2	39.1	44	15.5
		3	58.7	31.3	53.8	34.2	33.3
	Mineral	1	18.2	13.2	8.8	33.3	5.9
		2	17.2	9.8	15.2	12.8	3.7
		3	23.8	8.3	15.7	19.1	5.9
Avail. K	Organic	1	710	600	720	1080	584
		2	504	530	720	1170	580
		3	1060	665	630	850	855
	Mineral	1	412	480	468	940	524
		2	540	500	508	1080	476
		3	720	576	508	552	508

Table 10. Soil analysis data (μg/g) for deeper mineral soils collected at selected sites in the vicinity of the 8-8 battery.

Analyte	Depth	Distance and Direction			Control
		125m SE	2000m SE	1000m W	21 km NE
Avail. SO_4	15-30 cm	24	48	30	62
	30-60 cm	45	24	24	37
	60-90 cm	114	33	21	30
	90-120 cm	132	*	*	37
Total S	15-30 cm	615	824	525	700
	30-60 cm	427	277	219	169
	60-90 cm	532	210	184	254
	90-120 cm	331	*	*	621
NO_3-NO_2	15-30 cm	11.4	12.3	14.2	9.4
	30-60 cm	4.6	2.1	4.9	3.0
	60-90 cm	3	2.3	4.2	2.2
	90-120 cm	1.7	*	*	1.8
Avail. PO_4	15-30 cm	3.4	2.4	23.6	2.0
	30-60 cm	0.5	0.5	4.4	0.5
	60-90 cm	0.5	0.5	2	0.5
	90-120 cm	0.5	*	*	0.5
Avail. K	15-30 cm	289	528	852	540
	30-60 cm	113	126	524	302
	60-90 cm	75	126	254	302
	90-120 cm	51	*	*	149

* stones encountered, no sample collected