P1.14 In Situ Air Quality Monitoring of Smoke from Prescribed Burns of Boreal Forest in the Mountains of Banff National Park, Alberta Canada

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1. Introduction

In Western Canada many of the summer episodes of degraded air quality are caused by forest fire smoke. The capricious nature of wildfire generally makes air quality monitoring impractical near the fire. In late Spring 2003 a series of prescribed burns were planned in the Fairholme Range of Banff National Park in the Canadian Rockies providing an opportunity for air quality sampling in the vicinity of the fires. Portable programmable particulate samplers were deployed on five occasions in locations anticipated to receive substantial smoke from the planned ignitions. Subsequently the collected particulate was analyzed to identify some of the constituents. This sampling program was a pilot program to develop a preliminary understanding of wildfire smoke

2. Forest Details

Over a century of fire protection in Banff National Park has altered vegetation succession patterns yielding impacts on ecosysem as identified in The Banff National Park Management Plan (1997). These impacts include; decline in native biodiversity; increasing forest age, canopy cover, and continuity; increasing host population for forest insects and disease such as mountain pine beetle (*Dendroctonus ponderosae*); and increasing build-up of vegetation to fuel wildfires.

White (1985) provided the first historical perspective of fire within Banff National Park. This work documented fire occurrence from 1880 to 1980 using historical records and reports, historic photographic analysis, and dendrochronology. The dendochronological work was expanded by Rogeau (1996), producing a stand origina map for the entire park (see Figure 4 stand origin map of Fairholme Range area). Various statistical methods were used to determine the fire cycle, which is the time required to burn an area equal to an area of interest. For instance, if a study area covered 1000 km^2 of fire prone vegetation, the fire cycle would be the number of years it would take to burn an area of 1000 km^2, understanding some areas would burn more than once and other areas would remain unburned. The Canadian Rocky Mountain Parks, which includes Banff, Jasper, Kootenay, and Yoho, as well as neighboring provincial parks, supported a fire cycle of 60 years for at least four centuries prior to 1760 (Van Wagner *et al* in preparation). The burning rate then dropped sharply and a longer fire cycle of 130 years prevailed until 1940. Since 1940, the rate of burning has declined to virtually nil. This reduction in burned area is primarily due to the near-elimination of human-caused fires through fire prevention programs and to increasingly effective fire control of lightning ignitions in this ignition-limited fire environment (Wierzchowski et al 2002). Besides significant ecological effects of increasing fire cycles, biomass has accumulated rapidly.

The objective of the Fairholme Range Prescribed Fire is to reintroduce fire onto the park landscape in recognition of its major role in maintaining ecological processes and ultimately to restore ecological integrity to Banff National Park (Ferguson 2002). Further, the Fairholme Range Prescribed Fire will reduce hazardous fuel accumulations and serve to protect neighboring values at risk from uncontrolled wildfire. An additional objective of the prescribed fire is to

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assess air quality as a result of burning in this populated mountain environment.

The Fairholme Range Prescribed Fire is located in the Front Ranges of Banff National Park, east of the Continental Divide in the Canadian Rockies approximately 120 kilometres west of Calgary, Alberta (Figures 1, 2 & 6). The main area of the prescribed fire is located adjacent to the Trans Canada Highway in the Bow Valley between the towns of Banff and Canmore (Figure 3). Three additional subunits are located at Stewart Canyon, Devil's Gap and in the upper Carrot Creek basin. The combined area of vegetated land within the prescribed fire totals approximately 8500 hectares. Ecological (biophysical) land classification methods divide Banff National Park into three ecoregions based primarily on vegetation, which is in turn controlled by the cordilleran climate (Holland & Coen 1982). Montane forests, although accounting for very small part of the park, cover most of the prescribed fire area, with some lower subalpine forest found higher elevation sites. A narrow band of upper subalpine forest is found at treeline, below the alpine ecoregion. Climatically, the area is dominanted by a continental climatic regime, with well defined winter precipitation minima and summer maxima. Average annual precipitation is about 470 mm. See Figure 1 & 2: for the location of the Fairholme Range Prescribed Fire, Banff National Park. See Figure 3 & 4 for the area burned in 2003 and Year of Stand Origin, Fairholme Range.

Firing operations were initiated within the Fairholme Range Prescribed Fire area in April, 2003 and continued during appropriate burning conditions into the first week of June, 2003. A portion of the main ignition area between Canmore and Banff continued to smolder through June and July, flaring up in August as a result of extreme fire danger. By September 2003 about 5100 hecatares of the prescribed fire area had been burned. Spring firing operations focused on steep, dry south and west facing slopes. Fire behavior was characterized by intense surface fire and crown fire in montane and lower subalpine forest fuels.

Fuels in Banff National Park were assessed by White (1985b), who aggregated closed forest types into nine fire groups sharing similar fire and biomass characteristics. Within the montane ecoregion, grasslands and forests of Douglas fir (*Pseudotsuga menziesii*), trembling aspen (*Populus tremuloides*) and lodgepole pine (*Pinus contorta*) are found on well-drained sites. Moist sites in the montane are occupied by white spruce (*Picea glauca*), balsam poplar (*Populus balsamifera*) and wetlands. The lower subalpine ecoregion is covered by dense forests of lodgepole pine, Engelmann spruce (*Picea engelmannii*) and subalpine fir (*Abies lasiocarpa*). Figure 5 shows the closed forest types within the Fairholme Range Prescribed Fire area, while Table 1 provides fuel characteristics of most of the Fire Groups found in the area.

3. Sample Collection

Particulate samples were collected with Airmetrics MiniVol samplers operated in pairs with one Zeflour (Teflon) filter and the second with a quartz filter. Two sample periods (Minnewanka Ridge and Powerline) used $PM_{2.5}$ impactors with one pair of samplers programmed to sample during the afternoon covering the ignition and intense burning stage of the fires. The second pair was programmed to begin sampling late in the afternoon and continue overnight when fire behavior was expected to be less intense and more dominated by smouldering. The other three samples (Inglisbaldy, Minnewanka north ridge and Repeater Ridge) were collected with the pairs of samplers running simultaneously during the afternoon fire ignition and flaming period. One pair of samplers was equipped with $PM_{2.5}$ impactors and the second pair with PM_{10}.

The samplers were deployed in locations likely to receive smoke from the fire. The Minnewanka ridge site was directly above the burning so the smoke was generally on the order of seconds to minutes old. The power line site had some nearby burning but the most probable age for most of the smoke is on the order of one to two hours. Minnewanka North Ridge was directly adjacent to a valley with intense burning but the bulk of the smoke reaching that point was on the order of one hour old. Inglisbaldy was sampled during a period where there were no new fires so any smoke collected at that site was approximately three hours or more smoke age. Repeater Ridge was located where there was smoke traveling from several valleys to that point with the shortest smoke travel time around one hour and the longest under two.

The sites were reached by helicopter for the ridge locations and by vehicle along the power line. The filter holders were preloaded in the Banff parks building which was a typical office environment for airborne dust loading and potential contaminants. Filters were removed from their glass containers using Teflon tweezers, placed in the filter holders

which were in turn placed in plastic bags till site deployment. Sampler flow was measured using a BIOS DMP-1 onsite at deployment and again on instrument retrieval. The average flow for the sampling period was assumed as the average of the pressure and temperature corrected flows. At each site loaded filter holders were placed alongside the operating samplers with no flow drawn through the filters as onsite controls.

Once the filters had been retrieved they were taken out of the holders in the Banff park office. The filters were returned to their glass containers and then stored in a refrigerated box (cooled with a solid state Schmidt cooling device with no explicit temperature control) until they were delivered to the lab for analysis. Temperatures in the cooler were between 4 and 6 C.

4. Analysis

Analysis was performed by the Alberta Research Council laboratories located in Vegreville Alberta to obtain quantitative analytical data on 65 elements and 22 polycyclic aromatic hydrocarbons (PAHs), of the particulate matter collected on the filters. Filters were conditioned for 24 hours at constant relative humidity of 40 ± 1% and at constant temperature of 22 ± 3ºC prior to weighing. The filters were weighed gravimetrically before and after sampling on a Cahn 30 electrobalance in a temperature and relative humidity controlled environment. The elements were analyzed using portions of loaded Teflon filters. These were then digested it in nitric acid in a closed vessel at constant temperature. The digested solutions were diluted with deionized water and analyzed using an Inductively Coupled Plasma-Mass Spectrometer (ICPMS), Perkin-Elmer SCITEX Elan Model 5000, equipped with a Gemtip cross-flow nebulizer, Ryton spray chamber, plasma torch with a quartz injector, a Gilson four channel peristaltic pump (Model Miniplus III) and a Gilson 212B autosampler. The above procedure is patterned on the EPA methods 3052 and 6020.

PAH analysis was performed using a Hewlett Packard (HP) automated gas chromatograph mass selective detector (GC/MSD) system. A HP model 7683 auto-sampling injector precisely injects 1.0µL aliquots of both sample extracts and standard solutions into a HP gas chromatograph (Model 6890). The GC separates the sample into its individual components using a 30 meter .25 µm 5% methyl silicone column. The individual PAH's were scanned by a HP Model 5973 mass spectrometer in Select Ion Monitoring mode.

The GC/MSD system is calibrated at the beginning of each sample run by the introduction of five concentration levels of the target PAH's. The calibration is checked at the completion of each run. Target quantities are calculated against internal standards added just prior to loading samples onto the autosampler.

5. Results

Conifer trees were the primary fuel during the Banff study, which is the likely cause of discrepancy with other data. Table 2 summarizes published findings and provides a comparison of results. Oros and Simoneit (2000) analyzed the smoke emitted from conifer and deciduous trees. They compared and contrasted the differences seen in the PAHs and Particulate Matter elements emitted from the different species. The authors concluded that the following PAHs are not found in deciduous burning: Retene, 2-phenylnapthalene, cyclopenta(cd)pyrene, benzo(b/k)fluoranthene, benzo(e)pyrene, perylene, anthanthrene, benzo(ghi)perylene, triphenylene and indeno(1,2,3-cd)pyrene. Fluorene and 3,3,7-trimethyl-1,2,3,4-tetrahydrochyrsene are two PAHs not found in conifer emissions (Oros et al 2000a and 2000b).

Many PAHs and elements are characteristic of a specific species of trees, which becomes crucial when comparing results. It has been observed that polluted areas in the tropics exhibit rapid degradation of PAHs due to high solar intensity and humidity, causing an increase in photo-oxidation reactions as well as other secondary reactions (Heil 1998). Differing soil and forest ground floor would also be expected to contributed to significantly different emission characteristics from combustion. In the analysis the results for calcium and silicon are 3.55% and 5.09% of the weighted averages of total mass, respectively. In the study by Turn et al.(1997) the results for calcium and silicon are much lower. The concentrations of PM2.5 calcium and silicon respectively are 0.033%, 0.095% and 0.034%, 0.018% average mass for ponderosa pine slash and douglas fir slash, respectively. Table 3 compares the analysis results of Turn et al. (1997) study with the Banff analysis also including the percent uncertainty.

Figures 7 thru 9 represent the results of the analysis of selected PM and PAHs that tend to be the most significant species (excluding calcium

and silicon). Also shown are the different locations, size cuts for the particulate, and the speciation of the data. The species were selected by abundance and observation in other fire studies.

The results were compared with a conifer profile from by EPA,(2003). Figures 10 & 11 summarize the findings. The EPA profile represents the weighted average of 6 smoldering and 7 flaming phase samples, while the Banff data profile represents 3 smoldering and 4 flaming phase samples. The filters and locations chosen represent the ideal fire conditions and have the highest loading of PM. The error bars in the figures represent the relative percent uncertainty in the EPA conifer profile. Most of the Banff data resides within this uncertainty.

Potassium is considered a marker of biomass burning particles emitted during flaming fires (Muraleedharan et al 2000). Theu found that potassium, inemissions from tropical forest fires, accounted for between 10-20% of the aerosol mass. The Banff results show much lower values for potassium. The highest amount of potassium seen was 1.2% of total mass, at the power line site. Retene is also a marker of biomass burning but only for coniferous burns. Figures 12 to 14 compare emission rates for elements and PAHs at two different phases of fire growth, flaming and smoldering.

When Martins et al.(1994) analyzed fire samples in Oregon, Washington and Idaho they found that K, Cl, Mn, Ca, and Zn all have higher emission rates in the flaming phase and the lowest emission rates in the smoldering phase. This is also indicated in the Banff study. Chromium and nickel levels were lower during the flaming stage when compared to the smoldering phase. Most of the PAHs also have higher emissions in the flaming phase of combustion, with the exception of retene, phenanthrene, and 7,12-dimethylbenz(a)anthracene.

According to McMahon and Tsoukalas (1978) the flaming phase of backing fires, (against wind flow), emit more PAHs and PM. While heading fires (with wind flow) produce more PM emissions then backing fires. Overall the PAHs are often much lower in heading fires and both occur in the smoldering phase. We cannot conclude that the fires in Banff were all backing fires since some PAHs, as seen in the figures, have higher emissions in the smoldering phase then when compared to the flaming phase. However the results of McMahon and Tsoukalas suggest the prescribed fires in Banff may have been influenced by whether the fires were backing or heading fires.

Different size cuts (10 and 2.5 microns) of particulate matter were measured at the following sites: Inglisbaldy, Minnewanka North Ridge, and Repeater Ridge in order to determine if chemical composition would be different. It was found that no elements remained higher in PM2.5 when compared to PM10. On the other hand the following elements remained higher in PM10 throughout all three fire burns: Al, B, Ba, Ca, Cl, Fe, Mg, Na, S, Se, Si, Sr, and Ti (Refer to figures 15 to 17). Both size cut filters at each station experienced a similar amount of exposure to a flaming fire.

The percent characterization's for the filters, seen in table 4, are very low. This is most likely due to the lack of measurement of organic and elemental carbon. Only two samples were successfully analyzed for total carbon an average of 62.9%. Therefore we expect that at least half of the unknown concentration is elemental and organic carbon. It is also possible that the unknown mass contains higher molecular weight compounds, such as more complex PAHs, which may get stuck in the column of the GC instrument.

According to US Environmental Agency the 24 four standard for PM_{10} and $PM_{2.5}$ are 150 $\mu g/m^3$ and 65 $\mu g/m^3$, respectively. At Minnewanka Ridge we found the $PM_{2.5}$ concentration to be 1596 $\mu g/m^3$, averaged over five hours of monitoring bracketing a shorter period of intense fire burning on the order of two hours. At the power line the fire was a longer duration, which gave $PM_{2.5}$ concentrations of 748 $\mu g/m^3$ over a period of nine hours and 489 $\mu g/m^3$ over a period of five hours. This indicts that forest fires are an important natural source of atmospheric particulate matter.

6. Conclusions

Particulate monitoring near to forest fires was possible in the prescribed burns in Banff National Park. These samples provided an indication of the intensity and species represented in smoke from forest fires. Preliminary analysis of these data indicate a general consistency with other studies. Variations appear to be within the margin expected due to differences in species, fuel density, underlying soil and topography and experimental error.

Further studies would be substantially enhanced by more analysis of the carbon (elemental and organic) portion of the PM. Gaseous chemistry

could also provide valuable clues to the character of the fire during sampling (CO CO_2). The age of the smoke was estimated in these cases but should be explicitly considered in the design of any subsequent sampling.

This report is a preliminary summary of the chemical speciation and analysis of the data. Further analysis is required to confirm the tentative conclusions presented.

7. References

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Figures and Tables

	Fire Group 1	Fire Group 2	Fire Group 3	Fire Group 4	Fire Group 5	Fire Group 6
Description	warm/dry montane lodgepole pine & Douglas fir	warm/dry lower subalpine lodgepole pine	montane aspen	mesic montane spruce & Douglas fir	cool/moist lower subalpine lodgepole pine	lower subalpine spruce & fir
Closed Forest Vegetation Types	C1, C3, C6	C3, C6, C9, C19, C36	C16	C2, C5, C 26	C11, C18, C20, C29	C13, C19, C30, C31
Tree Density (stems/ha.)	1895	1765	680	1185	2105	1755
Bolewood Biomass (t/ha.)	107	93	99	136	127	150
Foliage Biomass (t/ha.)	9	9	5	20	16	25
Foliage & Branchwood Biomass (t/ha.)	26	26	29	52	38	64
Herb & Dwarf Shrub Biomass (t/ha.)	0.7	0.5	0.8	0.4	0.3	0.2
Shrub Biomass (t/ha.)	1.5	1.3	0.5	1.4	2.2	2.7
Fine Downed Wood (t/ha.)	1.7	2.0	0.8	2.7	1.7	2.3
Total Downed Wood (t/ha.)	28.5	36.5	13.0	49.1	39.8	52.1
Moss Biomass (t/ha.)	1.9	2.0	0.2	6.3	5.6	6.9
Litter Biomass (t/ha.)	4.1	3.7	10.1	2.7	2.1	1.7
Duff Biomass (t/ha.)	47	52	64	134	103	144
Total Ground Biomass (t/ha.)	53	58	74	145	111	152
Total Stand Biomass (t/ha.)	217	214	216	383	316	422

Table 1: Fuel Characteristics by Fire Group

Figure 1


ALBERTA
Hwy #2
Banff National Park
Lake Louise
Prescribed Fire Location
Banff
Hwy #1
Calgary
Canmore
BRITISH COLUMBIA
0
20
40
Kilometers

Figure 2

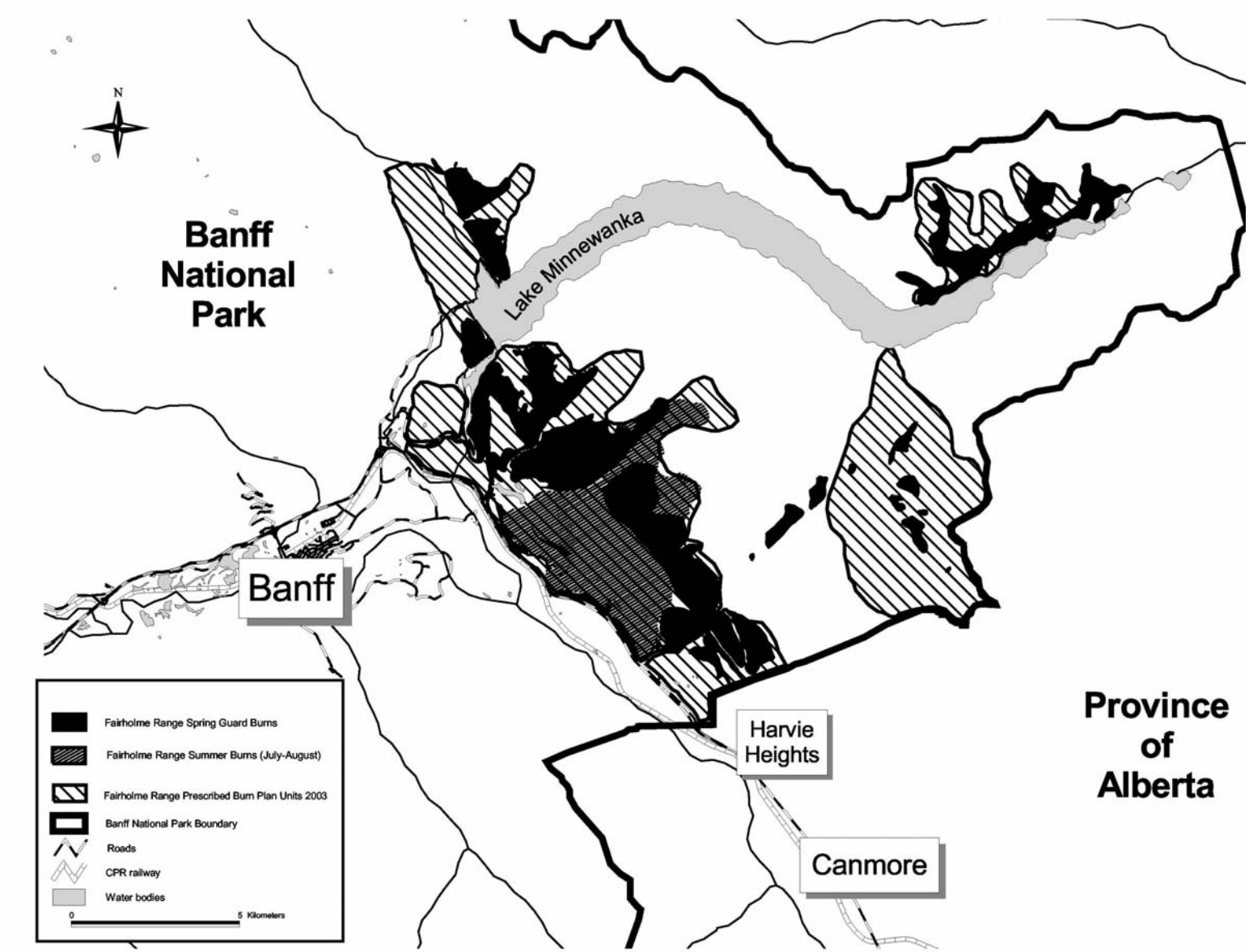
N
Banff
National
Park
Lake Minnewanka
Banff
Harvie
Heights
Canmore
Province
of
Alberta
Fairholme Range Spring Guard Burns
Fairholme Range Summer Burns (July-August)
Fairholme Range Prescribed Burn Plan Units 2003
Banff National Park Boundary
Roads
CPR railway
Water bodies
0
5 Kilometers

Figure 3

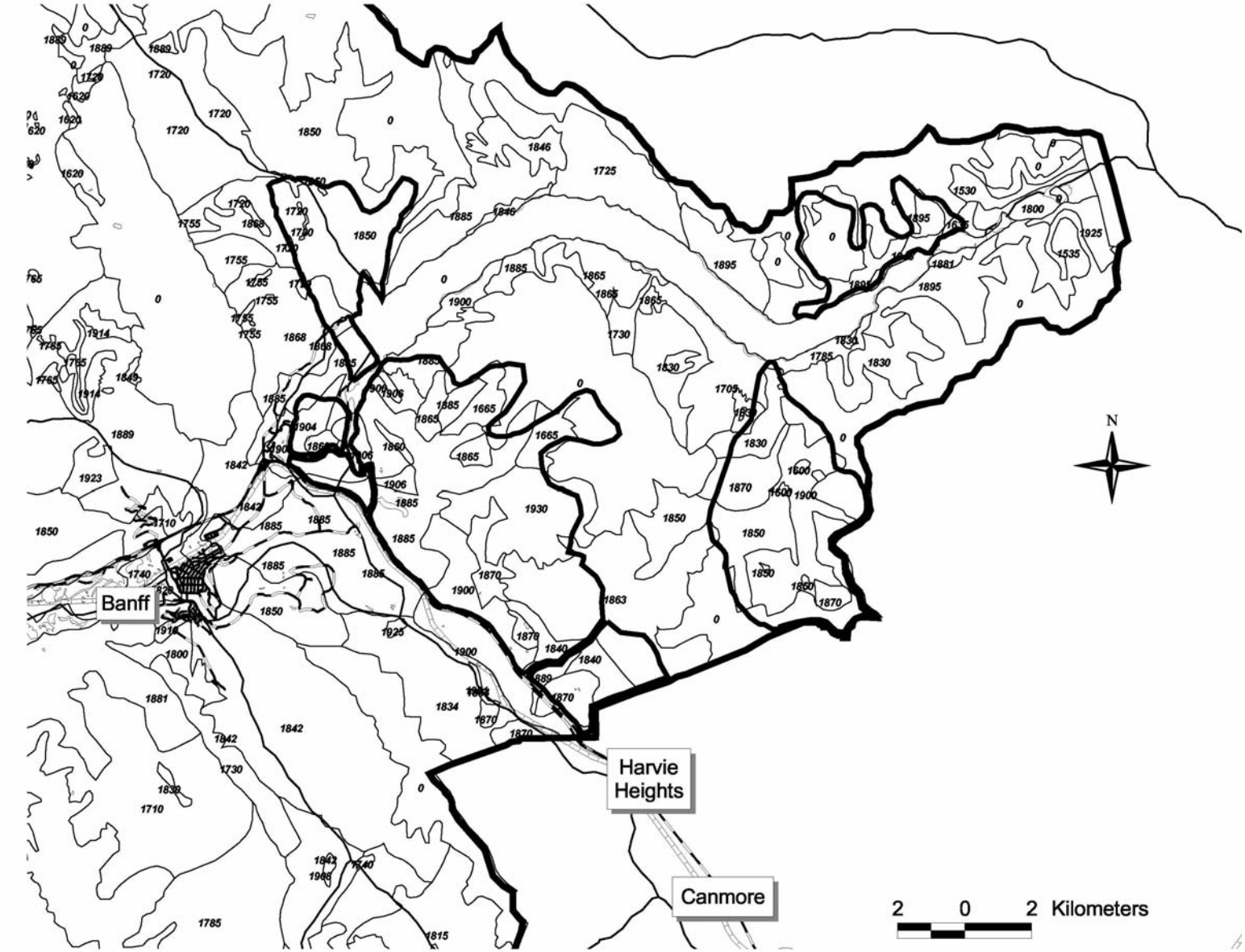

Figure 4

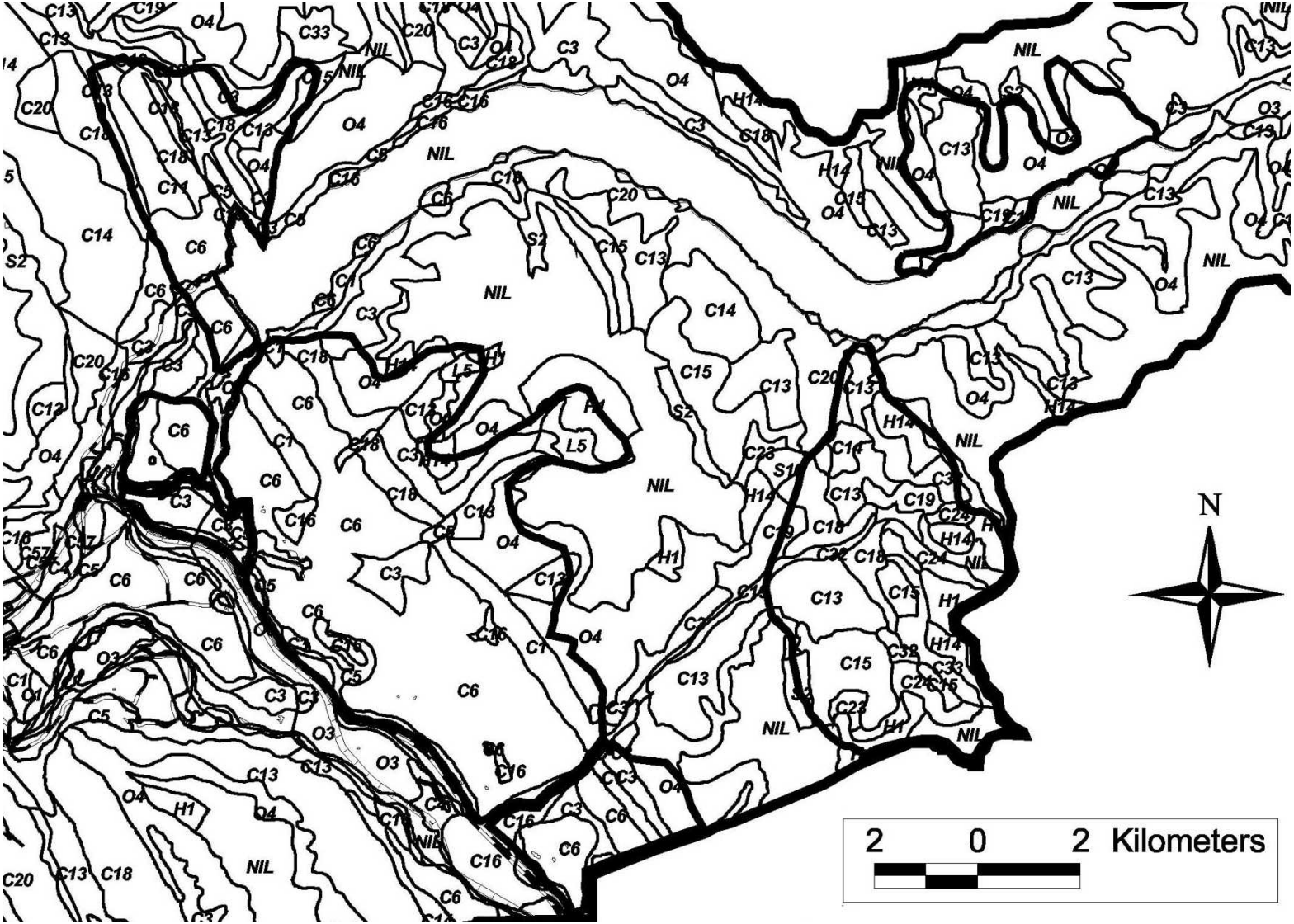

Figure 5

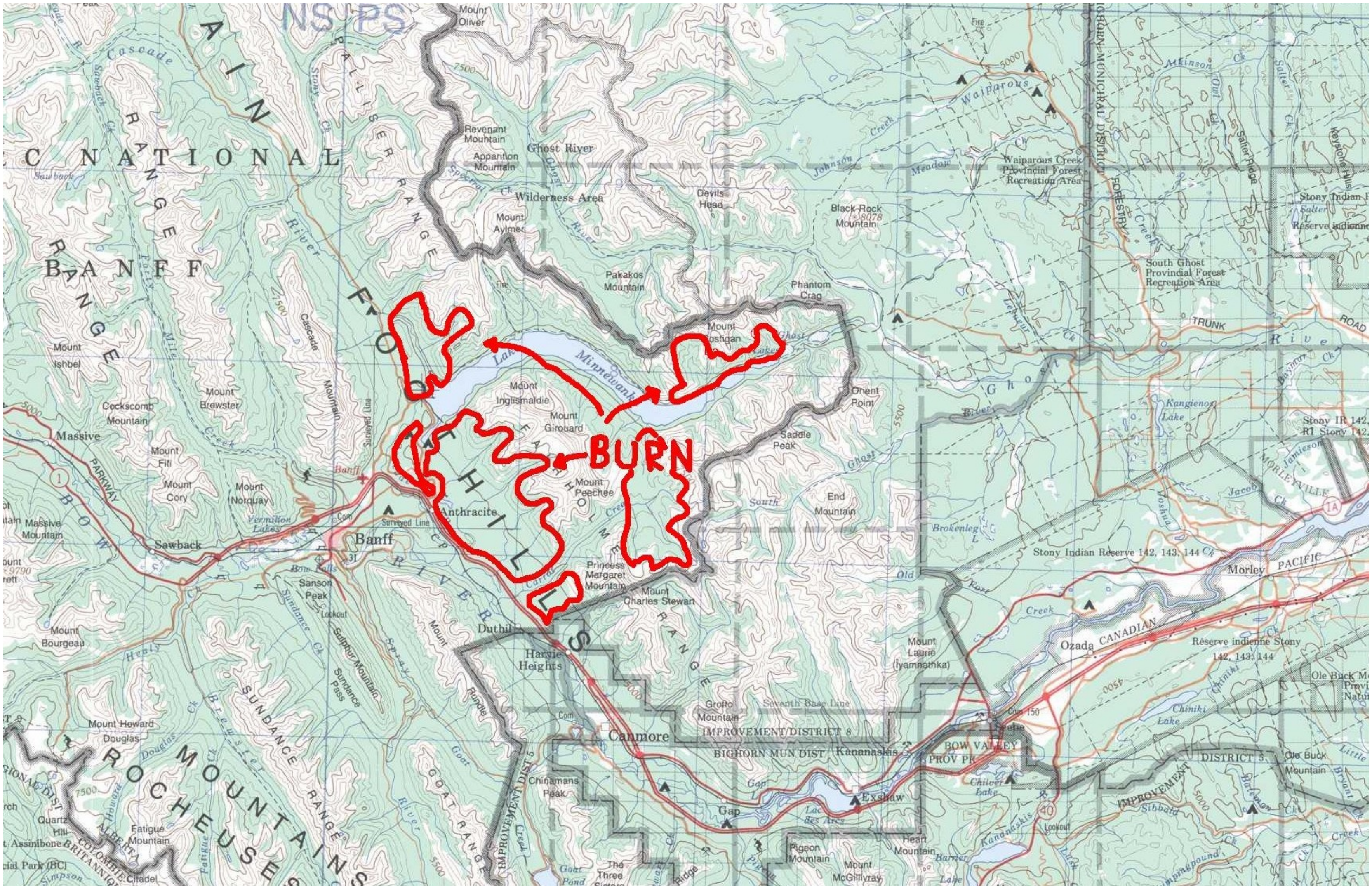
BURN
BANFF
NATIONAL
RANGE
FOOTHILLS
FAIRHOLME
RANGE
SUNDANCE RANGE
GOAT RANGE
ROCHEUSES
MOUNTAINS
Mount Oliver
Revenant Mountain
Apparition Mountain
Ghost River
Wilderness Area
Mount Aylmer
Devils Head
Black Rock Mountain
Pakakos Mountain
Phantom Crag
Mount Costigan
Minnewanka
Mount Inglismaldie
Mount Girouard
Mount Peechee
Saddle Peak
Orient Point
End Mountain
Anthracite
Princess Margaret Mountain
Mount Charles Stewart
Banff
Sawback
Massive
Mount Ishbel
Cockscomb Mountain
Mount Brewster
Mount Fifi
Mount Cory
Mount Norquay
Vermilion Lakes
Cascade Mountain
Sanson Peak
Mount Bourgeau
Mount Rundle
Sulphur Mountain
Sundance Pass
Duthil
Harvie Heights
Canmore
Grotto Mountain
IMPROVEMENT DISTRICT 8
BIGHORN MUN DIST
Kananaskis
BOW VALLEY PROV PK
Exshaw
Gap
Lac des Arcs
Pigeon Mountain
Mount McGillivray
Heart Mountain
Chinamans Peak
Mount Howard
Douglas
Fatigue Mountain
Mount Laurie (Iyamnathka)
Waiparous Creek Provincial Forest Recreation Area
South Ghost Provincial Forest Recreation Area
Stony Indian Reserve 142, 143, 144
Morley
Ozada
CANADIAN PACIFIC
Réserve indienne Stony 142, 143, 144
Kangienos Lake
Chiniki Lake
Old Buck Mountain
Jacob Ck
Ghost River
Brokenleg L
TRUNK ROAD
MORLEYVILLE
Seebe
Lookout
Surveyed Line

Figure 6

	Banff Alberta, Canada (Fuel Type Coniferous)	Jambi Sumatra, Asia (Tropical Rain Forest)	Ivory Coast, Africa (Tropical Rain Forest)	Brunei Darussulam, Africa (Tropical Rain Forest)	Brazil, Africa (Tropical Rain Forest)	Georgia, USA (Fuel Type Coniferous)	California and Oregon, USA Durango, Mexico (Coniferous Fuel)	California and Oregon, USA Yukon Territories, Canada (Deciduous Fuel)	Davis, California (Ponderosa Pine Slash)	Davis, California (Douglas Fir Slash)
Al	√	n/a	√		√	n/a	n/a	n/a	√	√
As		n/a		√		n/a	n/a	n/a		√
Ba	√	n/a				n/a	n/a	n/a		
Br	√	n/a			√	n/a	n/a	n/a	√	√
Ca	√	n/a	√	√	√	n/a	n/a	n/a	√	√
C		n/a	√	√	√	n/a	n/a	n/a	√	√
Cl	√	n/a	√	√	√	n/a	n/a	n/a	√	√
Cr	√	n/a			√	n/a	n/a	n/a		
Cu	√	n/a		√	√	n/a	n/a	n/a	√	
Fe	√	n/a	√	√	√	n/a	n/a	n/a	√	√
H		n/a		√		n/a	n/a	n/a		
K	√	n/a	√	√	√	n/a	n/a	n/a	√	√
Mg	√	n/a	√	√	√	n/a	n/a	n/a		
Mn	√	n/a	√		√	n/a	n/a	n/a	√	√
N		n/a		√		n/a	n/a	n/a		
Na	√	n/a	√	√	√	n/a	n/a	n/a		
Ni	√	n/a		√	√	n/a	n/a	n/a		
P	√	n/a	√		√	n/a	n/a	n/a	√	√
Pb	√	n/a			√	n/a	n/a	n/a	√	√
Rb	√	n/a			√	n/a	n/a	n/a	√	√
S	√	n/a	√	√	√	n/a	n/a	n/a	√	√
Si	√	n/a	√		√	n/a	n/a	n/a		
Sn	√	n/a				n/a	n/a	n/a		√
Sr	√	n/a			√	n/a	n/a	n/a	√	√
Ti	√	n/a			√	n/a	n/a	n/a		
V		n/a		√	√	n/a	n/a	n/a		
Zn	√	n/a	√	√	√	n/a	n/a	n/a	√	√
Zr	√	n/a			√	n/a	n/a	n/a		
anthanthrene					n/a		√		n/a	n/a
anthracene		√	√	√	n/a	√	√	√	n/a	n/a
benzo(a)anthracene	√	√			n/a	√		√	n/a	n/a
benzo(b)chrysene		√			n/a				n/a	n/a
benzo(b)fluoranthene		√			n/a		√		n/a	n/a
benzo(ghi)fluoranthene					n/a		√	√	n/a	n/a
benzo(b,,j,k)fluoranthene	√				n/a				n/a	n/a
benzo(k)fluoranthene		√			n/a		√		n/a	n/a
benzofluoranthene					n/a	√			n/a	n/a
benzo(ghi)perylene	√	√			n/a	√	√		n/a	n/a
benzo(c)phenanthrene	√				n/a	√			n/a	n/a
benzo(a)pyrene	√	√			n/a	√	√	√	n/a	n/a
benzo(e)pyrene	√	√			n/a	√	√		n/a	n/a
chrysene	√	√			n/a	√		√	n/a	n/a
coronene		√			n/a				n/a	n/a
cyclopenta(cd)pyrene					n/a		√		n/a	n/a
dibenzo(ae)anthracene		√			n/a				n/a	n/a
dibenzo(ah)anthracene	√	√			n/a				n/a	n/a
dibenzo(a,e)pyrene		√			n/a				n/a	n/a
7,12-dimethylben(a)anthracene	√				n/a				n/a	n/a
fluoranthene	√	√	√	√	n/a	√	√	√	n/a	n/a
fluorene		√	√	√	n/a			√	n/a	n/a
indeno(1,2,3-cd)pyrene	√	√			n/a	√	√		n/a	n/a
methyl anthrene					n/a	√			n/a	n/a
methyl benzopyrenes					n/a	√			n/a	n/a
methyl chrysene					n/a	√			n/a	n/a
methyl pyrene/fluoranthene					n/a	√			n/a	n/a
naphthalene		√	√	√	n/a				n/a	n/a
phenanthrene	√		√	√	n/a	√	√	√	n/a	n/a
2-phenylnapthalene					n/a		√		n/a	n/a
perylene		√			n/a	√	√		n/a	n/a
pyrene	√	√	√	√	n/a	√	√	√	n/a	n/a
retene	√				n/a		√		n/a	n/a
triphenylene		√			n/a		√		n/a	n/a

Table 2

Element	Average % Mass (n=9) PM2.5 Banff, AB Prescribed Burn Coniferous Fuel Type	Average % Mass Unc. (n=9) PM2.5 Banff, AB Prescribed Burn Coniferous Fuel Type	Average % Mass (n=2) PM2.5 Davis, CA Simulated Burn Ponderosa Pine Slash	Average % Mass Unc. (n=2) PM2.5 Davis, CA Simulated Burn Ponderosa Pine Slash	Average % Mass (n=2) PM2.5 Davis, CA Simulated Burn Douglas Fir Slash	Average % Mass Unc. (n=2) PM2.5 Davis, CA Simulated Burn Douglas Fir Slash
Al	0.496400%	0.202040%	0.02300%	0.02500%	0.01100%	0.00450%
As	0.000615%	0.000790%	0.00000%	0.00230%	0.00470%	0.00110%
B	0.004214%	0.014581%	-	-	-	-
Ba	0.005620%	0.003300%	0.00000%	0.06200%	0.00000%	0.04800%
Br	0.008231%	0.007288%	0.00350%	0.00070%	0.00400%	0.00060%
Ca	2.940000%	0.000614%	0.03300%	0.08300%	0.03400%	0.00610%
Cl	0.464750%	0.002909%	0.64000%	0.05000%	0.14000%	0.01100%
Cr	0.004396%	0.002769%	0.00000%	0.00200%	0.00000%	0.00160%
Cu	0.008747%	0.003039%	0.00470%	0.00080%	0.00000%	0.00080%
Fe	0.163120%	0.087514%	0.00330%	0.00360%	0.00390%	0.00280%
K	0.467430%	0.223500%	5.70000%	0.41000%	0.98000%	0.07000%
Mg	0.620460%	0.000139%	-	-	-	-
Mn	0.007709%	0.004822%	0.00260%	0.00100%	0.00230%	0.00080%
Na	0.169120%	0.066700%	-	-	-	-
Ni	0.002368%	0.001202%	0.00000%	0.00100%	0.00000%	0.00070%
P	0.224990%	0.035339%	0.01000%	0.03900%	0.00930%	0.00310%
Pb	0.002302%	0.000383%	0.00460%	0.00200%	0.00240%	0.00150%
Rb	0.000927%	0.000505%	0.02300%	0.00180%	0.00330%	0.00050%
S	1.700540%	0.003761%	1.40000%	0.10000%	0.26000%	0.01900%
Si	0.436726%	0.015126%	0.09500%	0.02100%	0.01800%	0.01240%
Sn	0.088225%	0.001657%	0.00570%	0.01600%	0.00390%	0.01200%
Sr	0.003366%	0.000763%	0.00020%	0.00100%	0.00010%	0.00080%
Ti	0.023862%	0.010357%	0.00000%	0.02100%	0.00000%	0.01600%
Zn	0.050270%	0.004363%	0.31000%	0.02200%	0.09700%	0.00690%

Table 3

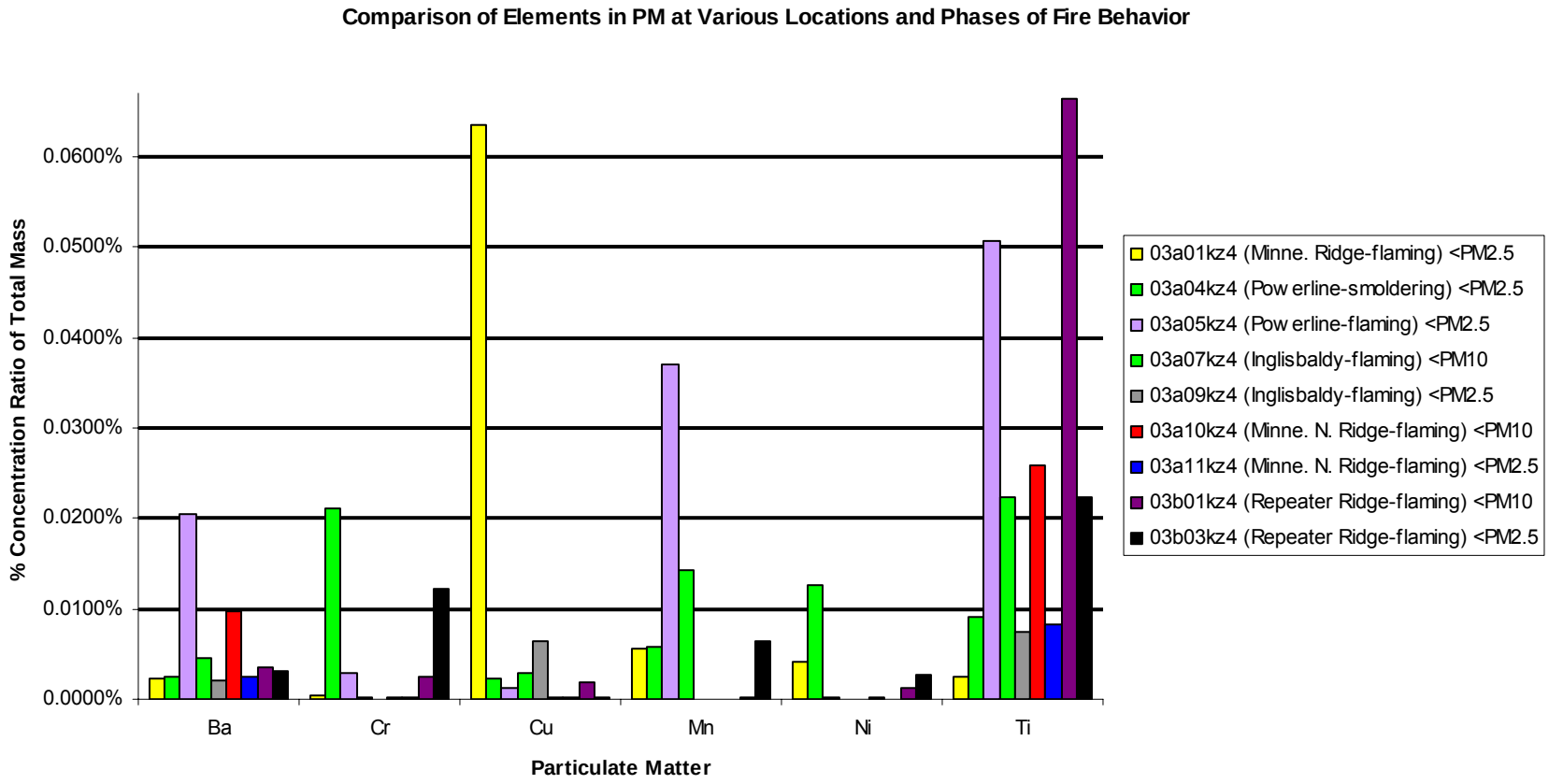
Comparison of Elements in PM at Various Locations and Phases of Fire Behavior
% Concentration Ratio of Total Mass
0.0600%
0.0500%
0.0400%
0.0300%
0.0200%
0.0100%
0.0000%
Ba
Cr
Cu
Mn
Ni
Ti
Particulate Matter
03a01kz4 (Minne. Ridge-flaming) <PM2.5
03a04kz4 (Pow erline-smoldering) <PM2.5
03a05kz4 (Pow erline-flaming) <PM2.5
03a07kz4 (Inglisbaldy-flaming) <PM10
03a09kz4 (Inglisbaldy-flaming) <PM2.5
03a10kz4 (Minne. N. Ridge-flaming) <PM10
03a11kz4 (Minne. N. Ridge-flaming) <PM2.5
03b01kz4 (Repeater Ridge-flaming) <PM10
03b03kz4 (Repeater Ridge-flaming) <PM2.5

Figure 7

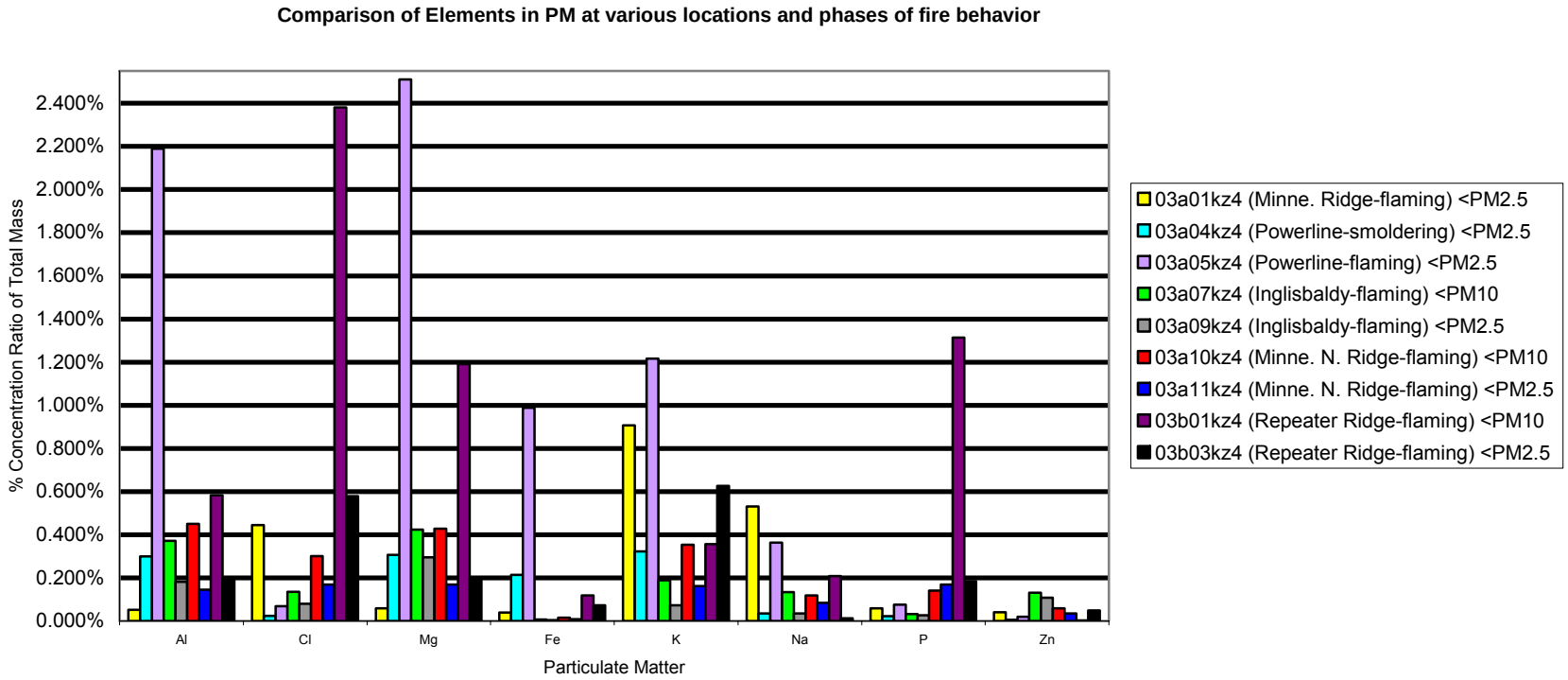
Comparison of Elements in PM at various locations and phases of fire behavior
% Concentration Ratio of Total Mass
2.400%
2.200%
2.000%
1.800%
1.600%
1.400%
1.200%
1.000%
0.800%
0.600%
0.400%
0.200%
0.000%
Al
Cl
Mg
Fe
K
Na
P
Zn
Particulate Matter
03a01kz4 (Minne. Ridge-flaming) <PM2.5
03a04kz4 (Powerline-smoldering) <PM2.5
03a05kz4 (Powerline-flaming) <PM2.5
03a07kz4 (Inglisbaldy-flaming) <PM10
03a09kz4 (Inglisbaldy-flaming) <PM2.5
03a10kz4 (Minne. N. Ridge-flaming) <PM10
03a11kz4 (Minne. N. Ridge-flaming) <PM2.5
03b01kz4 (Repeater Ridge-flaming) <PM10
03b03kz4 (Repeater Ridge-flaming) <PM2.5

Figure 8

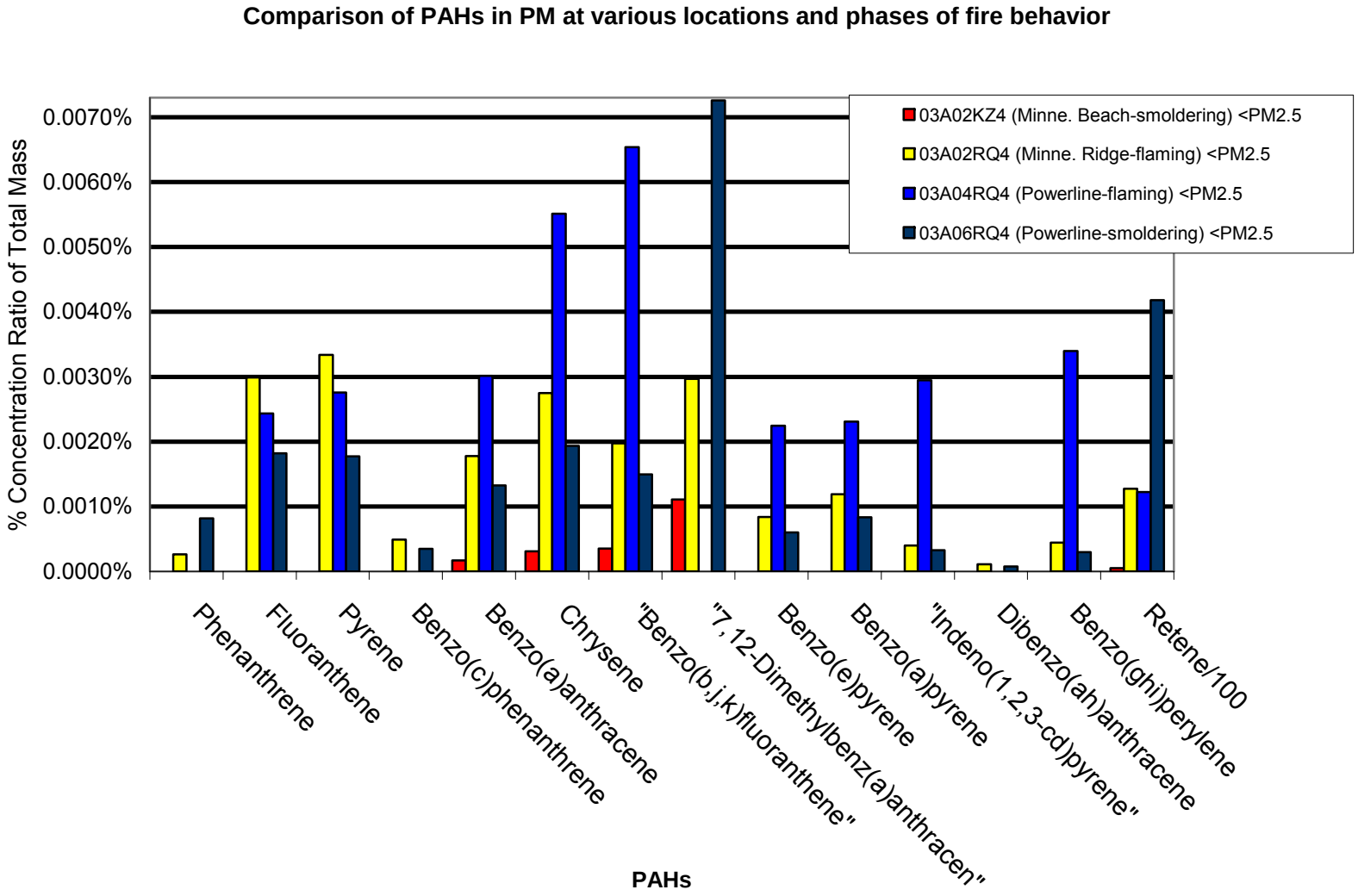
Comparison of PAHs in PM at various locations and phases of fire behavior
% Concentration Ratio of Total Mass
0.0070%
0.0060%
0.0050%
0.0040%
0.0030%
0.0020%
0.0010%
0.0000%
03A02KZ4 (Minne. Beach-smoldering) <PM2.5
03A02RQ4 (Minne. Ridge-flaming) <PM2.5
03A04RQ4 (Powerline-flaming) <PM2.5
03A06RQ4 (Powerline-smoldering) <PM2.5
Phenanthrene
Fluoranthene
Pyrene
Benzo(c)phenanthrene
Benzo(a)anthracene
Chrysene
"Benzo(b,j,k)fluoranthene"
"7,12-Dimethylbenz(a)anthracen"
Benzo(e)pyrene
Benzo(a)pyrene
"Indeno(1,2,3-cd)pyrene"
Dibenzo(ah)anthracene
Benzo(ghi)perylene
Retene/100
PAHs

Figure 9

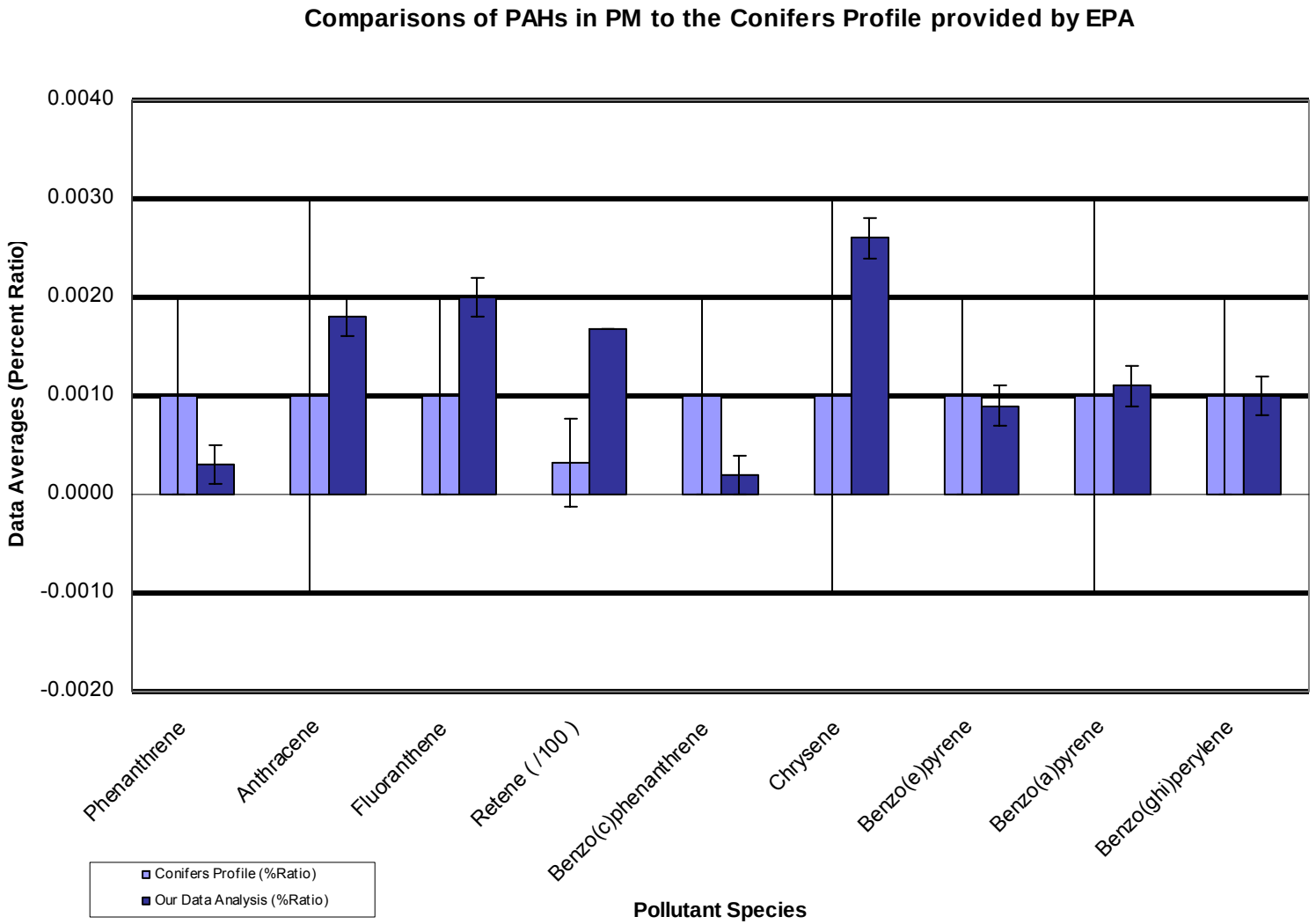
Comparisons of PAHs in PM to the Conifers Profile provided by EPA
Data Averages (Percent Ratio)
0.0040
0.0030
0.0020
0.0010
0.0000
-0.0010
-0.0020
Phenanthrene
Anthracene
Fluoranthene
Retene (/100)
Benzo(c)phenanthrene
Chrysene
Benzo(e)pyrene
Benzo(a)pyrene
Benzo(ghi)perylene
Conifers Profile (%Ratio)
Our Data Analysis (%Ratio)
Pollutant Species

Figure 10

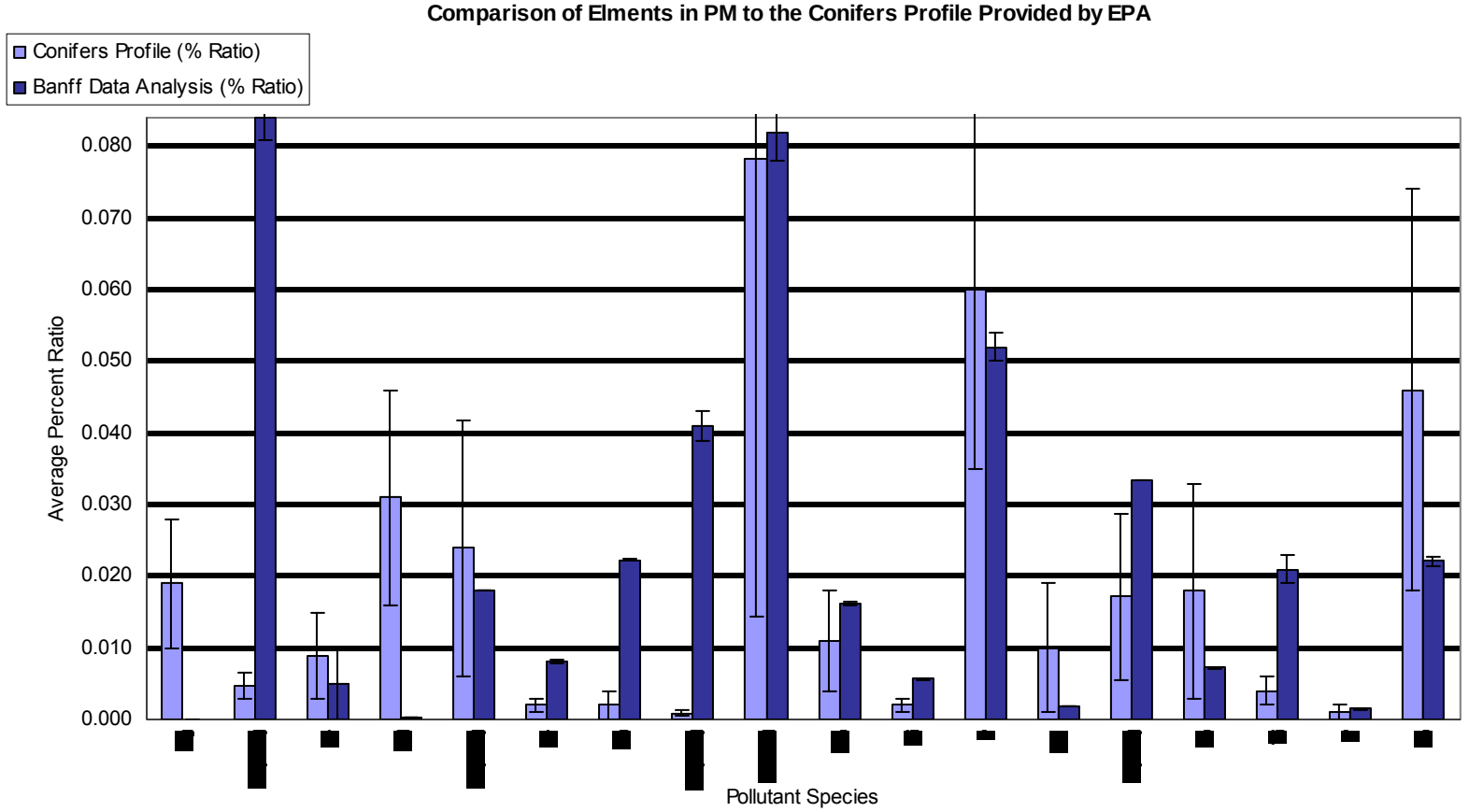
Comparison of Elments in PM to the Conifers Profile Provided by EPA
Conifers Profile (% Ratio)
Banff Data Analysis (% Ratio)
Average Percent Ratio
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
Pollutant Species

Figure 11

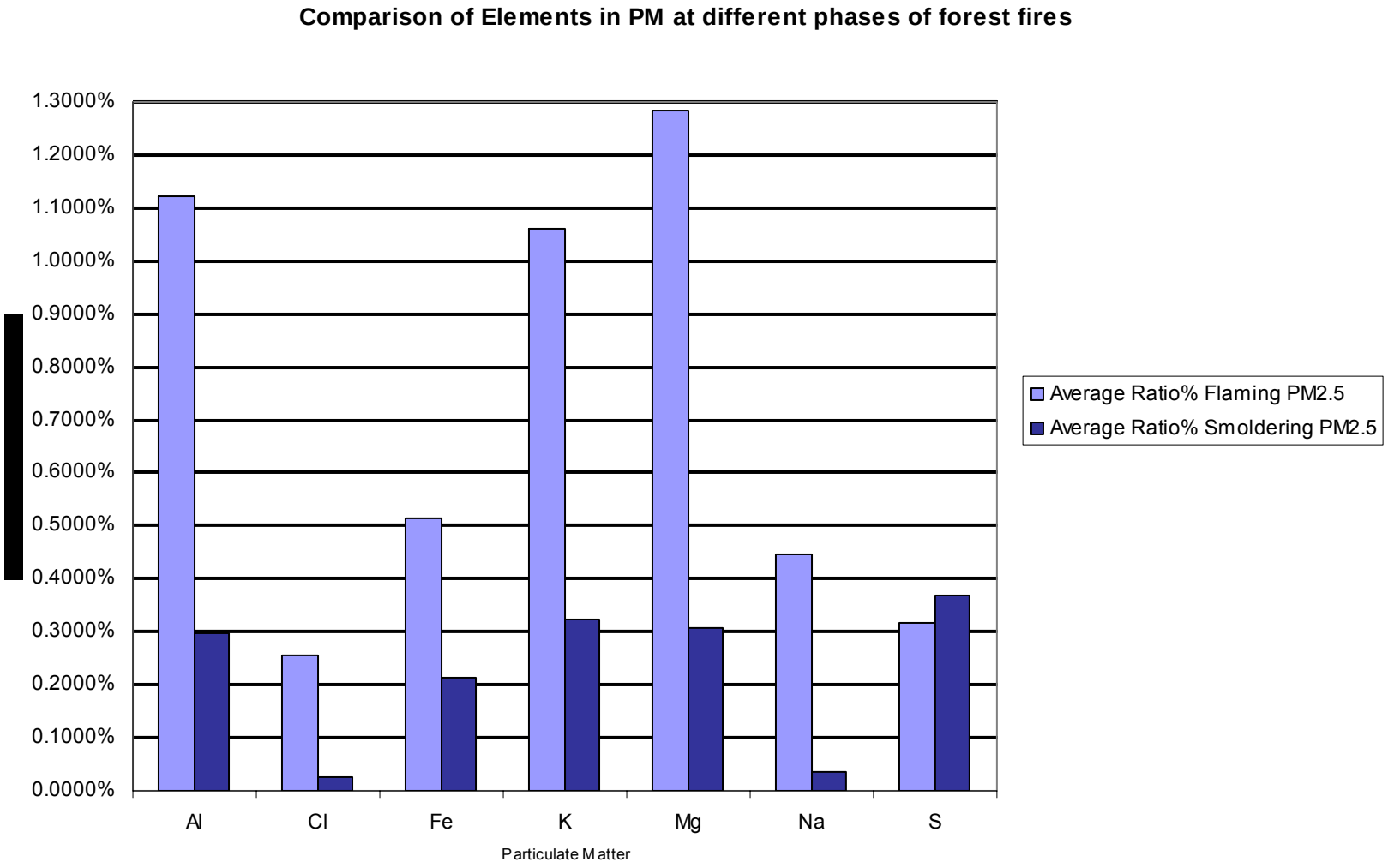
Comparison of Elements in PM at different phases of forest fires
1.3000%
1.2000%
1.1000%
1.0000%
0.9000%
0.8000%
0.7000%
0.6000%
0.5000%
0.4000%
0.3000%
0.2000%
0.1000%
0.0000%
Al
Cl
Fe
K
Mg
Na
S
Particulate Matter
Average Ratio% Flaming PM2.5
Average Ratio% Smoldering PM2.5

Figure 12

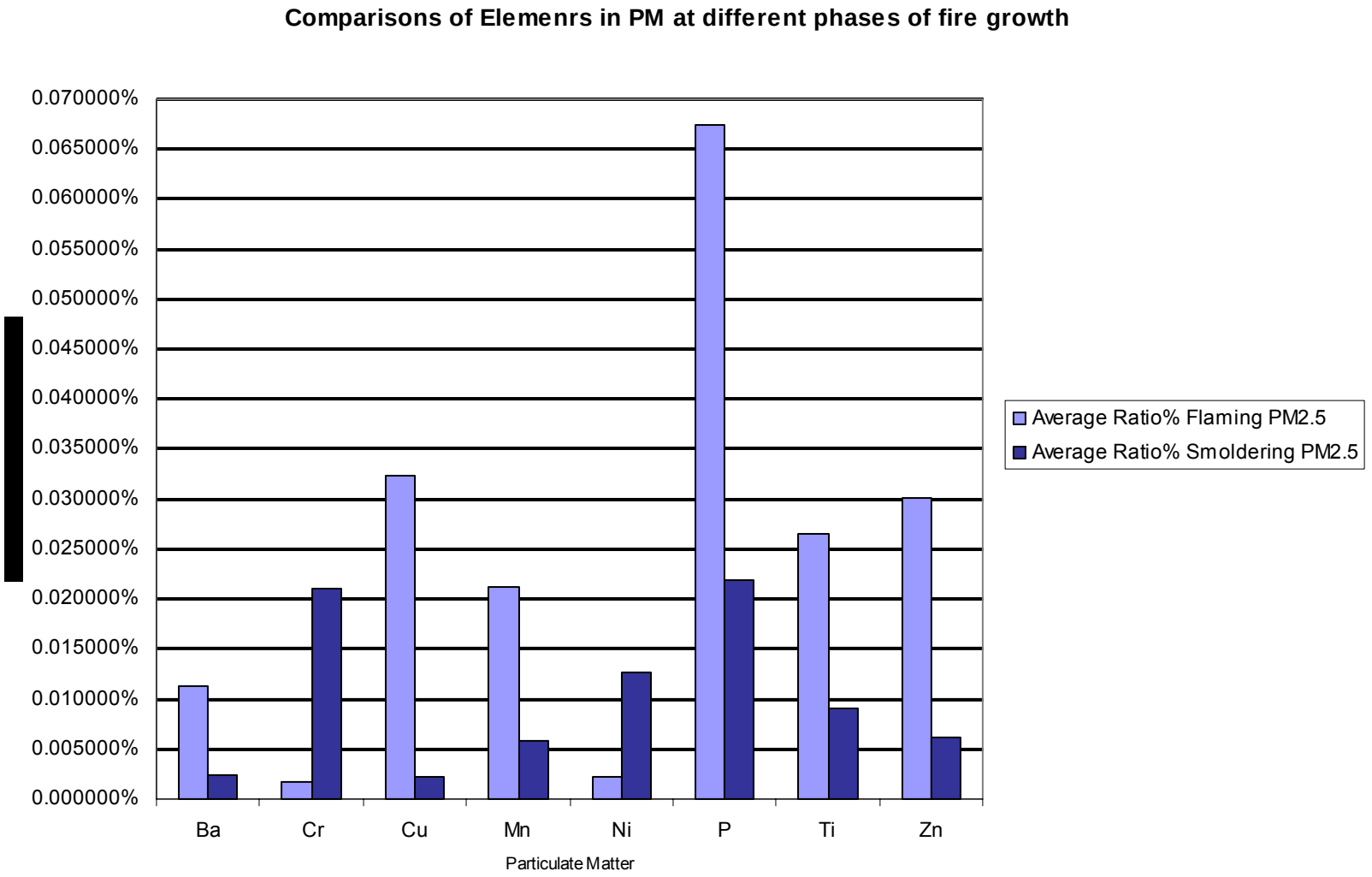
Comparisons of Elemenrs in PM at different phases of fire growth
0.070000%
0.065000%
0.060000%
0.055000%
0.050000%
0.045000%
0.040000%
0.035000%
0.030000%
0.025000%
0.020000%
0.015000%
0.010000%
0.005000%
0.000000%
Ba
Cr
Cu
Mn
Ni
P
Ti
Zn
Particulate Matter
Average Ratio% Flaming PM2.5
Average Ratio% Smoldering PM2.5

Figure 13

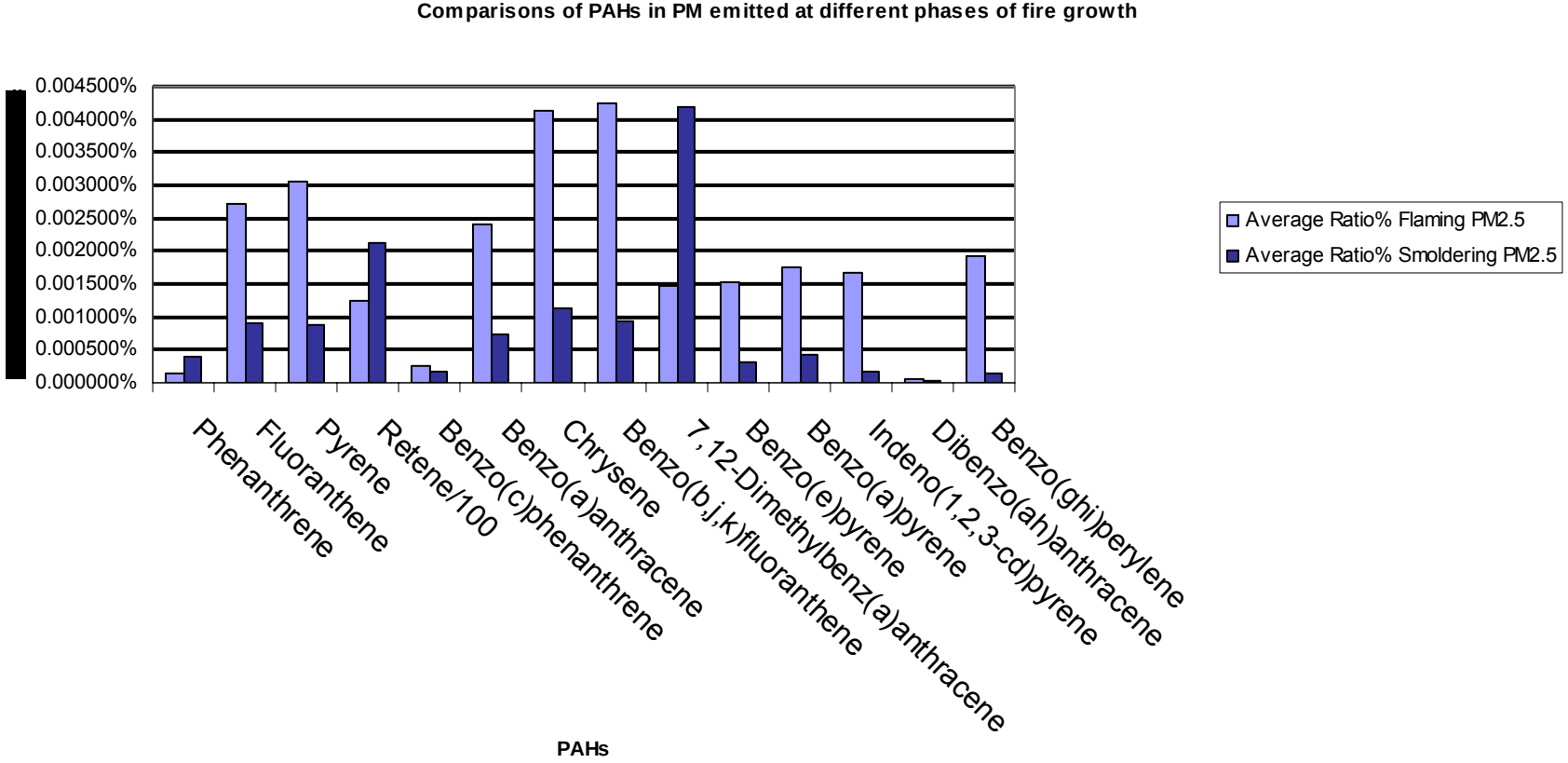
Comparisons of PAHs in PM emitted at different phases of fire growth
0.004500%
0.004000%
0.003500%
0.003000%
0.002500%
0.002000%
0.001500%
0.001000%
0.000500%
0.000000%
Phenanthrene
Fluoranthene
Pyrene
Retene/100
Benzo(c)phenanthrene
Benzo(a)anthracene
Chrysene
Benzo(b,j,k)fluoranthene
7,12-Dimethylbenz(a)anthracene
Benzo(e)pyrene
Benzo(a)pyrene
Indeno(1,2,3-cd)pyrene
Dibenzo(ah)anthracene
Benzo(ghi)perylene
PAHs
Average Ratio% Flaming PM2.5
Average Ratio% Smoldering PM2.5

Figure 14

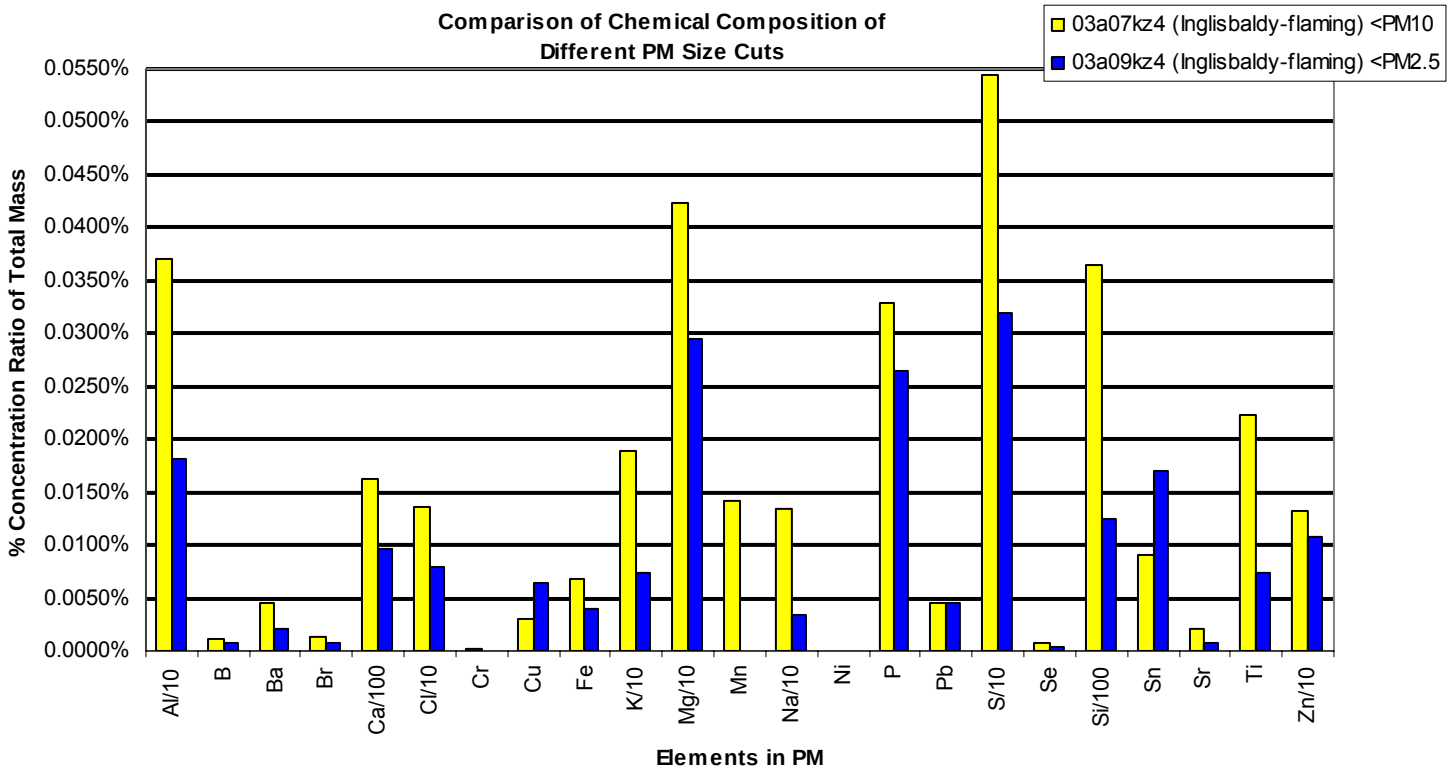
Comparison of Chemical Composition of Different PM Size Cuts
03a07kz4 (Inglisbaldy-flaming) <PM10
03a09kz4 (Inglisbaldy-flaming) <PM2.5
% Concentration Ratio of Total Mass
0.0550%
0.0500%
0.0450%
0.0400%
0.0350%
0.0300%
0.0250%
0.0200%
0.0150%
0.0100%
0.0050%
0.0000%
Al/10
B
Ba
Br
Ca/100
Cl/10
Cr
Cu
Fe
K/10
Mg/10
Mn
Na/10
Ni
P
Pb
S/10
Se
Si/100
Sn
Sr
Ti
Zn/10
Elements in PM

Figure 15

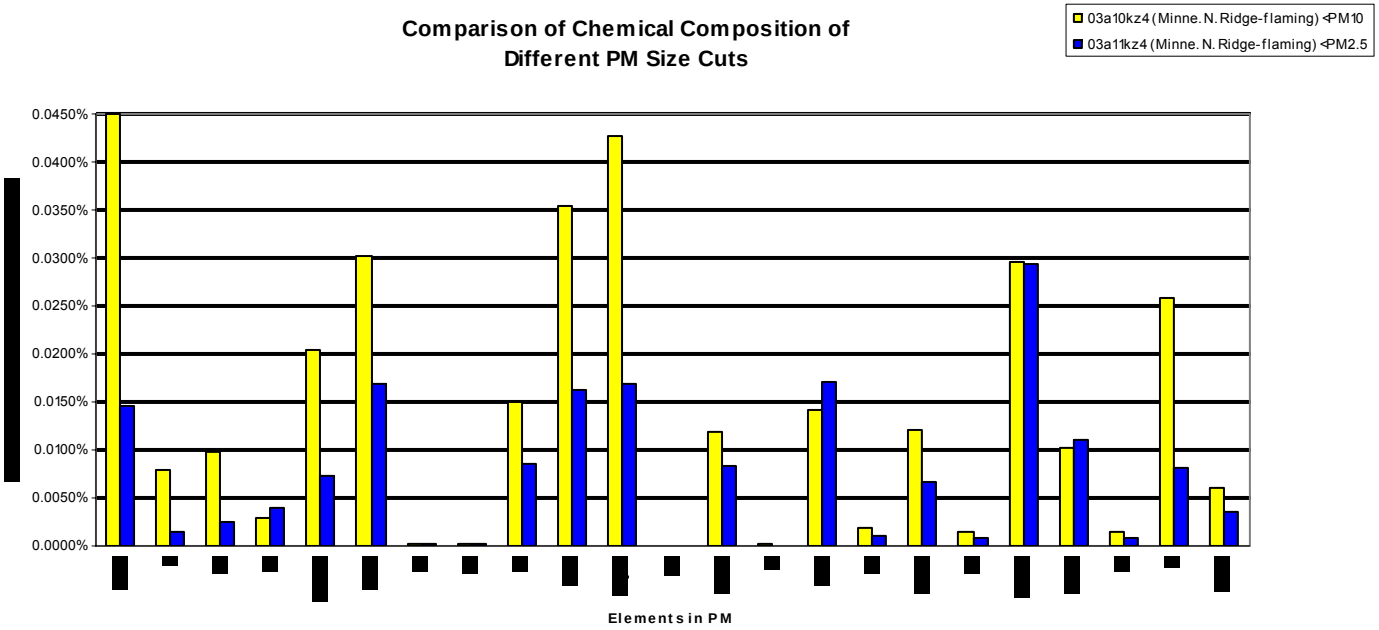
Comparison of Chemical Composition of
Different PM Size Cuts
03a10kz4 (Minne. N. Ridge-flaming) <PM10
03a11kz4 (Minne. N. Ridge-flaming) <PM2.5
0.0450%
0.0400%
0.0350%
0.0300%
0.0250%
0.0200%
0.0150%
0.0100%
0.0050%
0.0000%
Elements in PM

Figure 16

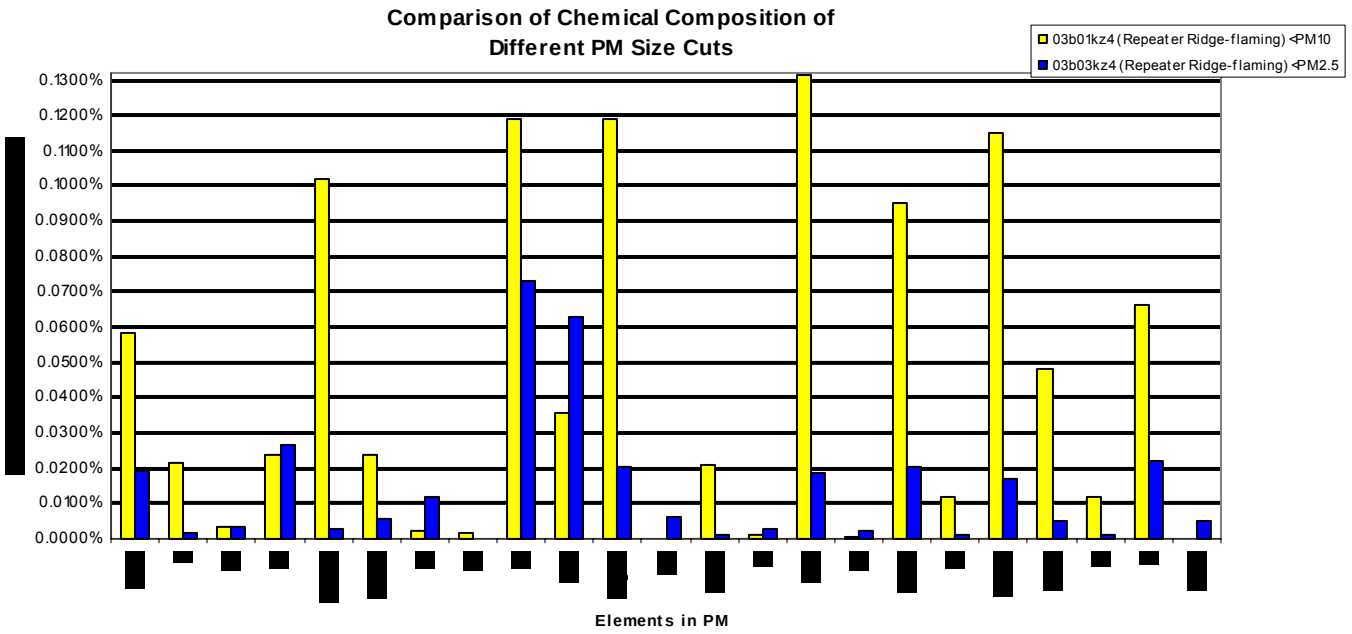
Comparison of Chemical Composition of Different PM Size Cuts
03b01kz4 (Repeater Ridge-flaming) <PM10
03b03kz4 (Repeater Ridge-flaming) <PM2.5
0.1300%
0.1200%
0.1100%
0.1000%
0.0900%
0.0800%
0.0700%
0.0600%
0.0500%
0.0400%
0.0300%
0.0200%
0.0100%
0.0000%
Elements in PM

Figure 17

Filter ID	Location	Ambient Or Control	PMCut	CollectionTime (min)	Filter Net Wt. (mg)	Filter Species Wt (mg)	Filter Wt. Of Unknown Species (mg)*	Percent Characterized	PM Concentration (µg/M3)
03A01KZ4	Minnewanka Ridge	Ambient	2.5	291	2.263	0.07654033	2.18645967	3.38%	1595.499519
03A02KZ4	Minnewanka Beach	Ambient	2.5	911	2.202	0.92281438	1.27918562	41.91%	483.8038004
03A04KZ4	Powerline	Ambient	2.5	556	2.053	0.0829402	1.9700598	4.04%	747.894342
03A05KZ4	Powerline	Ambient	2.5	300	0.723	0.2214319	0.5015681	30.63%	488.9782952
03A06KZ4	Powerline	Control	NA	NA	0.277	0.09490884	0.18209116	34.26%	NA
03A07KZ4	Inglisbaldy	Ambient	10	177	0.368	0.02694561	0.34105439	7.32%	423.6036893
03A09KZ4	Inglisbaldy	Ambient	2.5	179	0.628	0.02114772	0.60685228	3.37%	722.4960904
03A08KZ4	Inglisbaldy	Control	NA	NA	0.375	0.02875441	0.34624559	7.67%	NA
03A10KZ4	Minnewanka N Ridge	Ambient	10	299	0.166	0.01369044	0.15230956	8.25%	112.9598825
03A11KZ4	Minnewanka N Ridge	Ambient	2.5	299	0.296	0.01602593	0.27997407	5.41%	201.4093249
03A12KZ4	Minnewanka N Ridge	Control	NA	NA	0.167	0.01357863	0.15342137	8.13%	NA
03B01KZ4	Repeater Ridge	Ambient	10	390	0.021	0.00799586	0.01300414	38.08%	10.98977926
03B03KZ4	Repeater Ridge	Ambient	2.5	390	0.261	0.01596685	0.24503315	6.12%	133.9426285
03B02KZ4	Repeater Ridge	Control	NA	NA	0.06	0.02731732	0.03268268	45.53%	NA
03A01RQ4	Minnewanka Beach	Ambient	2.5	910	6.887	NA	NA	NA	NA
03A02RQ4	Minnewanka Ridge	Ambient	2.5	291	2.163	0.0031824	2.1598176	0.15%	1517.279741
03A03RQ4	Minnewanka Beach	Control	NA	NA	2.378	0	2.378	0.00%	NA
03A04RQ4	Powerline	Ambient	2.5	300	0.156	0.0002396	0.1557604	0.15%	105.0602034
03A05RQ4	Powerline	Control	NA	NA	0.002±0.004	NA	NA	NA	NA
03A06RQ4	Powerline	Ambient	2.5	973	2.99	0.0130654	2.9769346	0.44%	633.7015512
03A07RQ4	Inglisbaldy	Control	NA	NA	0.004±0.004	0.0000073	0.0039927	0.18%	NA
03A08RQ4	Inglisbaldy	Ambient	2.5	182	0.002±0.004	NA	NA	NA	NA
03A09RQ4	Inglisbaldy	Ambient	10	179	0.298	0.0000567	0.2979433	0.02%	341.7191192
03A10RQ4	Minnewanka N Ridge	Ambient	10	132	0.154	0.0000217	0.1539783	0.01%	238.3829731
03A11RQ4	Minnewanka N Ridge	Ambient	2.5	299	0.134	0.0001001	0.1338999	0.07%	91.27551444
03A12RQ4	Minnewanka N Ridge	Control	NA	NA	0.089	NA	NA	NA	NA
03B01RQ4	Repeater Ridge	Ambient	10	390	0.3	0.000124	0.299876	0.04%	157.6300441
03B02RQ4	Repeater Ridge	Control	NA	NA	0.098	NA	NA	NA	NA
03B03RQ4	Repeater Ridge	Ambient	2.5	390	0.306	NA	NA	NA	NA

Table 4