EPA-908/1-73-001

FLUORIDE IN GLACIER NATIONAL PARK:

A FIELD INVESTIGATION

U.S. ENVIRONMENTAL PROTECTION AGENCY
REGION VIII
Air and Water Programs Division
Denver, Colorado 80203

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Prepared for

U.S. ENVIRONMENTAL PROTECTION AGENCY
REGION VIII
Air and Water Programs Division
Denver, Colorado 80203

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SUMMARY

A reduction plant of the Anaconda Aluminum Company began operations at Columbia Falls, Montana, in 1955. In 1957 flora in the vicinity of the plant began to show foliage injury that is symptomatic of excessive accumulation of fluoride, an air contaminant emitted from the electrolytic reduction cells used in primary aluminum smelting.

During the years between the initial observations of suspected fluoride damage and 1968, when damage to pine trees became noticeably more widely spread in the area, Anaconda Aluminum Company twice expanded the plant. Following the second expansion in 1968, other areas around Columbia Falls and even areas in the southwestern part of Glacier National Park, which at its nearest point is 6 miles northeast of the aluminum plant, exhibited visible damage to flora.

In 1970 the National Park Service, U.S. Department of the Interior, was concerned that fluoride emissions from the aluminum plant were being carried into Glacier National Park. The Park Service requested the assistance of the National Air Pollution Control Administration, a predecessor of the Environmental Protection Agency (EPA), in assessing the effects of airborne fluorides on vegetation and wildlife in the Park.

In cooperation with other Federal and state agencies, EPA conducted field studies in and near Glacier National Park during 1970. This report presents results of the EPA studies, which include meteorological analyses, measurement of ambient fluoride concentrations, and assessment of the effects of fluorides on special test vegetation and indigenous flora within the Park. EPA also sponsored a more extensive study of vegetation and wildlife conducted by the University of Montana. Results of that 6-month study are described in a report, EPA-908/1-73-002. Investigations performed by the Forest Service are reported in "Environmental Pollution by Fluorides in Flathead National Forest and Glacier National Park" (U.S. Department of Agriculture, Missoula, Montana).

METEOROLOGICAL ANALYSES

Observations of the wind flow at various locations and elevations indicated two distinct air-flow patterns that affect the movement of airborne fluorides emitted at the aluminum plant. Upper-level winds, those at or above the mountaintop, are most prevalent from the southwest during the summer. Lower-level winds, those from ground level in the valleys to about mountaintop level, tend to reverse direction from day to night. These wind patterns interact to cause transport of fluoride emissions toward Glacier National Park a major portion of the time.

In daytime, prevailing up-valley air flows coupled with southwesterly winds aloft are conducive to the movement of fluorides across Teakettle Mountain and northeasterly into the

Park. The nighttime down-valley flow is conducive to movement of fluorides from the aluminum plant south and southwestward into Columbia Falls and along the lower valley of the Flathead River.

The highest concentrations of fluorides are likely to be carried into the Park during the daytime, principally during the midmorning hours. The nocturnal flow in the lower Flathead Valley tends to be sluggish and causes fluorides emitted during the nighttime hours to accumulate in the valley. After sunrise, pollutants that have accumulated in the lower valley combine with continuing emissions and mix in a deepening air layer until this layer reaches the top of Teakettle Mountain, where the pollutants are entrained into the upper wind flow. The pollutants are conveyed by the prevailing southwesterly upper wind over the upper Flathead Valley and intercept the mountainous terrain within the Park at the height of the upper wind level. Downward mixing of the air mass in the steep valleys within the Park is retarded during the morning by deep shadows that prevent solar heating of the ground. By midday more vigorous vertical mixing of the air mass in the upper valley causes a reduction of pollutant concentrations within the Park.

Summer through early fall appears to be the period of greatest transport of pollutants toward the Park. Favorable conditions for this movement are the longer daytime hours and the prevailing southwesterly winds. During other seasons winds are usually stronger, so that greater dispersion takes place and ambient concentrations are generally lower.

AMBIENT FLUORIDE CONCENTRATIONS

Ambient fluoride concentrations were detected by two methods: (1) impact measurements made over monthly periods by exposing chemically treated filter paper at 37 sites, and (2) volumetric measurements of gaseous and particulate concentrations over 12-hour periods made at a few sites with electrically operated samplers.

The impact measurements, which provide an index of gaseous fluoride concentrations over a period of time, showed rapid decrease with increasing distance from the aluminum plant, except in the northeasterly direction. The prevailing wind patterns and the higher ground elevations of exposure sites in Glacier National Park both contribute to elevated fluoridation rates that were measured 10 or more miles from the plant in the northeasterly direction. Fluoride readings at several sites within the Park consistently exceeded the State of Montana air quality standard for fluorides; the average value for the sampling station on Apgar Mountain exceeded the State standard by a factor of nearly 2.

The sampling results show that parts of Glacier National Park, especially the upper slopes of the Apgar Mountain, are exposed to relatively high levels of atmospheric fluoride. Consideration of the meteorology, topography, and geography of the area strongly suggests that high elevations elsewhere in the Park and the Flathead National Forest are similarly exposed to high ambient fluoride concentrations, the source of which is the aluminum plant at Columbia Falls.

Gaseous and particulate fluoride concentrations were continuously measured at four sites at lower elevations along the Park boundary, where electric power was available. Twenty-four-hour average gaseous fluoride concentrations exceeded the State of Montana Air Quality Standard only once during the study period. At higher, more exposed locations in the Park concentrations probably exceeded state standards more frequently.

EFFECTS ON VEGETATION

Study participants collected samples of vegetation in and near the Park for use in macro- and microscopical examination and chemical analysis.

An EPA plant pathologist and an independent consultant observed visible injury to conifers and other vegetation growing in and around the Park. The older needles of ponderosa pine growing in an exposed location on the western slope of Apgar Mountain showed considerable tip burn. Other coniferous species in the area showed severe foliar necrotic lesions on the 1968 and 1969 needles.

The variability of visible damage to vegetation within the Park suggests that location, topography, and meteorology, in addition to the quantity of fluoride emitted by the aluminum reduction plant, are key factors in exposure of vegetation to fluorides. For example, vegetation in some areas near the west boundary of the Park, presumably protected by topography from exposure to airborne fluorides, appeared free of foliar injury, but tip necrosis was clearly visible on older needles of sensitive white pine growing in areas situated deep within the interior of the Park along the presumed frequent path of the effluent plume from the aluminum plant.

Histological examination of injured needles from conifers exhibiting tip burn symptoms showed extensive pathological changes in the needle tissue that indicate chemical etiology of the needle necrosis. These changes were not caused by insect infestation, natural disease, or winter damage.

Injury symptoms on conifers observed in 1970 in all cases were confined to the older needles - those having initial growth in 1967, 1968, and 1969. Although the current-year needles of the affected trees showed no injury symptoms, it is probable that after longer exposure times these needles will show visible injury. The extent and severity of burn on 1967 through 1969 needles strongly suggest that serious and irreparable damage to the Park flora would occur in future years with fluoride emissions at the pre-1971 level.

Assessment of foliar injury and the probable causative agent was verified by a consultant associated with the University of California Research Center at Riverside. Chemical analysis of necrotic conifer needles at the Riverside laboratory indicated significant fluoride content, which substantiated the consultant's initial conclusions that the needle tip necrosis observed on older growth of sensitive pines in Glacier National Park was produced by ambient levels of fluorides.

Plants especially sensitive to fluorides were grown for several months in enclosed exposure chambers at three sites. Chambers equipped with devices to remove particulate and gaseous fluorides were operated as controls. In other chambers, plants were exposed to unfiltered ambient air. The plants included alfalfa, apricot trees, gladiolus, and several pine species. Although test procedure difficulties and the short exposure time hampered the interpretation of results, it is evident that a greater amount of fluorides accumulated in the vegetation exposed to ambient air than in plants exposed to filtered air.

INTRODUCTION

PURPOSE OF THE STUDIES

The Anaconda Aluminum Company dedicated a new aluminum reduction plant at Columbia Falls, Montana, in August 1955. Although officials of the company asserted that injury to indigenous flora and fauna by fluorides emitted in the reduction process would be negligible, the Forest Service, U.S. Department of Agriculture, observed in 1957 that some of the more susceptible flora in the vicinity of the aluminum plant were visibly damaged. Little evaluation or research into the extent of damage was accomplished until late 1969 and 1970.

During the years between the initial observations of suspected fluoride damage and the more extensive studies, Anaconda twice expanded the plant. Following the second expansion in 1968, dead and dying trees were observed over the entire west face of Teakettle Mountain, which is directly east of the aluminum plant. In other areas around Columbia Falls, east of Teakettle Mountain, and even in areas in the southwestern part of Glacier National Park, which at its nearest point is 6 miles northeast of the aluminum plant, the flora also exhibited visible damage.

The Anaconda Aluminum Company reported that fluorides were emitted during 1969 and early 1970 at the rate of approximately 7600 pounds per day (lb/day) but that emissions were reduced to about 5000 lb/day by September 1970. By early May 1971, emissions were reported to be about 2500 lb/day.

National Park Service officials became concerned that fluoride emissions from the aluminum plant were being carried by prevailing wind currents into Glacier National Park in sufficient concentrations to harm Park ecology. In 1970 they requested the assistance of the National Air Pollution Control Administration, now a component of the U.S. Environmental Protection Agency (EPA), in assessing the effects of airborne fluorides on vegetation and wildlife in the Park.

The EPA field investigations were designed to determine the predominant patterns of movement of airborne fluorides from the aluminum plant to the Park, to measure ambient concentrations of fluorides in the Park, and to assess effects of fluorides on indigenous flora within the Park. EPA investigators were assisted by personnel of the National Park Service, the Montana State Health Department, and the University of Montana, and by a consulting horticulturist.

DESCRIPTION OF THE AREA

Geography

Glacier National Park straddles the Continental Divide from the Canadian Border to Marias Pass, 60 miles south. This section of northwestern Montana includes some of the most spectacularly rugged mountain country in North America. From peaks well above 10,000 feet, the mountains pitch down to rivers and lakes that are nearly 3,100 feet above mean sea level (MSL).

The Flathead River system, shown in an area map in Figure 1, drains the western side of the Divide and forms the Park's western boundary. This drainage area is subdivided into an "upper valley" with narrow tributary canyons and swift streams and a "lower valley" more than 15 miles wide, through which the river meanders to Flathead Lake, approximately 8 miles southeast of Kalispell, Montana. The river leaves the upper valley through Badrock Canyon, which also constitutes the south wall of Teakettle Mountain. The Anaconda aluminum plant is situated a mile down-river from Badrock Canyon between the river and the west face of Teakettle Mountain.

Although several ranches are located in the upper valley, the area is primarily Park and National Forest land, with a limited road system along the rivers. The lower valley is relatively broad and flat, with a road network that follows section and quarter-section survey lines. In addition to ranching and the ranch-related service industries, a lumber industry processes timber from the surrounding mountains and from the upper valley. Low-cost electric power has attracted some additional industry, principally the aluminum plant at Columbia Falls.

Climatology

The climate of the Flathead River drainage area may be

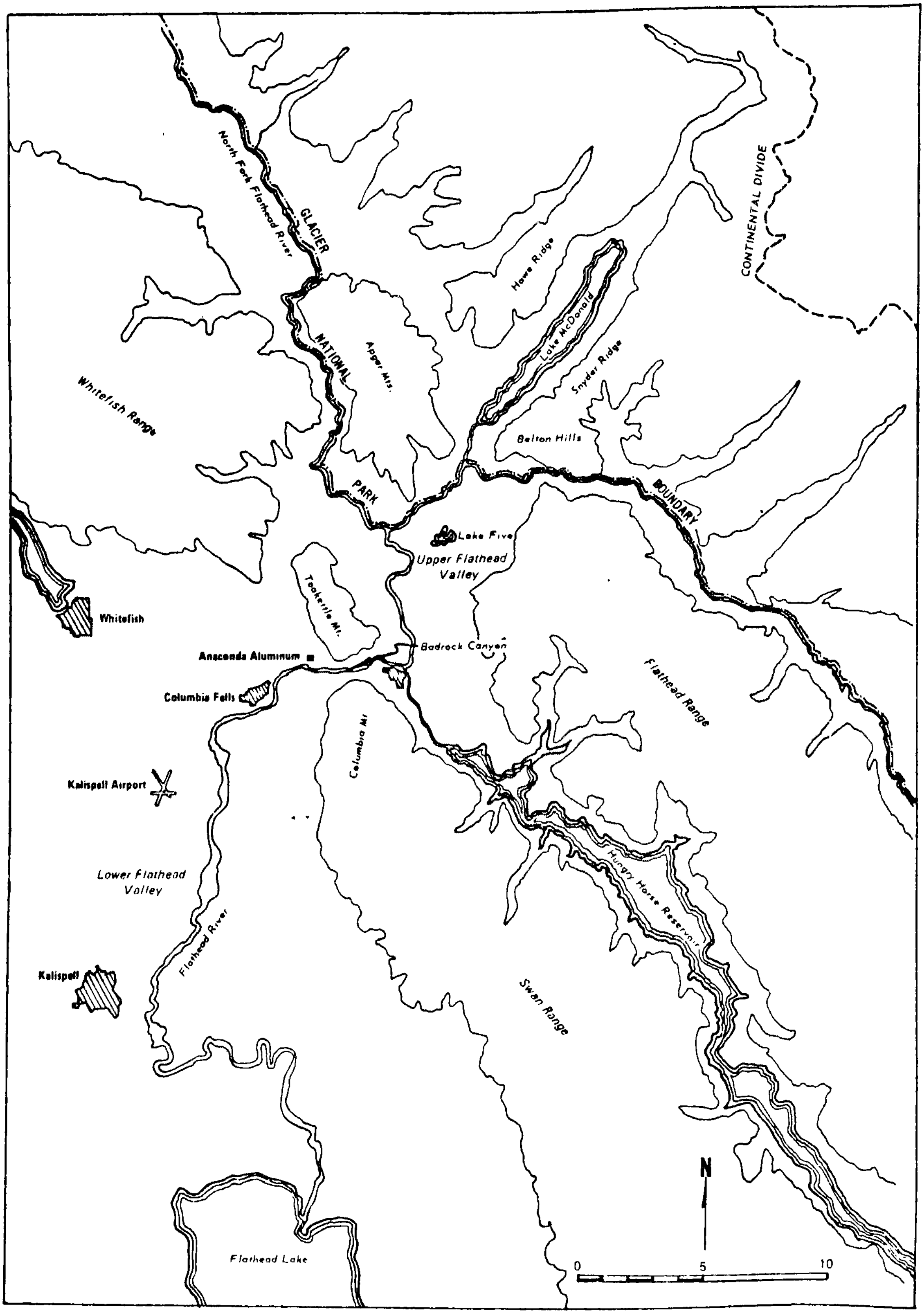

Figure 1. Orientation map showing Anaconda Aluminum Plant and the Glacier National Park area.

classed as Alpine with a strong maritime modification. The range of climate extends from that of the permanently snow-covered mountain peaks to that found along the shores of Flathead Lake, where small fruit orchards flourish in a 3-month frost-free belt.

The higher mountains receive as much as 150 inches of precipitation annually, primarily as snow, on their west-facing slopes. Snow accumulates to depths of more than 10 feet during the winter, and, although the shores of Lake McDonald (3100 feet above MSL) are snow-free by May, drifts may remain on the lower north-facing mountain slopes into August. Snow-covered glaciers are permanent features of the high slopes of some peaks.

Significant differences in temperature, precipitation, and wind flow are associated not only with elevation but also with orientation of the mountainsides, proximity of ridgelines, and location of the larger lakes. Because of its size and depth, Flathead Lake normally contains a large open water area throughout the winter. This heat source exerts a strong modifying influence on the climate of the lower valley.

Selected climatological summary data are presented in Table 1. The table includes Marias Pass because it lies at approximately the same elevation as the saddle in Teakettle Mountain and the Apgar Lookout overlooking West Glacier. Although this pass is well-removed from the area of study, its climatic data are thought to be representative of similarly

Table 1. CLIMATOLOGICAL CHARACTERISTICS OF GLACIER NATIONAL PARK REGION. (NORMALS, MEANS, AND EXTREMES BASED ON APPROXIMATELY 30 YEARS OF RECORDS.)

Station and Elevation, ft MSL	Temperature, °F				Mean No. of Days that temperature remained ≤32°F		Precipitation, inches		
	Mean Daily		Extremes of Record				All Forms, mean	Snow and Sleet	
	Max.	Min.	Max.	Min.	Max.	Min.		mean	monthly max.
			April						
Kalispell 2965	57	31	81	14	0	20	1.04	2.4	8.1
West Glacier 3145	54	30	80	3	a	21	2.00	4.5	24.0
Polebridge 3690	53	25	86	-12	a	26	1.55	4.1	24.8
Marias Pass 5213	45	23	74	-30	3	26	2.93	25.5	87.0
			July						
Kalispell	84	48	104	32	0	a	1.04	0.0	0.0
W. Glacier	80	47	98	32	0	a	1.48	T[b]	T[b]
Polebridge	81	41	101	27	0	2	1.18	0	0
Marias Pass	73	40	93	26	0	4	1.35	T[b]	T[b]
			October						
Kalispell	56	32	81	15	0	21	1.24	1.1	9.9
W. Glacier	53	33	79	15	a	16	2.57	2.0	28.0
Polebridge	55	27	85	-21	a	23	1.84	3.1	16.5
Marias Pass	49	29	82	-7	2	21	3.14	11.9	61.0
			January						
Kalispell	28	12	50	-26	17	30	1.37	20.0	34.8
W. Glacier	28	14	49	-37	18	30	2.99	36.6	74.5
Polebridge	28	7	51	-46	19	30	2.63	32.8	91.2
Marias Pass	23	7	48	-55	23	31	4.17	44.0	123.0
			Annual						
Kalispell	55	31	105	-35	52	195	15.42	67.3	49.7
W. Glacier	53	31	98	-37	53	192	29.11	134.2	74.5
Polebridge	54	25	101	-46	56	238	22.32	119.6	91.2
Marias Pass	47	25	96	-55	94	247	38.29	251.3	123.0

a Less than 12 hours
b Trace

exposed locations under study. Much of the Park area under study is, however, higher than Marias Pass and has a correspondingly shorter growing season and a more severe climate.

METEOROLOGICAL STUDY

WIND DATA

A meteorological study of air flow was performed to obtain information on principal wind trajectories in the area and their influence on transport and dispersion of air contaminants from the aluminum plant. Knowledge of the local air-flow patterns is essential for understanding the emissions problem and for evaluating data generated in the air quality and vegetation studies.

The major air-flow patterns in this mountainous area are those of the upper- and lower-level winds. The upper winds, as influenced by the major geographic features, reflect the general motion of the atmosphere near mountaintop level. Upper winds are measured periodically by free flight balloons, normally scheduled at noon and midnight Greenwich time. Since none of these balloon flights originate within the study area, the upper wind data were obtained from the National Weather Service's stations at Spokane, Washington (200 miles west of the Continental Divide) and at Great Falls, Montana (80 miles east of the Divide). No additional upper wind data were used.

The low-level wind patterns are influenced by the intersection of the upper winds with the localized mountain and valley winds, the latter often subject to pronounced changes during a day. Low-level winds may be continuously monitored by surface-mounted wind recording instruments. For this study, surface wind data recorded hourly by the National Weather Service at the Kalispell Airport (located about 8 miles southwest of Columbia Falls) were supplemented by data from wind recording instruments operated from mid-June through late December of 1970 at three sites in the area. The locations of these sites and their relationship to nearby topographical features are shown in Figure 2. Wind sensors at these sites were exposed 32 feet above ground in open pasture except at Station 3, where a 40-foot mast barely reached above the surrounding lodgepole pines.

Upper Winds

The National Weather Service obtains upper air wind measurements twice each day at Spokane, Washington, 200 miles west-southwest of the study area, and at Great Falls, Montana, 80 miles to the east-southeast. The frequencies of occurrence of wind directions for the summer months of 1961 through 1965 are shown in Table 2. At Spokane, the winds 1500 meters above mean sea level (m MSL) are predominatly from the southwest. At Great Falls, on the eastern side of the Continental Divide, the winds at 2000 m MSL are slightly stronger and more westerly.

In the absence of winds aloft data for Glacier National Park, it is difficult to define the behavior of winds at and above the general ridge level (about 2000 m MSL). Climatological values of the 700 millibar (mb) pressure heights (about 3000 m MSL) indicate that during the summer the prevailing winds should be west-southwest to southwest in the vicinity of the study area. Downward extrapolation of these winds for 1000 meters should give a more southerly component to the winds near the ridgeline because of the influence of friction nearer the ground. Although the magnitude of the direction change cannot be accurately stated because of the roughness of the terrain, a change of 10 to 20 degrees is a reasonable estimate.

The winds aloft appear to follow expected meteorological patterns on the western side of the Continental Divide. The behavior of large-scale atmospheric motions when encountering a mountain chain is discussed in most basic texts on dynamical meteorology. The usual behavior is for the winds on the down-slope side to be directed to the right of the wind direction on the upslope side. This appears to be the reason for the more frequent westerly winds at Great Falls. The magnitude of the turning is partially dependent upon wind speed. In winter, when winds are usually stronger, the winds aloft at Spokane are still predominantly from the southwest, but at Great Falls the frequencies of occurrence of west and west-northwest winds increase to 28.6 and 19.5 percent, respectively.

Lower Winds

Data obtained from the three EPA wind recording stations (Figure 2) indicate marked differences, apparently caused by the typical mountain and valley local wind-flow patterns.

Seasonal changes are also apparent. The dominant summer diurnal wind pattern at low levels is described below; variations that occur in fall, winter, and spring are mentioned briefly.

Because Station 2 was situated near the mouth of the Middle Fork River, upslope winds were most frequently registered as upstream flow. During downslope drainage situations, flow from the northwest along the Middle Fork often alternated with that from the North Fork, causing either northwest or northeast winds during much of the night. At other times, cool air drained from adjacent mountains. Dominant wind flow patterns measured during the summer of 1970 at this station are shown in Figure 3.

The persistent west wind at Station 3, shown in Figure 4, was attributed to drainage from the Bailey Lake region and to daytime channeling when southerly and westerly winds in the lower basin of the Flathead caused outflow around the north shoulder of Teakettle Mountain.

Nighttime drainage of the large area of higher country above Badrock Canyon results in very dominant northeast winds at Station 5, as depicted in Figure 5. The winds persist well into the daytime before the upslope flow from the valley to the mountains begins.

Wind patterns for the summer season at Kalispell Airport are presented in Figure 6. The frequent south and south-southeast winds are attributed to the daytime up-valley and lake effects. The frequent winds from the north through

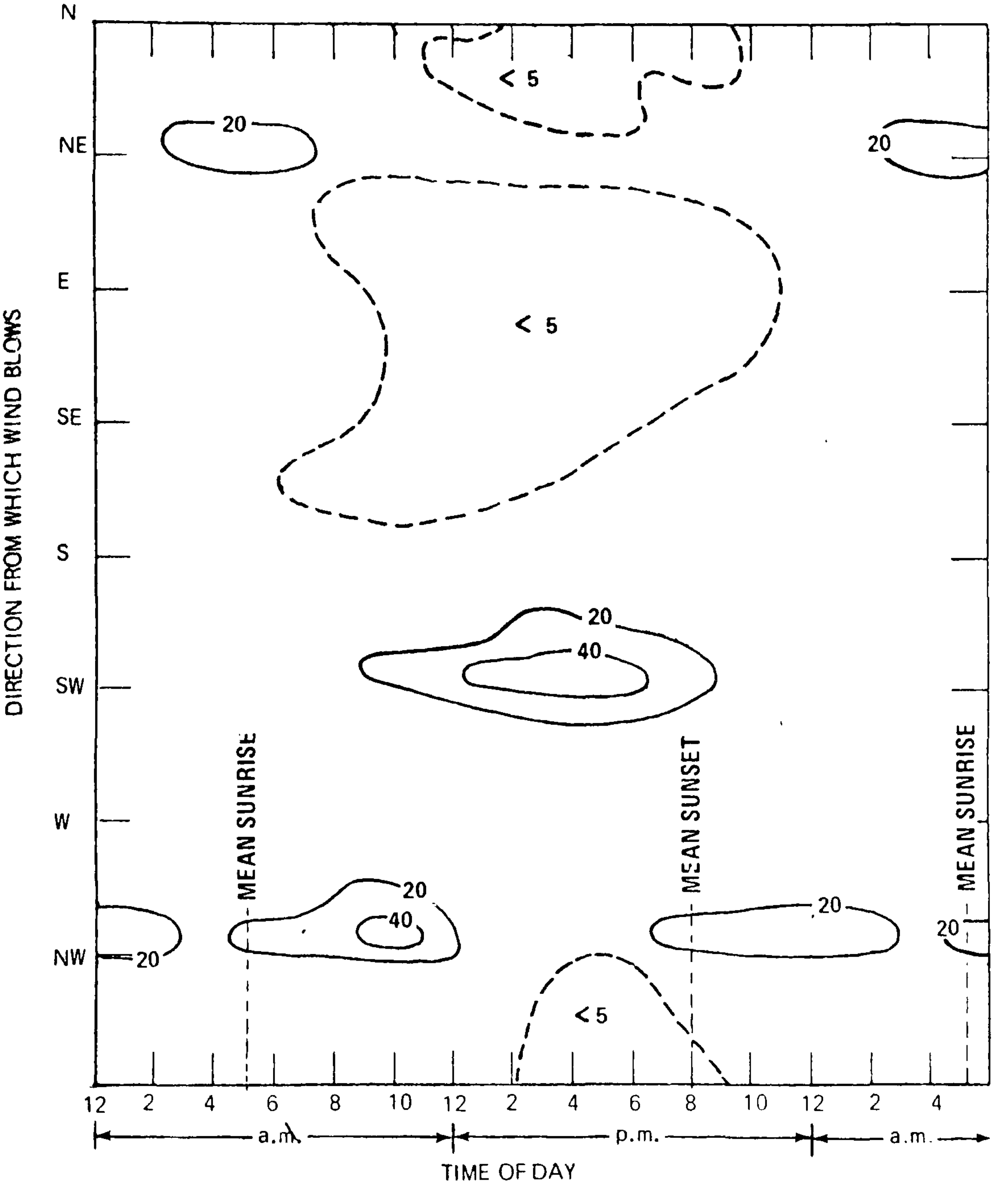

Figure 3. Dominant wind-flow patterns measured June through September, 1970 at Blankenship Station (No. 2). Isolines show percent occurrence of wind directions at indicated times.

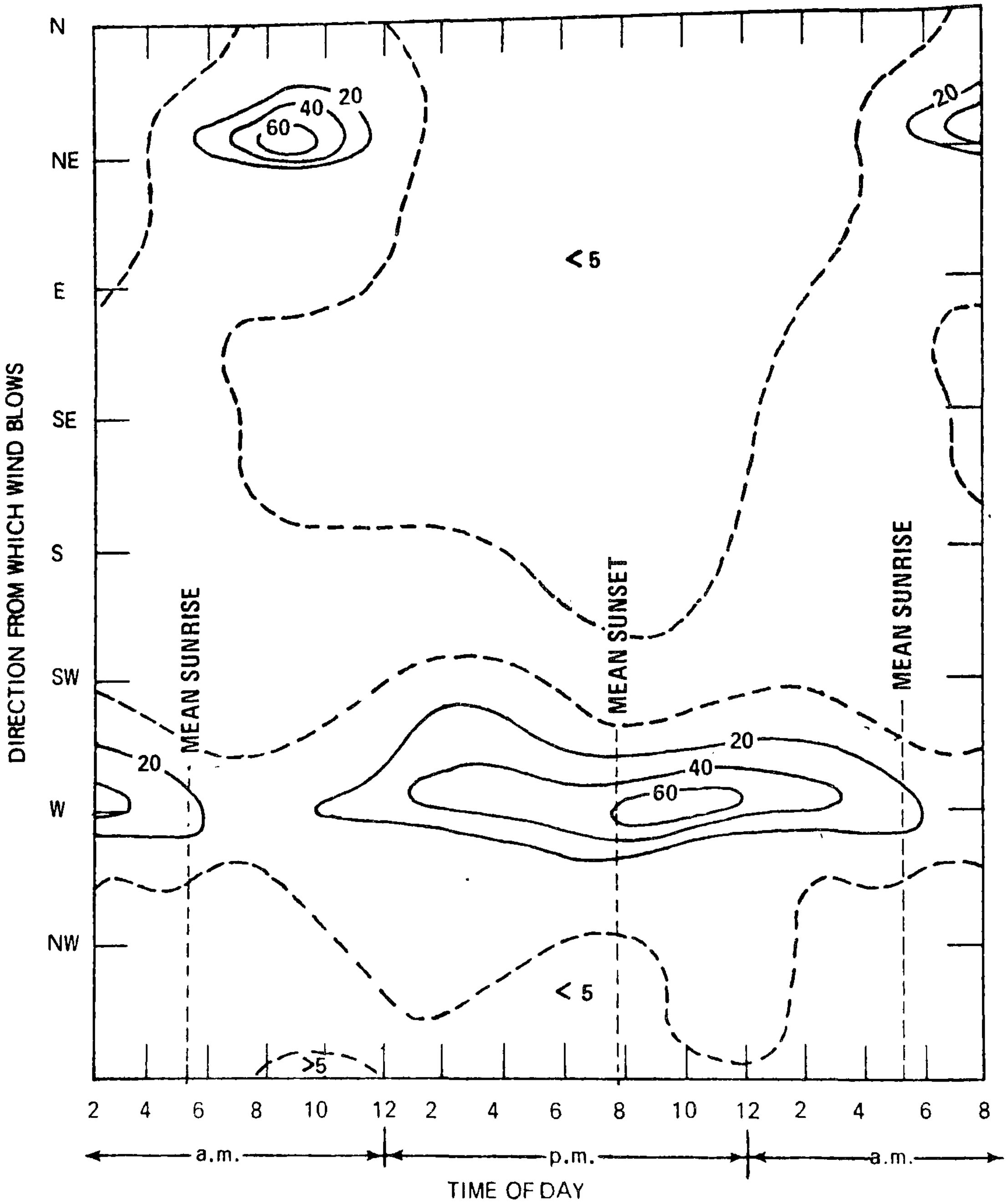

Figure 4. Dominant wind-flow patterns measured June through September, 1970 at Rose Station (No. 3). Isolines show percent occurrence of wind directions at indicated times.

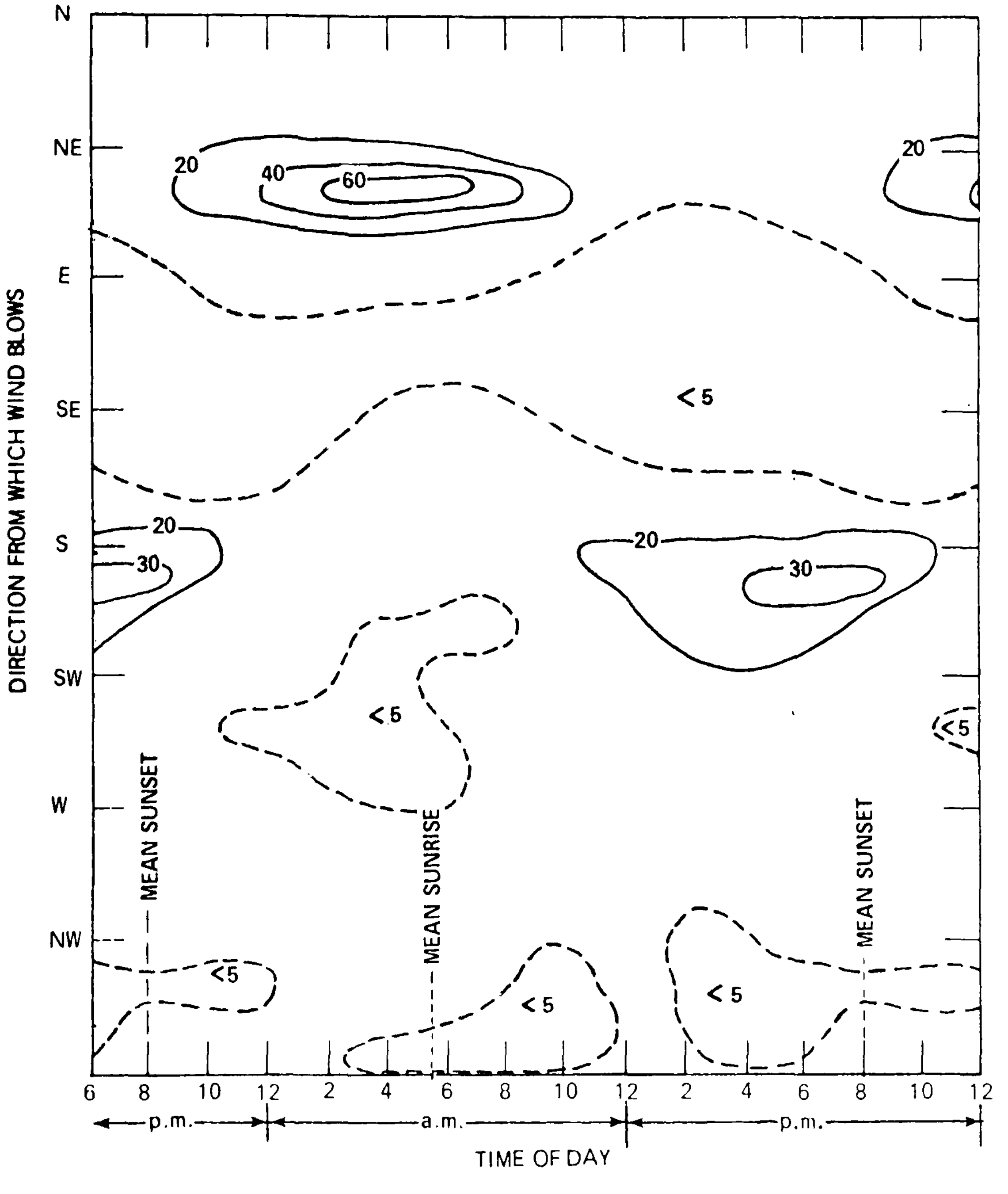

Figure 5. Dominant wind-flow patterns measured June through September, 1970 at DeMerritt Station (No. 5). Isolines show percent occurrence of wind directions at indicated times.

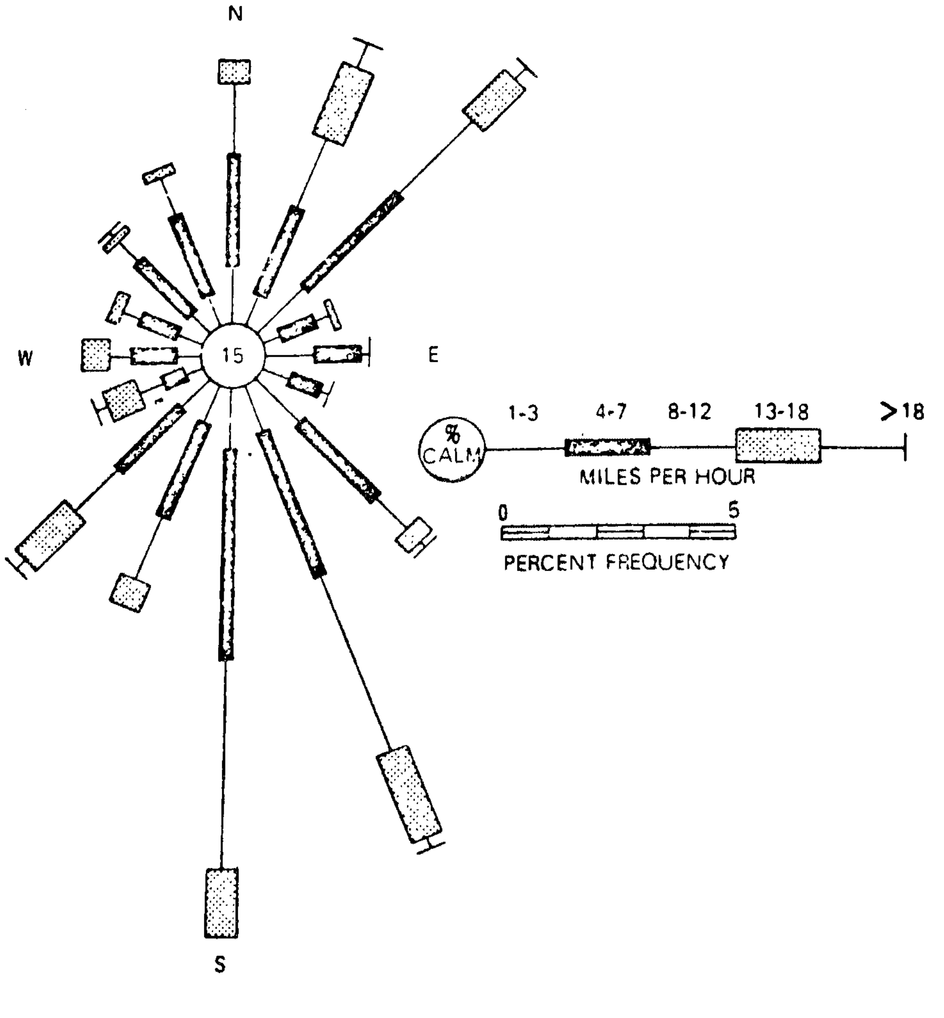

Figure 6. Wind rose for the months of June, July, and August at Kalispell, Montana (1950 through 1959).

northeast sector must be ascribed to nighttime down-valley flow toward the lake.

NIGHTTIME AIR MOVEMENTS

The lower Flathead Valley from Columbia Falls south to Flathead Lake is protected to a large extent from the winds aloft by the mountains that surround it on three sides; it is relatively open only to the south. During nights when radiational cooling at ground level is effective, the air near the ground cools rapidly, becomes more dense, and begins to flow along the ground toward lower elevations. Effluents emitted from industrial operations are warm and rise until they are no longer buoyant but remain below the crest of the confining mountains.

The air from the upper valley drains through Badrock Canyon and passes Station 5 as a northeasterly wind. This down-valley wind becomes apparent at 10:00 p.m., reaches a maximum frequency of 67 percent near sunrise, and usually dissipates shortly after noon. The same air current is apparent at the airport, where it is more diffuse and northerly because of the inclusion of additional air currents as it spreads over the flat valley floor to Flathead Lake.

DAYTIME AIR MOVEMENTS

At sunrise the west sides of both the upper and lower valleys, with their east-facing slopes are warmed rapidly; the opposite valley walls, which remain in deep shadow, are cool. As vertical currents develop over sun-heated slopes, cooler replacement air from the down-valley flow is entrained and wind directions consequently shift.

As direct sunshine progresses onto the broad lower valley floor, the related developing vertical currents progress upward into the blanket of stagnant air that accumulated during the night and mix the air downward to the surface as well as upward. Mixing continues to deepen until the mountaintop levels are reached and the valley air begins to be entrained by the prevailing upper winds.

The shift of wind direction toward the slopes heated by the early morning sun is most striking at Station 3. This northeasterly wind appears to blow from the shaded side of the Apgar Mountains to the sunny side of Teakettle Mountain between the hours of 7:00 a.m. and 1:00 p.m., exceeding 60 percent frequency from about 8:00 a.m. to about 10:00 a.m. during the 1970 period depicted in Figure 4. During the morning, this flow of clean air into the upper valley shields the east face of Teakettle from effluents being carried aloft.

Up-valley wind flow develops about mid-day, and the mixing layer deepens until air from above the top of Teakettle is mixed with surface air throughout the upper valley during much of the afternoon. By this time, the nighttime stagnant air has already been carried away from the lower valley by the prevailing winds, and only the current emissions are mixed through the deep layer of air to the surface in the upper valley so that the higher concentrations do not reach the floor of the upper valley.

The overall wind pattern when upper winds are from the southwest and the lower valley convection has broken through into the upper flow is shown pictorially in Figure 7. The viewer looks to the northeast across Teakettle Mountain and the upper Flathead Valley to Lake McDonald. Direct sunshine has not penetrated the valleys in sufficient strength by mid-morning to reverse the down-valley winds along the river although upslope flow exists on the sunny, east-facing slopes and the down-valley flow has turned somewhat toward these slopes. In the upper valley beyond Teakettle Mountain, the clean air flowing down along the rivers shields the surface from fluoride-laden air entrained in the upper-level winds. This is the preponderant mid-morning wind pattern during the summer.

On days when southwest upper winds prevail, the day's highest concentrations of fluoride are carried into the Park during the forenoon. At sunrise the previous night's accumulation of plant effluents together with the current emissions are held within the lower valley and mixed in a deepening layer until this layer reaches and is entrained by the upper flow. The lower valley effluents are then carried in the upper flow over the upper valley and into the Park, where they intercept terrain elements common to the height of the effluent plume. As convective activity increases, the air mass undergoes more complete mixing to higher levels of the atmosphere

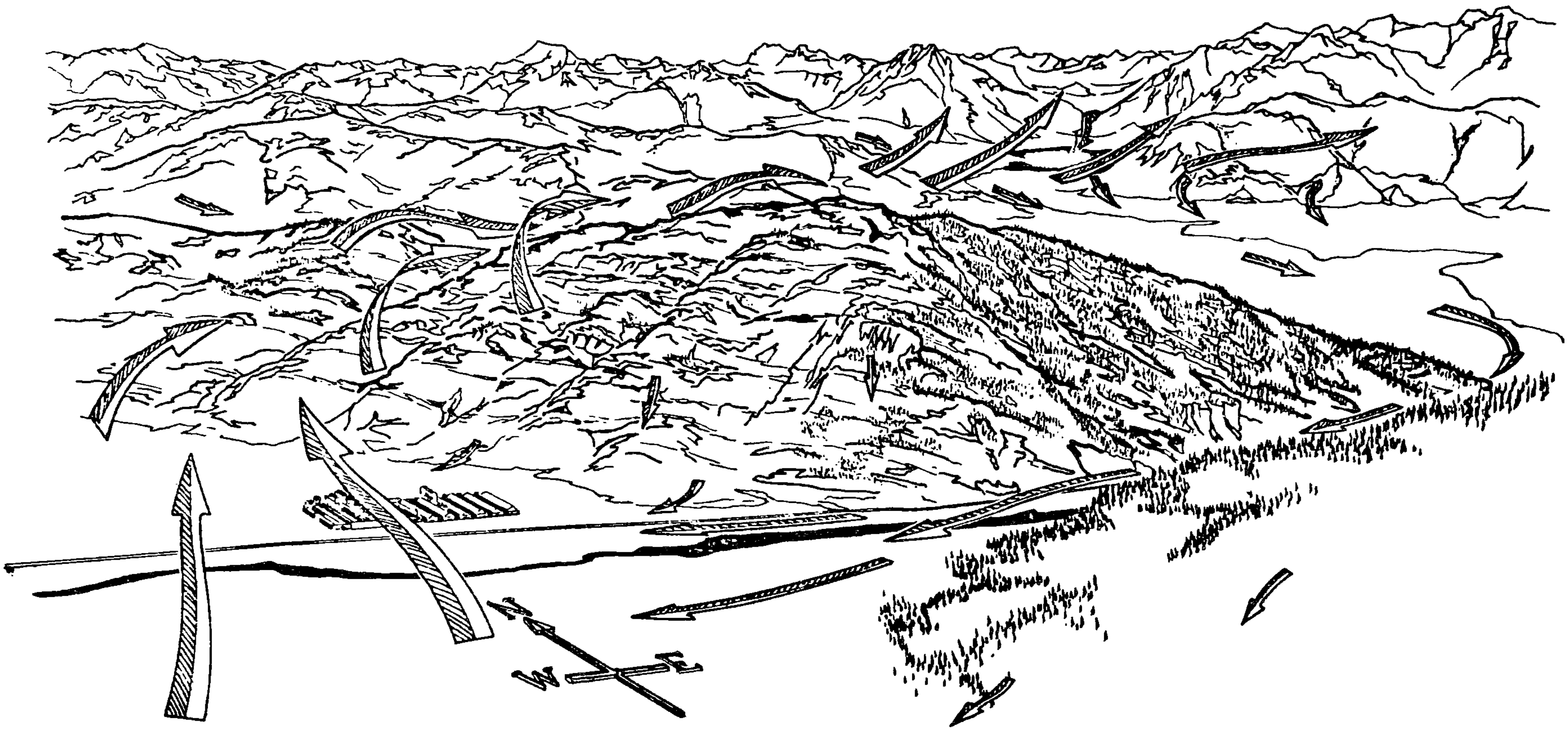

Figure 7. Simplified drawing of typical midmorning wind-flow patterns in upper Flathead Valley.

and the remaining effluents are diluted.

With the increase in surface heating, the typical up-valley wind pattern develops in both the upper and the lower valleys, augmented by a lake-to-land breeze from Flathead Lake.

SEASONAL CHANGES

The southwest through west-southwest daytime winds above Teakettle Mountain are of major importance, because they apparently carry effluents from the aluminum plant at Columbia Falls to the Park. Frequencies of these transport winds are estimated as follows from considerations presented in the earlier section on Upper Winds:

SW-WSW DAYTIME WINDS, TEAKETTLE MOUNTAIN

Summer		Fall		Winter		Spring	
Frequency, %	Average speed, mph	Frequency, %	Average speed, mph	Frequency, %	Average speed, mph	Frequency, %	Average speed, mph
47	17	40	24	46	28	41	25

The highest frequency of wind direction that would carry effluents into the Park, and also the lowest average wind speed, occur in summer. Both factors would lead to relatively high fluoride levels at receptors. Because the winds tend to blow toward the Park during daylight hours, the longer summer days, which average 15.2 hours between sunrise and sunset, increase the amount of time that emissions are carried into the Park.

An effort was made to estimate the relative seasonal impact of the aluminum plant on the Park. Qualitative dispersion estimates were performed assuming constant fluoride emission rate and diffusion parameters for the four seasons. Calculating on the basis of seasonal wind direction frequency, average wind speed, and duration of sunlight, the relative impact in summer was equated to 100, with corresponding values of 43 for fall, 38 for winter, and 54 for spring. The calculations, however, did not consider the impact of accumulated pollutants transported into the Park as a result of the local wind-stability pattern discussed earlier. The most conducive conditions for development of this local pattern are generally light wind flow together with essentially cloudless skies, conditions that normally are most frequent in late summer through early fall. These considerations suggest that the potential for damage by fluorides within the Park is greatest in summer through early fall.

REPRESENTATIVENESS OF STUDY PERIOD

Climatic records for 1970 from the Kalispell Airport, which is 8 miles southwest of the aluminum plant, have been compared with the 30-year mean. April 1970 in the Glacier area appears to have been rather cool and dry with strong surface winds, while the following 3 months were slightly warmer and wetter than normal. The fall months were again somewhat cooler and drier than their "normal" counterparts. Since these were not major deviations from the normal weather pattern, the data for 1970 can be considered representative of normal years.

Vegetation growth may have been somewhat better than normal because of the relatively warm, wet summer.

AIR QUALITY STUDY

Two basic types of measurements are used to detect atmospheric fluorides. One, obtained by impaction of air on a chemically treated surface, indicates fluoridation rate or 'dosage,' given as μg F/cm^2-day. The other gives concentration of fluoride in air by volume, that is, μg F/m^3. For convenience of reference, the first method is designated as an 'impact' method and the second as a 'volumetric' method. The impact measurements are obtained by exposing chemically treated filter paper to the air in the test area. The inexpensive impact samplers are readily located at different sites and are useful in delineating spatial distribution of fluoride pollution. Since the amount of gaseous fluoride taken up by the treated paper surface correlated reasonably well with the amount of fluoride accumulated in vegetation during the same time interval, the fluoride 'dosage' rate data provided by this method are useful indicators of potential long-term or chronic fluoride damage to vegetation.

The volumetric concentration measurements are made with a sequential sampler that is capable of separating gaseous and particulate fluorides. Since this type of measurement requires electric power, the volumetric measurements were limited to a few sites where power was available.

IMPACT MEASUREMENTS

Thirty-six sites for impact sampling were established throughout the study area within a radius of 20 miles from the aluminum plant. These sites were arranged so that a representative geographical distribution of fluoride levels in the study area might be ascertained. Site locations are shown in Figure 8.

The sampling devices used by EPA differ from standard limed paper used by the Montana State Health Department in that filter paper circles are impregnated with sodium formate reagent whereas the Montana standard limed paper uses calcium formate. The methods of exposing these devices to fluorides also differed. The EPA fluoridation plates were placed in brackets and attached to posts, utility poles, or trees with the exposed side facing downward. The State of Montana exposed the standard limed paper monitors in louvered shelters that allowed the air to contact both sides of the paper.

At some of the EPA stations, more than one plate was exposed as a check on reproducibility of results. Since the EPA plate configuration differed from the standard limed paper and exposure shelter used by the State of Montana, fluoridation rates were measured at four sites with both types of devices to allow correlation of readings given by the two methods. The plates and limed papers were exposed for monthly intervals and returned to the laboratory for analysis.

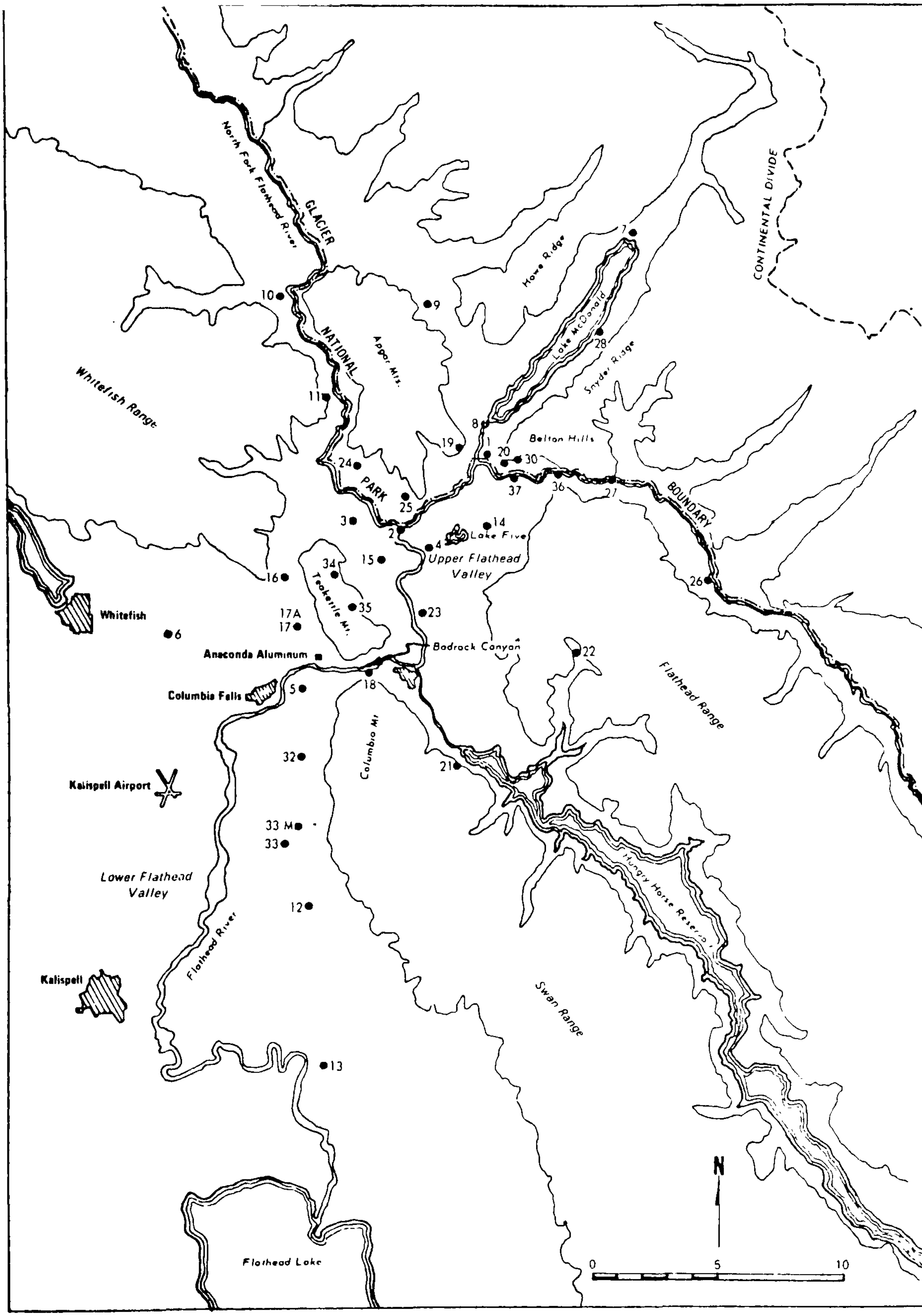

Figure 8. Location of fluoridation plate exposure sites.

Fluoridation rates obtained in the study area from July through November 1970 are shown in Table 3. Information on each site, including elevation, is presented in Table 4.

The significance of the fluoridation measurements in assessing the potential for fluoride contamination of the Park is best shown by graphic display of the spacial patterns. The geographical distribution of the average monthly fluoridation rates in ng F/cm^2-day over the 5-month period is shown in Figure 9. Such isopleths are obtained by plotting points of constant fluoride level based on the available data and joining these points with smooth-curved contours. A significant degree of judgment is involved in such construction because sampling data do not represent the entire area. A further complication is caused by the uneven mountainous terrain. In spite of these difficulties, the values clearly decreased as distance from the aluminum plant increased, except in the northeast quadrant where the influence of prevailing wind patterns and higher ground elevations in the Park caused the fluoridation pattern to be displaced and elongated.

Although there was no volumetric monitoring station atop Teakettle Mountain, results from the several impact sampling stations on this mountain indicate a trend of higher fluoride concentrations with increasing elevation. For instance, at site 35 on Teakettle and at site 19 on Apgar Mountain, where high values of fluorides were recorded, the plates were at a higher elevation than those at any of the other exposure sites.

Table 3. MONTHLY FLUORIDATION RATES MEASURED WITH EPA PLATES

Site number	Fluoridation rate, ng F/cm²-day					
	July	August	September	October	November	Average monthly rate
1[a]	11[b]	13[b]	9[b]	10[b]	10[b]	11
2[a]	14[b]	13[b]	20[b]	11[b]	13[b]	14
3[a]	10[b]	10[b]	10[b]	4[b]	6[b]	8
4[a]	15[b]	23[b]	11[b]	12[b]	13[b]	15
5	29	30	32	16		27
6	15	10[b]	7[b]	4[b]		9
7[a]	14	9	8	7		10
8[a]	15	8	7	6	8	9
9[a]	10	5	4	4		6
10	9	5	4	2		5
11	9	8	3	2		6
12	7		3	2		4
13	10		4	4		6
14	13	12	9	5	6	9
15	17	19	14[b]	9[b]	10[b]	14
16	12	12	6[b]	5[b]		9
17	38	83[b]	43[b]	43[b]	23[b]	46
18	23	30[b]	21[b]	25[b]	37[b]	27
19[a]	20	29	48	22		30
20[a]	13	16	8	5	5	9
21	10	4[b]	5[b]	4[b]		6
22	8	5[b]	5[b]	3[b]		5
23	13	18[b]	13[b]	8[b]	16[b]	14
24[a]	9	8	5	3		6
25[a]	24	24[b]	26[b]	11[b]	18[b]	21
26	10	7[b]	6[b]	4[b]		7
27	6	7[b]	6[b]	4[b]	8[b]	6
28[a]	10	6	5	3		6
30[a]				8	8[b]	8
32		15[b]	9[b]	10		12
33		6[b]	5[b]	4[b]		5
33M		6[b]	5[b]	4[b]		5
34		37	41			39
35			50[b]	91[b]		71
36					9	9
37[a]					9	9

[a]Exposure sites located in or near Glacier Park.

[b]Value is average of two or more duplicate readings.

Table 4. LOCATION AND ELEVATION OF FLUORIDATION NETWORK SITES IN AND NEAR GLACIER NATIONAL PARK

Site number	Elevation above mean sea level, feet	Location
1	3150	Glacier Park; near Fire Weather Station
2	3100	Blankenship Ranch
3	3200	Rose Ranch
4	3250	Near railroad and Blankenship Road crossing
5	3040	DeMerritt Property
6	3000	Northeast of Whitefish
7	3145	Upper Lake McDonald; at Ranger Station
8	3145	Lower Lake McDonald; near Apgar
9	3800	Camas Creek Road; on trail to Huckeberry Mountain
10	3350	North Fork Road; near Big Creek Ranger Station
11	3500	North Fork Road; 5 miles north of Station 3
12	2993	Northwest end of Lake Blaine
13	2900	South of Creston; along Highway 35
14	3250	Highway 2; 2 miles south of Park headquarters
15	3400	East side of Teakettle Mountain
16	3320	North Ford Road; near Turnbull Creek turnoff
17	3100	Dehlbom Property
18	3050	Badrock Canyon
19	5200	Apgar Lookout
20	3150	Park Headquarters
21	3580	Vicinity of Hungry Horse Dam
22	4200	Emery Hill
23	3150	Coram
24	3400	Boehm's Bear Den
25	3280	Base of Apgar ridge
26	3400	Red Eagle; near Nyack
27	3260	Kootenai Creek; east of West Glacier
28	3145	Southeast side of Lake McDonald
30	3400	Hill above Park Headquarters
32	3070	North of Morning Slough Lake
33	3050	South of Morning Slough Lake
33	3050	Southeast of Morning Slough Lake
34	3920	Teakettle Mountain; 3 miles north of Relay Tower
35	4200	Teakettle Mountain, 1.5 miles north of Relay Tower
36	3400	Hill near gravel pit, on Highway 2
37	3250	Hill above Park Headquarters; 150 feet below site 30

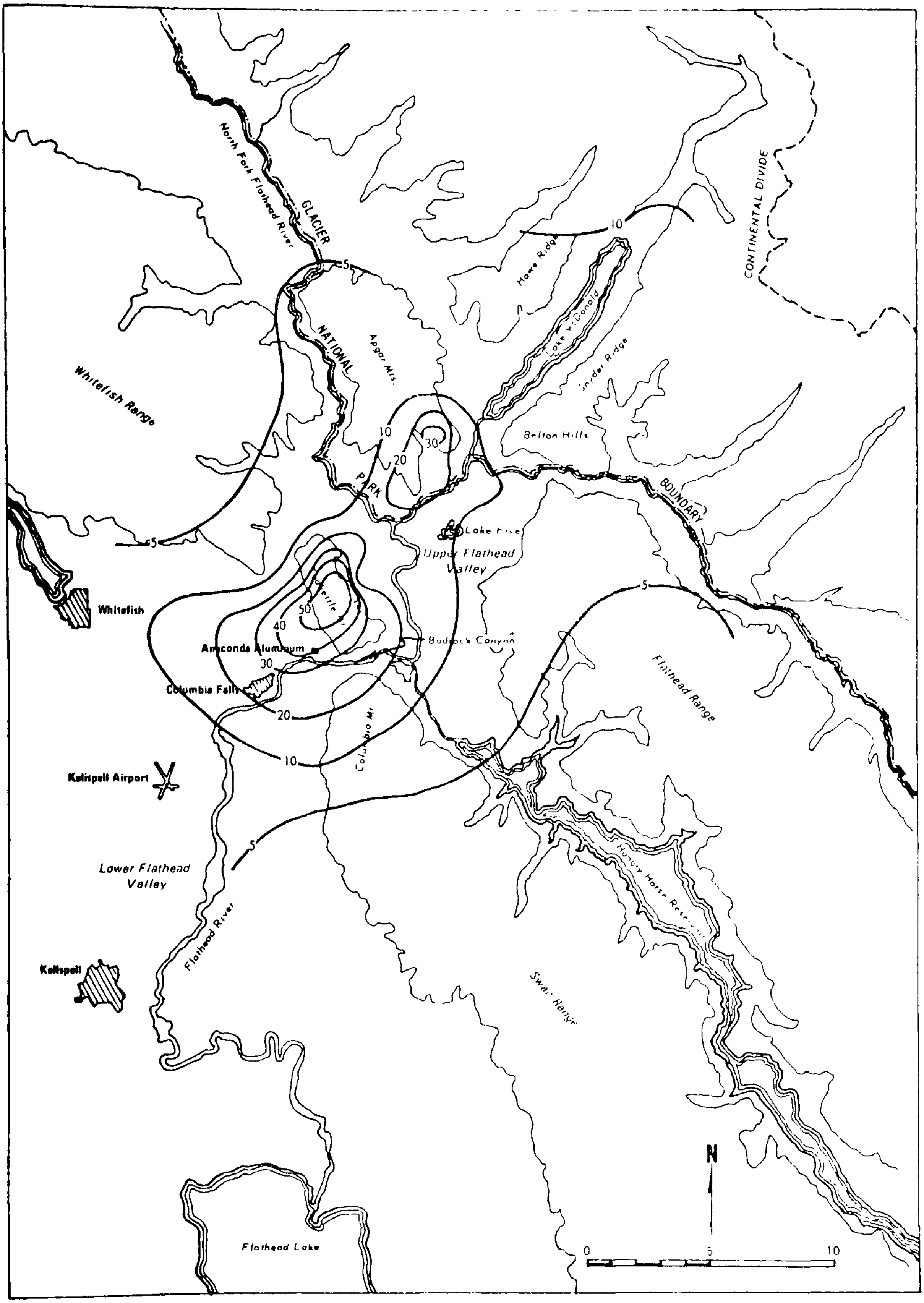

Figure 9. Distribution of average monthly fluoridation rates. (Isoline values in ng F/cm^2-day)

Thus, the primary area of high fluoridation values appears about 1 to 2 miles northeast of the aluminum plant on Teakettle Mountain, and the values increase with increasing elevation of the sampler. A secondary area of high fluoridation values appears on the upper slopes of Apgar Mountain, 10 miles from the plant.

Correlation of Data: Plate and Limed Paper Methods

The Montana State Health Department has adopted ambient air quality standard (0.30 μg F/cm^2-28 day) for fluoride based on the measurement by the calcium formate (limed) paper method. The Montana State air pollution control regulations include specifications for preparation, exposure, and analysis of the paper. Although the plate method used by EPA differs from the method used by the State, the readings provided by the two methods can be correlated.

Limed (calcium formate) papers were exposed in louvered shelters of the type normally used by the State at the four stations (shown in Figure 10) at which the EPA investigators measured ambient fluoride concentrations both volumetrically and by the plate method. Duplicate sets of limed papers were exposed for calendar-month intervals and were returned to the State laboratory for analysis. Analytical data furnished by the State laboratory are given in Table 5 with data obtained in analysis of the EPA plates, which were exposed at the same sites for the same period of time. Fluoridation rates obtained by both methods are expressed in units used by the State, μg F/cm^2-28 day.

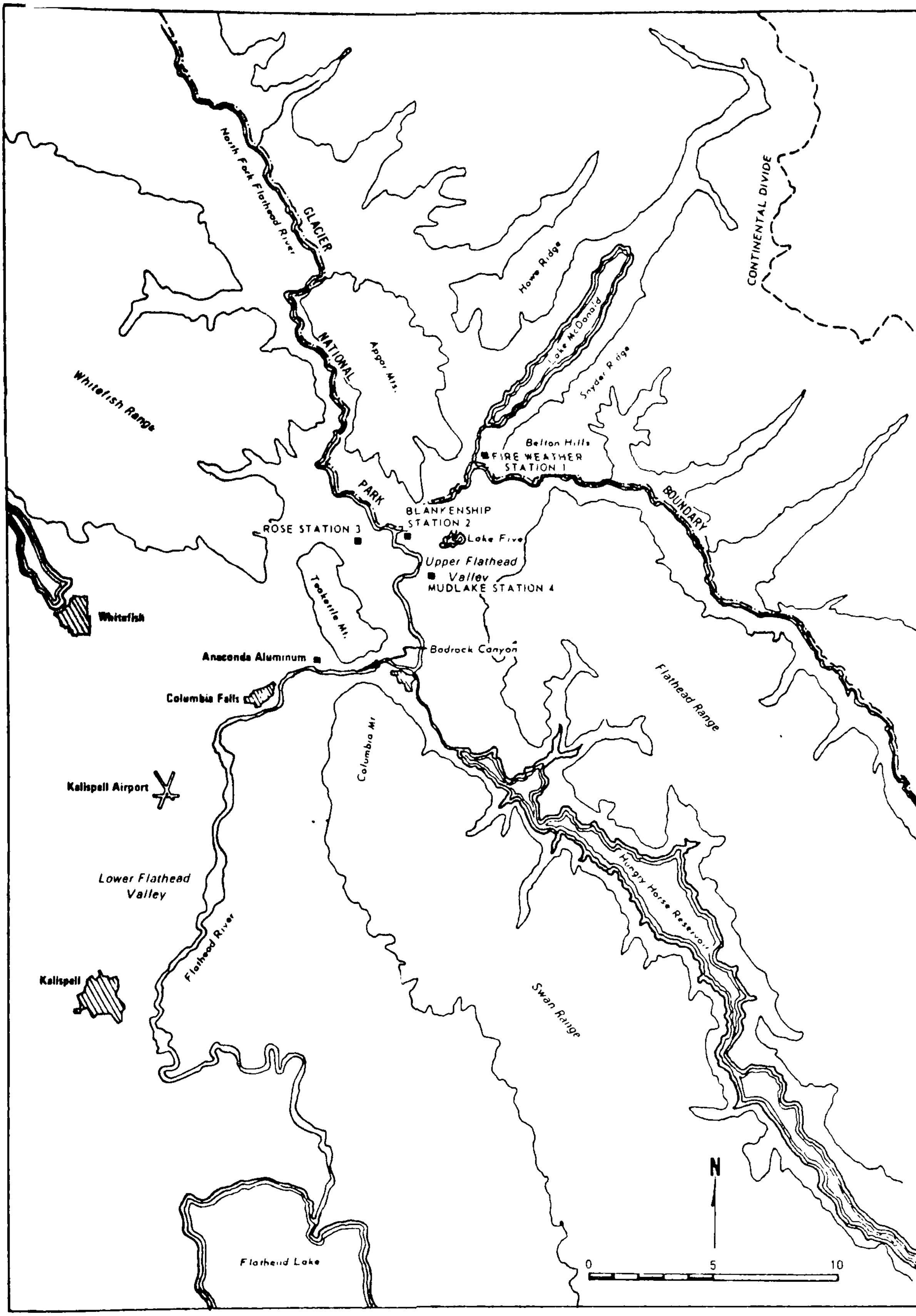

Figure 10. Location of volumetric fluoride monitoring stations and plant exposure shelters.

Table 5. COMPARISON OF FLUORIDATION RATES MEASURED BY EPA PLATE AND MONTANA LIMED PAPER METHODS[a]

Sample period[b]	Station number[c]	Fluoridation rate, μg F/cm²-28 day		Ratio: paper/ plate
		Plate	Limed paper	
July	1	0.31	0.23	0.74
	2	0.39	0.22	0.56
	3	0.28	0.25	0.89
	4	0.42	0.45	1.07
September	1	0.25	0.17	0.67
	2	0.56	0.23	0.41
	3	0.28	0.11	0.39
	4	0.31	0.24	0.77
October	1	0.28	0.13	0.46
	2	0.31	0.14	0.45
	3	0.11	0.09	0.81
	4	0.34	0.21	0.61
November	1	0.28	0.17	0.60
	2	0.36	0.22	0.61
	4	0.36	0.23	0.63
	25	0.50	0.42	0.84
December	2	----	0.26	----
	4	0.47	0.38	0.80
	25	0.67	0.62	0.92

[a] Data on limed paper measurements supplied by Montana State Health Department.

[b] Limed papers for August were lost in transit.

[c] All stations are located in Glacier National Park or near the Park boundary.

Comparison of values for the 5-month period disclosed that those obtained by the plate method consistently averaged about one-third higher than those obtained by the limed paper method. Although other factors may contribute to the higher fluoridation values given by the plates, one explanation for the difference is the method of exposure. The plate configuration exposes the filter paper more openly to the atmosphere, whereas the louvered shelter used by the State may restrict air flow around the limed papers and offer less ventilation. Statistical analysis of the two sets of data indicates that the fluoridation rates given by the plates should be multiplied by a factor of 0.68 for comparability with rates given by limed paper. The fluoridation rates obtained at all of the EPA stations (Table 3) were multiplied by this factor and adjusted to a 28-day rate to provide the monthly fluoridation rates shown in Table 6.

These results show that the average fluoridation rates measured at four of the fifteen stations located in or near Glacier Park approach or exceed the State standard. The average value for site 19 on Apgar Mountain exceeds the standards by a factor of nearly 2. All the monthly readings obtained during the study at this site were above the State standard.

Applying the correlation factor of 0.68 and the adjustment for the 28-day exposure to the projected distribution patterns shown in Figure 9 suggests that much of the area within the

Table 6. CONVERSION OF FLUORIDATION RATES MEASURED BY PLATE METHOD[a] TO EQUIVALENT STATE OF MONTANA VALUES

Station number	Equivalent fluoridation rate, μg F/cm^2-day		
	Minimum	Maximum	Average
1[b]	0.17	0.25	0.21
2[b]	0.21	0.38	0.27
3[b]	0.08	0.19	0.15
4[b]	0.21	0.44	0.29
5	0.30	0.61	0.51
6	0.08	0.29	0.17
7[b]	0.13	0.27	0.19
8[b]	0.11	0.29	0.17
9[b]	0.08	0.19	0.11
10	0.04	0.17	0.10
11	0.04	0.17	0.11
12	0.04	0.13	0.08
13	0.08	0.19	0.11
14	0.10	0.25	0.17
15	0.17	0.36	0.27
16	0.10	0.23	0.17
17	0.44	1.58	0.88
18	0.40	0.70	0.51
19[b]	0.38	0.91	0.57
20[b]	0.10	0.30	0.17
21	0.08	0.19	0.11
22	0.06	0.15	0.10
23	0.15	0.34	0.27
24[b]	0.06	0.17	0.11
25[b]	0.21	0.50	0.40
26	0.08	0.19	0.13
27	0.08	0.15	0.11
28[b]	0.06	0.19	0.11
30[b]	0.15	0.15	0.15
32	0.17	0.29	0.23
33	0.08	0.11	0.10
33M	0.08	0.11	0.10
34	0.70	0.78	0.74
35	0.95	1.73	1.35
36[b]			0.17[c]
37[b]			0.17[c]

[a]Rates from Table 2.

[b]Stations located in or near Glacier National Park.

[c]Based on one month's data.

20 μg F/cm^2-day isoconcentration lines is subjected to long-term fluoride contamination in excess of the State standard. This includes nearly all of the higher elevations within the realm of influence of the aluminum plant emissions.

In summary, the impact monitoring devices proved to be extremely useful in defining areas of high fluoride concentration. Fluoridation plates or limed papers can be readily exposed at sites in the most inaccessible areas of the Park and surrounding territory and thus can provide surveillance not obtainable by other measurement methods.

VOLUMETRIC MEASUREMENTS

Volumetric measurements of gaseous and particulate fluoride concentrations were made at four locations from June 26 to October 23, 1970. The monitoring stations were located near the Park boundary from 7 to 11 miles in a northeasterly direction from the aluminum plant, as shown in Figure 10. Availability of electric power and nearness to the Park determined location of the stations.

Atmospheric samples were collected over 12-hour intervals with a sequential sampler capable of separating gaseous and particulate fluorides. Gaseous fluorides in the air samples were selectively absorbed on bicarbonate-coated glass tubes. After removal of the gaseous fluoride component, the particulate fluoride component was collected on a chemically treated filter mounted on the outlet end of the tube. The glass tubes and filters were returned to an EPA laboratory for analysis. The gaseous and particulate sample components were measured using a specific fluoride electrode.*

A timer built into the sampler allowed continuous collection of 12-hour samples from 9 a.m. to 9 p.m. (daytime) and from 9 p.m. to 9 a.m. (nighttime). Samples adequate for analysis were obtained approximately 70 percent of the time that the samplers were operated.

Average concentrations (μg F/m^3) of gaseous and particulate fluorides measured at each of the four stations are summarized in Table 7. Tabulations of the raw data are given in the appendix.

The average daily (calendar day) gaseous fluoride concentrations recorded at the four stations in or near the Park (Stations 1 through 4) ranged from 0.06 to 0.10 μg F/m^3 during the 4-month period. A maximum daily average concentration of 0.66 μg F/m^3 (0.83 ppb)+ was measured at Station 2 (Blankenship). During one 24-hour period spanning two calendar days, however, the average exceeded the State standard (0.8 μg F/m^3): the average at Blankenship from 9 a.m. September 5 to 9 a.m. September 6 was 0.88 μg F/m^3.

Gaseous concentrations made up about one-third to one-half of the total fluoride measured at each station. At all but one of the stations (Station 3), 12-hour gaseous fluoride levels were nearly twice as high during the day as they were

* Anal. Chem. 40 (11): 1658-1661. September 1968.
+ Based on conversion factor of 1 part per billion = 0.8 μg F/m^3.

Table 7. SUMMARY OF 12-HOUR GASEOUS AND PARTICULATE FLUORIDE CONCENTRATIONS MEASURED IN GLACIER NATIONAL PARK AND SURROUNDING AREA, JUNE 26 to OCTOBER 23, 1970

($\mu g\ F/m^3$)

Station	Fluoride component	Daytime		Nighttime		24-hour[a]	
		Maximum	Average	Maximum	Average	Maximum	Average
1	Gaseous	0.34	0.09	0.25	0.05	0.25	0.07
	particulate	0.84	0.18	1.18	0.13	0.91	0.15
2	Gaseous	0.65	0.12	1.02	0.07	0.66	0.10
	particulate	0.73	0.22	0.98	0.12	0.64	0.17
3	Gaseous	0.16	0.06	0.12	0.06	0.14	0.06
	particulate	0.51	0.12	0.32	0.11	0.36	0.12
4	Gaseous	0.48	0.14	0.20	0.06	0.28	0.10
	particulate	1.12	0.27	1.33	0.17	0.84	0.21
17[b]	Gaseous	3.65	0.48	1.05	0.18	2.11	0.33
	particulate	2.70	0.79	2.41	0.55	1.57	0.65

[a] Average of daytime and nighttime values.

[b] Special sampling station operated from August 17 to October 21, 1971 at Dehlbom residence about 1.5 miles north of the aluminum plant.

at night. The difference in air-flow patterns during daytime and nighttime is thought to account for the higher concentrations of gaseous and particulate fluorides during the day.

A tendency toward higher maximum concentrations was observed at Stations 2 and 4. Stations 2 and 4 are nearer the aluminum plant and are in line with the predominant air flow from the plant toward Lake McDonald. Station 3, at which the lowest values were consistently recorded, is located toward the North Fork and is evidently largely bypassed by plumes from the plant.

Midway through the study, sampling was discontinued at Station 3 and the air sampler was moved to a special sampling site in the vicinity of Columbia Falls (Dehlbom). Data from this station, designated 17, are included in Table 7. The fluoride levels recorded at Station 17 are markedly greater than the levels recorded at the other volumetric sampling locations. The tabulation of fluoridation rates in Table 3, however, lists values obtained at Station 19 on Apgar Mountain that are in the same range as values measured at Station 17 by impact sampling. This suggests that long-term and probably short-term fluoride exposures at various sites in the Park may occasionally approach or exceed the levels encountered at Station 17 located near the aluminum plant.

VEGETATION STUDIES

Phytotoxicity of airborne gaseous fluoride is well documented in the literature. Fluoride is an accumulative toxicant, and development of plant injury is usually associated with fluoride buildup in the leaf over a relatively long period in contrast to short-time exposure that normally causes injury with most atmospheric phototoxicants. Also, the fluoride ion is relatively stable in contrast to many pollutants that break down or change chemically within the leaf. Leaves on the same plant can differ considerably in fluoride content because leaves differ in age or exposure time.

Since deciduous plants lose their leaves annually, there is no opportunity for buildup of fluorides in the trees from one year to the next. Conifers, however, retain their needles and can accumulate fluorides over a longer period of time.

A wide variation in sensitivity is recognized; some species may accumulate in excess of 100 parts per million (ppm) on a dry weight basis without displaying any symptoms of injury, whereas other species may develop extensive areas of dead tissue when much less fluoride has been accumulated. It is generally accepted that fluoride concentrations in plants up to 10 ppm may be considered normal occurrence and that some plants, particularly those closely related to tea, may accumulate much larger amounts in the absence of atmospheric contaminants. In a plant community such as that found in Glacier National Park, concentrations exceeding 10 ppm in grasses and pine needles are probably associated with atmospheric contamination.

In July 1969, prior to the 1970 study period, an EPA botanist investigated vegetation in the Columbia Falls area for possible damage from fluoride. Characteristic tip damage and margin burn were found on pine, apple, and willow trees and on gladiolus. Chemical analyses, shown in Table 8, indicated that the vegetation tissue was contaminated by fluorides.

During the 1970 study period indigenous vegetation was examined for visible damage, fluoride chemical composition, and histological damage. In addition studies were performed with selected vegetation grown under controlled conditions.

INDIGENOUS VEGETATION

Visual Observations

In July 1970 vegetation in Glacier National Park and surrounding areas was examined for evidence of fluoride-type markings.

Columbia Falls and Vicinity - Severe needle tip necrosis was observed on ponderosa pine (P. Ponderosa) at three locations within Columbia Falls. The injury was confined to needles on the growth produced in 1968, while the 1969 needles and immature

Table 8. FLUORIDE CONTENT OF VEGETATION SAMPLES OBTAINED IN 1969

Vegetation	F^-, µg/gm
Lodgepole pine (needle tip)	70
Lodgepole pine (needle base)	70
Gladiolus (leaf tip 2 in.)	170
Gladiolus (leaf base 2 in.)	90
Apples (leaf margin)	190
Apples (leaf mid-section)	150
Willow (leaf margin)	210
Willow (leaf mid-section)	70

current-season (1970) needles appeared free of injury. The brown necrotic tip of 1968 needles was about 2 to 3 centimeters long on trees in the area. Each necrotic tip showed 2 to 4 dark brown bands and a sharp line of demarcation between healthy and necrotic tissue. This symptom is characteristic of injury produced on sensitive pines by fluorides in polluted atmospheres.

Young pine trees in the ornamental plantings at the entrance to the Columbia Falls Forest Ranger Station showed considerable injury of the 1968 needles, less injury of the 1969 needles, and no apparent injury of 1970 needles. The oldest leaves of a young birch tree growing in the same area were severely injured. Necrosis at the margin of these leaves extended between the principal veins almost to the mid-rib. Younger leaves on the same shoots showed intercostal and marginal symptoms. The injury symptoms were of the type that may be associated with accumulation of fluorides.

Ponderosa trees at various points along the highway from Columbia Falls south to Bigfork were examined for symptoms of injury by air pollutants. Tip necrosis of needles was observed for at least 10 miles southeast of Columbia Falls. A large commercial planting of conifers about 20 miles from Columbia Falls appeared to be free of injury.

Teakettle Mountain - Young lodgepole pine and other shrubs at the top of Teakettle Mountain and on the south slope above the aluminum reduction plant were severely marked with necrotic lesions. Many of the young pine trees were heavily defoliated and partially or entirely dead. The needle tip necrosis ranged from red-brown to light brown with numerous dark brown bands. Typical fluoride-type symptoms were also found on trees at the top of the mountain.

The 1968 needles of Douglas fir trees were heavily marked with fleck-like chlorotic lesions and a general golden-brown discoloration. Needles produced more recently were free of this symptom. Wild strawberry leaves showed marginal necrosis and dark purple pigmentation between the major veins extending toward the mid-rib. Bear grass was severely injured, with light tan necrosis on the top 10 inches or more of mature leaves.

North Slope of Teakettle Mountain - Tip necrosis was observed on 1968 needles of white pine trees scattered along the north slope of the mountain; the 1969 and 1970 needles appeared to be free of injury. The symptoms were particularly severe on a few trees at the base of the mountain on Wright's Ranch.

A young planting of ponderosa pine near Lake Five was heavily marked with necrotic tips (3 and 4 centimeters long) on 1968 growth; more recent growth showed no visible symptoms. Similar symptoms were observed on lodgepole pine (P. Contorta) along the roadside in the same area.

Glacier Park - Iris growing wild at the site of an old homestead showed necrotic damage on leaf tips. Necrosis on some of the oldest leaves extended 6 inches or more. Some tip burn on 1969 needles of a young Douglas fir was also observed at this location.

About 3 miles south of the McDonald Creek bridge at the base of Apgar Mountain, mature ponderosa pine trees showed considerable tip burn on 1968 needles. The burn was more severe on needles growing upward than on those hanging downward from the shoots. The necrotic tip was 2 to 3 centimeters long with 3 to 5 dark brown bands. The 1969 needles on many shoots were considerably shorter than 1968 needles.

White pine trees at Glacier National Park Headquarters showed necrotic tip burn on 1968 needles and some burn on 1967 needles. The burn was about 5 centimeters long, and symptoms were much more severe on the lower 30 to 40 feet of the two trees examined than on the upper portions. Branches in the tops of the trees exhibited very little injury.

White pine trees at the Lake McDonald Ranger Station and on the Wheeler property west of the station were marked with tip burn on 1968 needles. Necrotic areas of tips were 1.5 to 2 centimeters long.

Tip burn was observed on white pines about 6 miles north of the north shore of Lake McDonald. The trees were growing on a ledge approximately 500 feet above the highway on the east side of the stream. Necrosis was found only on the tips of 1968 needles.

In brief summary of the field observations, necrotic tip burn on ponderosa pine and necrosis of some leaves on broad leaf plants were observed near the aluminum reduction plant and in Columbia Falls. These symptoms appeared to be identical with symptoms characterized as fluoride type. Similar symptoms on 1968 needles were observed for several miles southeast of the plant. The symptoms suggest that vegetation in the vicinity of Columbia Falls was exposed to high atmospheric fluoride concentrations in 1968 and perhaps early in 1969. Since that time, injury appears to be light and is probably confined to a radius of a few miles around the plant. Heaviest injury is apparent on the south slope of Teakettle Mountain.

Needle burn on 1968 needles of sensitive pine species in Glacier National Park indicates that excessive fumigation with fluorides probably occurred in 1968; tissus analyses confirmed this observation. Observations from the top of Teakettle Mountain confirm that fluoride-type symptoms are prevalent to the top of the mountain. Wind movement from the south-southwest would carry any pollutants reaching the top of the mountain up the middle fork of Flathead River into the Lake McDonald area. Although no evidence of recent foliage injury was observed within the Park, it is possible that chronic symptoms of fluoride accumulation may be manifested at a later date, as the newer growth is exposed to low ambient levels of fluoride over an extended period of time.

Chemical Analyses

Samples of indigenous vegetation were collected during the summer of 1970. Fluoride content of samples collected and analyzed by the University of California is reported in Table 9. These samples were obtained from 1968 needles which exhibited tip necrosis. All were obtained from within Glacier National Park.

Table 9. FLUORIDE CONTENT OF VEGETATION SAMPLES COLLECTED AND ANALYZED BY UNIVERSITY OF CALIFORNIA

Sample	Fluoride content, µg/g	
	Needle tip	Needle base
Ponderose pine	69	8
White pine park headquarters	29	4
White pine Lake McDonald	12	16
White pine 6 mi. North of Lake McDonald	48	4

Needles were cut into two approximately equal lengths, and the tip and base sections were analyzed separately. Before analysis, samples were dried for 48 hours at 45°C in a forced-draft oven and were ground to pass a 40-mesh screen. The tip sections contained both necrotic and green tissue.

Results of the analyses substantiate the conclusions that needle tip necrosis observed on 1968 growth of ponderosa and western white pine in the vicinity of Lake McDonald was produced by fluoride accumulation.

Additionally, vegetation samples exhibiting injury suspected to be caused by fluoride were collected by an EPA botanist and analyzed in the EPA North Carolina laboratories. For analysis the needles were divided into two nearly equal parts -- the tip (top half) and the base (bottom half). Results of these analyses appear in Table 10.

The normal expected fluoride content of <u>whole</u> conifer needles is less than 10 ppm (based on control data of the Forest Service and University of Montana). The fluoride content

Table 10. FLUORIDE CONTENT OF VEGETATION SAMPLES COLLECTED AND ANALYZED BY EPA (Fluoride in μg/g)

White Pine
Glacier Park HQ, 7/16/70

1967 needles	tip	30
	base	12
1968 needles	tip	36
	base	13
1969 needles	tip	28
	base	8
1970 needles	tip	8
	base	5

White Pine
6 mi. N of Lake McDonald, 7/16/70

1968 needles	tip	19
	base	8
1969 needles	tip	54
	base	18

Ponderosa Pine
4 mi. SW Park HQ, 7/16/70

1967 needles	tip	83
	base	8
1968 needles	tip	68
	base	5
1969 needles	tip	50
	base	9
1970 needles	tip	10
	base	4

Ponderosa Pine
Teakettle Mountain, 7/16/70

1968 needles	tip	295
	base	101
1969 needles	tip	213
	base	56
1970 needles		34

Ponderosa Pine
Monitoring Site 4, 10/22/70

1969 needles	tip	122
	base	9
1970 needles	tip	39
	base	11

Ponderosa Pine
Dr. Kruck Residence, 7/16/70

needle ends	312

Ponderosa Pine
Columbia Falls Park, 7/16/70

needle ends	119

Table 10. (continued). FLUORIDE CONTENT OF VEGETATION SAMPLES COLLECTED AND ANALYZED BY EPA
(Fluoride in μg/g)

Lodgepole Pine **4.5 mi. W Park HQ, 7/16/70**	
1968 needles	63
1969 needles	15
Lodgepole Pine **Monitoring Site 4, 10/22/70**	
1968 needles	72
1969 needles	
tip	61
base	14
1970 needles	
tip	15
base	11
Lodgepole Pine **Teakettle Mountain, 7/16/70**	
1968 needles	
tip	328
base	37
1969 needles	
tip	260
base	46
Douglas Fir **Middle Fork Ranger Station, 10/22/70**	
1968 needles	
tip	141
base	32
1969 needles	
tip	74
base	16
1970 needles	
tip	20
base	5
Birch **Columbia Falls Ranger Station 7/16/70**	
1970 leaves	94
Bear Grass **Park HQ, 10/22/70**	43
Snowberry **Monitoring Site 4 10/22/70**	4

of many of the samples reported in Table 10 is much higher than this background level of 10 ppm. Accumulation in the tip portion of the needles ran as high as 141 ppm, and only two of the samples showed fluoride levels as low as background when the tip and base measurements were combined. The data further confirm that fluoride has accumulated in the tissue of vegetation growing in and near the Park in sufficient quantities to produce the observed tip necrosis.

Generally, the fluoride accumulation in 1968 needles was greater than in 1969 needles, and in 1969 needles than in the current 1970 needles. The high fluoride content of 1968 and 1969 needle growth may reflect exposure to higher ambient fluoride levels during these years as well as cumulative effects of the longer exposure period.

The high fluoride content (43 µg F/g) of bear grass collected at Park headquarters exceeds the State standard of 35 ppm for forage, considered to be the maximum safe concentration for animal ingestion.

Histological Examination

Injured needles from Park trees showing burn symptoms were examined microscopically. By means of a hand-sectioning technique, tissue sections were obtained without the distortion induced by killing or dehydration of the tissue. Clear and workable sections were obtained by softening the hard tissue in a solution composed of 20 percent glycerin, 10 percent alcohol, and 70 percent distilled water. Thionine stain gave clarity and resolution to the initial stages of injury. Sections were taken from the green, uninjured portion of the needles immediately preceding the demarcation line between injured and uninjured tissue.

Examination of the specimens revealed that the parenchymatous tissues of palisade and spongy cells were collapsed and some chloroplasts had lost their integrity. The epithelial cells of the resin canal showed swelling and expansion. The vascular bundles were distorted and adjacent cells had collapsed.

The extensive changes in the injured needle tissue indicated that the causative agent of the needle necrosis was chemical.

CONTROLLED EXPOSURES OF SELECTED VEGETATION

Cylinder-shaped, fiberglas greehouses were located at three of the sites where volumetric ambient fluoride measurements were conducted. Stations 1, 2, and 3 (shown in Figure 10) were selected for the exposure tests because of the availability of electric power and the proximity to the Park.

At sites 1 and 2, shelters of the same type as those used for ambient expo ures were equipped with filters to remove particulate and gaseous fluorides. In these control shelters, ambient air was blown through a series of filters before entering the shelter and then was pulled from the shelter by an exhaust blower. In the regular test shelters, unfiltered ambient air was drawn by the air movement induced by an exhaust blower. In all shelters, fans circulated air at a rate of about 1 air-volume-change-per-minute.

Plants exposed included ponderosa, Scotch, and white pines, alfalfa, Chinese apricot, and Snow Princess gladiolus. Trees were obtained from these sources: white pine--Coeur d'Alene, Idaho, ponderosa pine--Potamac Valley, Missoula, Montana; Scotch pine--St. Regis, Montana; and Chinese apricot--Denver, Colorado.

The pines were 3 to 4 years old and were placed at the sites 1 to 2 weeks after bud break. The apricot trees were 5 to 6 years old. All trees remained during this exposure period in the soil in which they were delivered by the nursery.

Gladiolus and alfalfa were grown hydroponically in a vermiculite support medium. Plastic pots containing the plants were placed in shallow plastic trays to which a deionized water netrient solution was added twice a week. On a weekly schedule, all plants were flushed with distilled water, and the trays were cleaned to rid them of algae. In the latter stages of the study heaters were placed inside the shelters to prevent freezing.

The selected plant varieties were also grown in garden plots near the shelters at sites 1, 2, and 3. A garden plot was also established at the air sampling station near Mud Lake (site 4). Gladiolus and alfalfa were planted in native soil at each of the garden plots, but the trees were left in their containers with the original soil. The garden plots were watered about every other day with deionized water and once a week with nutrient solution.

Moderate tip burn was observed on Gladiolus and Apricot leaves. Gladiolus were harvested for analysis on September 14 as buds were opening after about 11 weeks of growth. Alfalfa and part of the apricot leaves were also harvested at this time. At the end of the 16-week study, the rest of the apricot leaves and the new growth of alfalfa was harvested. Pine needles were also collected from the test trees at this time and were classified as 1969 and 1970 needle growth for analyses.

Samples from plants grown in the exposure shelters and the garden plots were analyzed at the EPA laboratory in Durham, North Carolina. Unwashed plant samples were identified, sorted, oven-dried, and ground for automated wet-chemical analysis with an autoanalyzer. Results are reported in μg F/g dry weight in Tables 11 through 14.

Results of the controlled exposure of selected vegetation indicate that nearly all samples exposed to this ambient air accumulated more fluoride than did those grown in the purified air of the control chambers. This accumulation appears to be of marginal significance, however, it must be remembered that the vegetation encountered low concentrations of fluoride as demonstrated by the air quality measurements made at these same exposure sites.

Table 11. FLUORIDE ACCUMULATION IN 1969 AND 1970 NEEDLES OF WHITE, PONDEROSA, AND SCOTCH PINES EXPOSED FROM JUNE 25 TO OCTOBER 21, 1970

(μg F/g)

Exposure/location	White pine		Scotch pine		Ponderosa pine	
	1969	1970	1969	1970	1969	1970
Plant shelters						
Site 1	16.5	10.6	34.5	12.6	36.1	9.8
Site 2	8.3	16.7		12.4	39.6	10.7
Site 3	18.3	25.3	23.5	8.7	46.1	10.5
Garden plots						
Site 1	7.3	7.8	10.0	5.5	19.1	7.1
Site 2	11.4	9.1		7.1	14.3	6.9
Site 3	12.7	6.2	6.3	5.0	16.6	6.8
Site 4	18.5	14.2	14.3	8.2	19.0	9.4
Control shelters[a]	6.1	5.1	9.2	4.2	15.5	5.6

[a]Fluoride content of the plants in both control shelters.

Table 12. FLUORIDE ACCUMULATION IN ALFALFA LEAVES AND STEMS EXPOSED IN 1970 STUDY

Exposure/location	Fluoride content, μg F/g	
	July 24 through September 14	September 14 through October 21
Plant shelters		
Site 1	13.9	13.6
Site 2	12.5	11.5
Site 3	11.1	15.1
Garden plots		
Site 1	21.3	
Site 2	19.3	
Site 3	24.7	
Site 4	32.1	
Control plant shelters	4.4	5.0

Table 13. FLUORIDE ACCUMULATION IN CHINESE APRICOT LEAVES EXPOSED IN 1970 STUDY

Exposure/location	Fluoride content, μg F/g	
	July 14 through September 14	September 14 through October 21
Plant shelters		
Site 1	6.7	15.9
Site 2	8.4	24.3
Site 3	10.7	19.7
Garden plots		
Site 1	10.2	14.6[a]
Site 2	9.9	
Site 3	9.6	
Site 4	12.8	
Control plant shelters	2.6	2.0

[a]Date of exposure was July 14 to September 26.

Table 14. FLUORIDE ACCUMULATION IN GLADIOLUS LEAF TISSUE EXPOSED FROM JUNE 25 THROUGH SEPTEMBER 14, 1970

Exposure/location	Fluoride content, μg F/g		
	0 to 2 inches from tip	2 to 4 inches from tip	4 to 6 inches from tip
Plant shelters			
Site 1	20.6	6.7	8.1
Site 2	24.0	12.4	9.3
Site 3	23.9	9.9	10.2
Garden plots			
Site 1	26.8	10.1	7.5
Site 2	43.6	9.1	8.9
Site 3	28.2	10.9	9.0
Control plant shelters	12.0	8.9	5.2

APPENDIX: DATA OBTAINED IN VOLUMETRIC SAMPLING

Station 1 - Glacier Park

(μg/m^3)

DATE	TIME	GAS	PART	TOTAL
7/ 9	900	0.00	0.00	0.00
7/ 9	2100	0.11	0.00	0.00
7/10	900	0.10	0.00	0.00
7/10	2100	0.06	0.00	0.00
7/11	900	0.09	0.00	0.00
7/11	2100	0.07	0.00	0.00
7/12	900	0.07	0.00	0.00
7/12	2100	0.00	0.00	0.00
7/13	900	0.27	0.09	0.36
7/13	2100	0.22	0.05	0.27
7/14	900	0.21	0.27	0.48
7/14	2100	0.13	0.05	0.18
7/15	900	0.24	0.30	0.54
7/15	2100	0.11	0.09	0.20
7/16	900	0.11	0.02	0.13
7/16	2100	0.09	0.02	0.11
7/17	900	0.12	0.04	0.16
7/17	2100	0.09	0.03	0.12
7/18	900	0.09	0.02	0.11
7/18	2100	0.07	0.02	0.09
7/19	900	0.23	0.31	0.54
7/19	2100	0.12	0.11	0.23
7/20	900	0.20	0.17	0.37
7/20	2100	0.13	0.05	0.18
7/21	900	0.23	0.07	0.30
7/21	2100	0.14	0.10	0.24
7/22	900	0.12	0.11	0.23
7/22	2100	0.00	0.00	0.00
7/23	900	0.17	0.12	0.29
7/23	2100	0.11	0.05	0.16
7/24	900	0.14	0.13	0.27
7/24	2100	0.00	0.00	0.00
7/25	900	0.12	0.25	0.37
7/25	2100	0.10	0.09	0.19
7/26	900	0.34	0.27	0.61
7/26	2100	0.11	0.12	0.23
7/27	900	0.10	0.15	0.25
7/27	2100	0.00	0.00	0.00
7/28	900	0.09	0.08	0.17
7/28	2100	0.05	0.11	0.16
7/29	900	0.10	0.22	0.32
7/29	2100	0.05	0.09	0.14
7/30	900	0.03	0.02	0.05
7/30	2100	0.03	0.03	0.06
7/31	900	0.05	0.18	0.23
7/31	2100	0.02	0.00	0.00
8/ 1	900	0.03	0.03	0.06
8/ 1	2100	0.03	0.01	0.04
8/ 2	900	0.02	0.01	0.03
8/ 2	2100	0.00	0.00	0.00
8/ 3	900	0.12	0.59	0.71
8/ 3	2100	0.03	0.00	0.00
8/ 4	900	0.02	0.03	0.05
8/ 4	2100	0.02	0.05	0.07
8/ 5	900	0.03	0.28	0.31
8/ 5	2100	0.03	0.05	0.08
8/ 6	900	0.09	0.55	0.64
8/ 6	2100	0.04	0.16	0.20
8/ 7	900	0.10	0.36	0.46
8/ 7	2100	0.06	0.31	0.37
8/ 8	900	0.05	0.12	0.17
8/ 8	2100	0.04	0.22	0.26
8/ 9	900	0.06	0.39	0.45
8/ 9	2100	0.05	0.20	0.25
8/10	900	0.05	0.21	0.26
8/10	2100	0.06	0.07	0.13
8/11	900	0.05	0.22	0.27
8/11	2100	0.03	0.10	0.13
8/12	900	0.09	0.16	0.25
8/12	2100	0.04	0.09	0.13
8/15	900	0.00	0.00	0.00
8/15	2100	0.03	0.23	0.26
8/16	900	0.15	0.15	0.30
8/16	2100	0.05	0.12	0.17
8/17	900	0.04	0.05	0.09
8/17	2100	0.03	0.16	0.19
8/18	900	0.10	0.00	0.00
8/18	2100	0.02	0.02	0.04
8/19	900	0.09	0.14	0.23
8/19	2100	0.03	0.14	0.17
8/20	900	0.11	0.16	0.27
8/20	2100	0.03	0.12	0.15
8/21	900	0.12	0.14	0.26
8/21	2100	0.04	0.08	0.12
8/22	900	0.11	0.12	0.23
8/22	2100	0.05	0.09	0.14
8/23	900	0.20	0.16	0.36
8/23	2100	0.05	0.17	0.22
8/24	900	0.07	0.05	0.12
8/24	2100	0.03	0.02	0.05
8/25	900	0.08	0.11	0.19
8/25	2100	0.02	0.09	0.11
8/26	900	0.09	0.32	0.41
8/26	2100	0.02	0.10	0.12
8/27	900	0.13	0.16	0.29
8/27	2100	0.02	0.05	0.07
8/28	900	0.09	0.08	0.17
8/28	2100	0.02	0.12	0.14
8/29	900	0.02	0.01	0.03
8/29	2100	0.02	0.01	0.03
8/30	900	0.11	0.31	0.42
8/30	2100	0.03	0.18	0.21
8/31	900	0.07	0.07	0.14
8/31	2100	0.05	0.02	0.07
9/ 1	900	0.12	0.12	0.24
9/ 1	2100	0.02	0.02	0.04
9/ 2	900	0.10	0.22	0.32
9/ 2	2100	0.02	0.18	0.20
9/ 3	900	0.09	0.10	0.19

* 0.0 indicates invalid sample

Station 1 - Glacier Park

(μg/m^3)

9/ 3	2100	0.05	0.20	0.25
9/ 4	900	0.08	0.19	0.27
9/ 4	2100	0.02	0.02	0.04
9/ 5	900	0.15	0.15	0.30
9/ 5	2100	0.25	0.30	0.55
9/ 6	900	0.19	0.27	0.46
9/ 6	2100	0.05	0.09	0.14
9/ 7	900	0.05	0.12	0.17
9/ 7	2100	0.05	0.06	0.11
9/ 8	900	0.02	0.00	0.00
9/ 8	2100	0.03	0.16	0.19
9/ 9	900	0.08	0.15	0.23
9/ 9	2100	0.01	0.01	0.02
9/10	900	0.10	0.12	0.22
9/10	2100	0.02	0.01	0.03
9/20	900	0.06	0.29	0.35
9/20	2100	0.02	0.03	0.05
9/21	900	0.05	0.16	0.21
9/21	2100	0.02	0.14	0.16
9/22	900	0.02	0.05	0.07
9/22	2100	0.01	0.04	0.05
9/23	900	0.04	0.08	0.12
9/23	2100	0.01	0.12	0.13
9/24	900	0.06	0.37	0.43
9/24	2100	0.02	0.23	0.25
9/25	900	0.07	0.16	0.23
9/25	2100	0.01	0.08	0.09
9/26	900	0.08	0.25	0.33
9/26	2100	0.01	0.08	0.09
9/27	900	0.02	0.14	0.16
9/27	2100	0.02	0.18	0.20
9/28	900	0.02	0.07	0.09
9/28	2100	0.00	0.00	0 00
10/ 1	900	0.09	0.34	0.43
10/ 1	2100	0.01	0.23	0.24
10/ 2	900	0.02	0.07	0.09
10/ 2	2100	0.01	0.08	0.09
10/ 4	900	0.03	0.15	0.18
10/ 4	2100	0.03	0.23	0.26
10/ 6	900	0.01	0.02	0.03
10/ 6	2100	0.01	0.02	0.03
10/16	900	0.00	0.00	0.00
10/16	2100	0.02	1.18	1.20
10/17	900	0.02	0.21	0.23
10/17	2100	0.02	0.09	0.11
10/18	900	0.09	0.84	0.93
10/18	2100	0.08	0.98	1.06
10/19	900	0.08	0.53	0.61
10/19	2100	0.01	0.03	0.04
10/20	900	0.02	0.04	0.06
10/20	2100	0.04	0.26	0.30
10/21	900	0.02	0.07	0.09
10/21	2100	0.02	0.07	0.09
10/22	900	0.05	0.39	0.44
10/22	2100	0.02	0.21	0.23
10/23	900	0.02	0.06	0.08
10/23	2100	0.01	0.10	0.11

Station 2 - Glacier Park
(μg/m^3)

6/26	900	0.19	0.23	0.42
6/26	2100	0.11	0.15	0.26
6/27	900	0.14	0.27	0.41
6/27	2100	0.12	0.31	0.43
6/28	900	0.09	0.09	0.18
6/28	2100	0.05	0.08	0.13
6/29	900	0.09	0.29	0.38
6/29	2100	0.09	0.29	0.38
6/30	900	0.20	0.35	0.55
6/30	2100	0.10	0.16	0.26
7/ 1	900	0.00	0.12	0.00
7/ 1	2100	0.07	0.11	0.18
7/ 2	900	0.02	0.23	0.25
7/ 2	2100	0.05	0.00	0.00
7/ 3	900	0.00	0.00	0.00
7/ 3	2100	0.05	0.00	0.00
7/ 4	900	0.00	0.00	0.00
7/ 4	2100	0.07	0.00	0.00
7/ 5	900	0.00	0.00	0.00
7/ 5	2100	0.05	0.00	0.00
7/ 6	900	0.00	0.00	0.00
7/ 6	2100	0.06	0.00	0.00
7/ 7	900	0.00	0.00	0.00
7/ 7	2100	0.05	0.00	0.00
7/ 8	900	0.00	0.00	0.00
7/ 8	2100	0.05	0.00	0.00
7/ 9	900	0.00	0.00	0.00
7/ 9	2100	0.06	0.00	0.00
7/10	900	0.08	0.00	0.00
7/10	2100	0.06	0.00	0.00
7/11	900	0.12	0.16	0.28
7/11	2100	0.05	0.05	0.10
7/12	900	0.12	0.09	0.21
7/12	2100	0.10	0.04	0.14
7/13	900	0.09	0.13	0.22
7/13	2100	0.09	0.07	0.16
7/14	900	0.13	0.23	0.36
7/14	2100	0.07	0.11	0.18
7/15	900	0.21	0.19	0.40
7/15	2100	0.11	0.07	0.18
7/16	900	0.25	0.02	0.27
7/16	2100	0.19	0.00	0.00
7/17	900	0.26	0.03	0.29
7/17	2100	0.19	0.02	0.21
7/18	900	0.16	0.02	0.18
7/18	2100	0.14	0.03	0.17
7/19	900	0.13	0.35	0.48
7/19	2100	0.12	0.36	0.48
7/20	900	0.24	0.42	0.66
7/20	2100	0.14	0.12	0.26
7/21	900	0.26	0.60	0.86

7/21	2100	0.11	0.18	0.29
7/22	900	0.13	0.13	0.26
7/22	2100	0.09	0.06	0.15
7/23	900	0.12	0.24	0.36
7/23	2100	0.20	0.27	0.47
7/24	900	0.09	0.37	0.46
7/24	2100	0.10	0.17	0.27
7/25	900	0.18	0.30	0.48
7/25	2100	0.11	0.04	0.15
7/26	900	0.20	0.48	0.68
7/26	2100	0.10	0.12	0.22
7/27	900	0.07	0.44	0.51
7/27	2100	0.05	0.02	0.07
7/28	900	0.05	0.17	0.22
7/28	2100	0.05	0.12	0.17
7/29	900	0.09	0.03	0.12
7/29	2100	0.04	0.01	0.05
7/30	900	0.03	0.01	0.04
7/30	2100	0.03	0.05	0.08
7/31	900	0.04	0.11	0.15
7/31	2100	0.02	0.02	0.04
8/ 1	900	0.02	0.02	0.04
8/ 1	2100	0.02	0.02	0.04
8/ 2	900	0.02	0.02	0.04
8/ 2	2100	0.10	0.16	0.26
8/ 3	900	0.04	0.32	0.36
8/ 3	2100	0.04	0.05	0.09
8/ 4	900	0.03	0.03	0.06
8/ 4	2100	0.04	0.02	0.06
8/ 5	900	0.06	0.12	0.18
8/ 5	2100	0.05	0.05	0.10
8/ 6	900	0.16	0.30	0.46
8/ 6	2100	0.06	0.07	0.13
8/ 7	900	0.12	0.17	0.29
8/ 7	2100	0.05	0.05	0.10
8/ 8	900	0.06	0.10	0.16
8/ 8	2100	0.05	0.04	0.09
8/ 9	900	0.13	0.48	0.61
8/ 9	2100	0.05	0.06	0.11
8/10	900	0.06	0.20	0.26
8/10	2100	0.04	0.09	0.13
8/11	900	0.09	0.25	0.34
8/11	2100	0.05	0.15	0.20
8/12	900	0.00	0.00	0.00
8/12	2100	0.07	0.05	0.12
8/15	900	0.00	0.00	0.00
8/15	2100	0.03	0.13	0.16
8/16	900	0.20	0.20	0.40
8/16	2100	0.14	0.13	0.27
8/17	900	0.04	0.05	0.09
8/17	2100	0.03	0.06	0.09
8/18	900	0.08	0.07	0.15
8/18	2100	0.02	0.02	0.04

Station 2 - Glacier Park
($\mu g/m^3$)

8/19	900	0.14	0.12	0.26
8/19	2100	0.03	0.27	0.30
8/20	900	0.19	0.24	0.43
8/20	2100	0.05	0.04	0.09
8/21	900	0.23	0.10	0.33
8/21	2100	0.03	0.12	0.15
8/22	900	0.17	0.10	0.27
8/22	2100	0.04	0.11	0.15
8/23	900	0.23	0.31	0.54
8/23	2100	0.06	0.36	0.42
8/24	900	0.12	0.16	0.28
8/24	2100	0.05	0.04	0.09
8/25	900	0.14	0.17	0.31
8/25	2100	0.04	0.09	0.13
8/26	900	0.12	0.20	0.32
8/26	2100	0.03	0.12	0.15
8/27	900	0.14	0.22	0.36
8/27	2100	0.02	0.03	0.05
8/28	900	0.07	0.15	0.22
8/28	2100	0.03	0.08	0.11
8/29	900	0.05	0.12	0.17
8/29	2100	0.02	0.04	0.06
8/30	900	0.30	0.50	0.80
8/30	2100	0.05	0.40	0.45
8/31	900	0.13	0.11	0.24
8/31	2100	0.06	0.02	0.08
9/ 1	900	0.19	0.12	0.31
9/ 1	2100	0.05	0.04	0.09
9/ 2	900	0.24	0.44	0.68
9/ 2	2100	0.05	0.13	0.18
9/ 3	900	0.16	0.30	0.46
9/ 3	2100	0.00	0.00	0.00
9/ 4	900	0.09	0.21	0.30
9/ 4	2100	0.03	0.02	0.05
9/ 5	900	0.30	0.30	0.60
9/ 5	2100	1.02	0.98	2.00
9/ 6	900	0.65	0.59	1.24
9/ 6	2100	0.11	0.16	0.27
9/ 7	900	0.00	0.35	0.00
9/ 7	2100	0.05	0.12	0.17
9/ 8	900	0.04	0.02	0.06
9/ 8	2100	0.04	0.04	0.08
9/ 9	900	0.08	0.11	0.19
9/ 9	2100	0.02	0.03	0.05
9/10	900	0.16	0.13	0.29
9/10	2100	0.02	0.02	0.04
9/11	900	0.01	0.02	0.03
9/11	2100	0.02	0.01	0.03
9/12	900	0.00	0.00	0.00
9/12	2100	0.01	0.02	0.03
9/13	900	0.01	0.01	0.02
9/13	2100	0.00	0.00	0.00
9/14	900	0.05	0.12	0.17
9/14	2100	0.01	0.11	0.12
9/16	900	0.14	0.27	0.41
9/16	2100	0.02	0.05	0.07
9/18	900	0.05	0.21	0.26
9/18	2100	0.03	0.08	0.11
9/20	900	0.05	0.09	0.14
9/20	2100	0.02	0.06	0.08
9/21	900	0.07	0.12	0.19
9/21	2100	0.03	0.06	0.09
9/22	900	0.05	0.32	0.37
9/22	2100	0.04	0.10	0.14
9/23	900	0.00	0.16	0.00
9/23	2100	0.02	0.20	0.22
9/24	900	0.10	0.32	0.42
9/24	2100	0.02	0.25	0.27
9/25	900	0.05	0.12	0.17
9/25	2100	0.02	0.05	0.07
9/26	900	0.05	0.19	0.24
9/26	2100	0.02	0.09	0.11
9/27	900	0.05	0.15	0.20
9/27	2100	0.02	0.19	0.21
9/28	900	0.07	0.39	0.46
9/28	2100	0.01	0.06	0.07
10/17	900	0.02	0.25	0.27
10/17	2100	0.01	0.11	0.12
10/18	900	0.03	0.73	0.76
10/18	2100	0.03	0.35	0.38
10/19	900	0.15	0.60	0.75
10/19	2100	0.03	0.04	0.07
10/20	900	0.06	0.40	0.46
10/20	2100	0.20	0.60	0.80
10/21	900	0.09	0.19	0.28
10/21	2100	0.09	0.43	0.52

Station 3 - Glacier Park

(μg/m^3)

6/26	900	0.06	0.16	0.22
6/26	2100	0.07	0.19	0.26
6/27	900	0.08	0.08	0.16
6/27	2100	0.03	0.05	0.08
6/28	900	0.02	0.03	0.05
6/28	2100	0.03	0.05	0.08
6/29	900	0.05	0.44	0.49
6/29	2100	0.03	0.13	0.16
6/30	900	0.02	0.05	0.07
6/30	2100	0.02	0.02	0.04
7/ 1	900	0.00	0.05	0.00
7/ 1	2100	0.05	0.05	0.10
7/ 2	900	0.00	0.07	0.00
7/ 2	2100	0.05	0.04	0.09
7/ 3	900	0.00	0.00	0.00
7/ 3	2100	0.05	0.00	0.00
7/ 4	900	0.00	0.00	0.00
7/ 4	2100	0.05	0.00	0.00
7/ 5	900	0.00	0.00	0.00
7/ 5	2100	0.04	0.00	0.00
7/ 6	900	0.00	0.00	0.00
7/ 6	2100	0.04	0.00	0.00
7/ 7	900	0.00	0.00	0.00
7/ 7	2100	0.04	0.00	0.00
7/ 8	900	0.00	0.00	0.00
7/ 8	2100	0.04	0.00	0.00
7/ 9	900	0.00	0.00	0.00
7/ 9	2100	0.04	0.00	0.00
7/10	900	0.16	0.00	0.00
7/10	2100	0.05	0.00	0.00
7/11	900	0.16	0.14	0.30
7/11	2100	0.12	0.09	0.21
7/12	900	0.13	0.06	0.19
7/12	2100	0.10	0.02	0.12
7/13	900	0.12	0.32	0.44
7/13	2100	0.11	0.05	0.16
7/14	900	0.12	0.05	0.17
7/14	2100	0.09	0.05	0.14
7/15	900	0.09	0.06	0.15
7/15	2100	0.08	0.02	0.10
7/16	900	0.09	0.04	0.13
7/16	2100	0.09	0.09	0.18
7/17	900	0.09	0.05	0.14
7/17	2100	0.08	0.05	0.13
7/18	900	0.09	0.04	0.13
7/18	2100	0.08	0.02	0.10
7/19	900	0.12	0.14	0.26
7/19	2100	0.09	0.09	0.18
7/20	900	0.15	0.15	0.30
7/20	2100	0.08	0.08	0.16
7/21	2100	0.00	0.00	0.00
7/22	900	0.06	0.19	0.25
'22	2100	0.05	0.05	0.10
23	900	0.05	0.00	0.00
/23	2100	0.04	0.20	0.24
7/24	900	0.05	0.27	0.32
7/24	2100	0.04	0.13	0.17
7/25	900	0.07	0.30	0.37
7/25	2100	0.05	0.05	0.10
7/26	900	0.07	0.23	0.30
7/26	2100	0.04	0.08	0.12
7/28	900	0.00	0.00	0.00
7/28	2100	0.02	0.12	0.14
7/29	900	0.03	0.10	0.13
7/29	2100	0.02	0.09	0.11
7/30	900	0.02	0.04	0.06
7/30	2100	0.02	0.08	0.10
7/31	900	0.02	0.12	0.14
7/31	2100	0.02	0.07	0.09
8/ 1	900	0.02	0.06	0.08
8/ 1	2100	0.02	0.10	0.12
8/ 2	900	0.04	0.04	0.08
8/ 2	2100	0.03	0.51	0.54
8/ 3	900	0.06	0.20	0.26
8/ 3	2100	0.03	0.05	0.08
8/ 4	900	0.04	0.05	0.09
8/ 4	2100	0.00	0.00	0.00
8/ 5	900	0.05	0.16	0.21
8/ 5	2100	0.04	0.12	0.16
8/ 6	900	0.07	0.23	0.30
8/ 6	2100	0.04	0.06	0.10
8/ 7	900	0.07	0.20	0.27
8/ 7	2100	0.03	0.09	0.12
8/ 8	900	0.07	0.32	0.39
8/ 8	2100	0.04	0.25	0.29
8/ 9	900	0.07	0.16	0.23
8/ 9	2100	0.05	0.08	0.13
8/10	900	0.04	0.14	0.18
8/10	2100	0.02	0.09	0.11
8/11	900	0.02	0.12	0.14
8/11	2100	0.00	0.00	0.00

Station 4 - Glacier Park
(μg/m³)

6/25	900	0.08	0.00	0.00
6/25	2100	0.04	0.24	0.28
6/26	900	0.26	0.26	0.52
6/26	2100	0.12	0.20	0.32
6/27	900	0.12	0.19	0.31
6/27	2100	0.09	0.14	0.23
6/28	900	0.12	0.12	0.24
6/28	2100	0.07	0.14	0.21
6/29	900	0.12	0.25	0.37
6/29	2100	0.05	0.05	0.10
6/30	900	0.10	0.08	0.18
6/30	2100	0.09	0.25	0.34
7/ 1	900	0.18	0.30	0.48
7/ 1	2100	0.00	0.00	0.00
7/ 3	900	0.00	0.00	0.00
7/ 3	2100	0.14	0.00	0.00
7/ 4	900	0.00	0.00	0.00
7/ 4	2100	0.20	0.00	0.00
7/ 5	900	0.00	0.00	0.00
7/ 5	2100	0.16	0.00	0.00
7/ 6	900	0.00	0.00	0.00
7/ 6	2100	0.12	0.00	0.00
7/13	900	0.00	0.00	0.00
7/13	2100	0.09	0.05	0.14
7/15	900	0.44	0.36	0.80
7/15	2100	0.12	0.05	0.17
7/16	900	0.14	0.03	0.17
7/16	2100	0.12	0.05	0.17
7/17	900	0.24	0.16	0.40
7/17	2100	0.12	0.07	0.19
7/18	900	0.09	0.07	0.16
7/18	2100	0.10	0.05	0.15
7/19	900	0.28	0.37	0.65
7/19	2100	0.10	0.23	0.33
7/20	900	0.10	0.10	0.20
7/20	2100	0.16	0.07	0.23
7/21	900	0.09	0.18	0.27
7/21	2100	0.12	0.69	0.81
7/22	900	0.16	0.53	0.69
7/22	2100	0.07	0.15	0.22
7/23	900	0.25	0.48	0.73
7/23	2100	0.09	0.16	0.25
7/24	900	0.11	0.15	0.26
7/24	2100	0.10	0.12	0.22
7/25	900	0.09	0.00	0.00
7/25	2100	0.08	0.03	0.11
7/26	900	0.16	0.44	0.60
7/26	2100	0.08	0.16	0.24
7/27	900	0.05	0.41	0.46
7/27	2100	0.04	0.11	0.15
7/28	900	0.05	0.12	0.17
7/28	2100	0.04	0.09	0.13
7/29	900	0.12	0.20	0.32
7/29	2100	0.03	0.17	0.20
7/30	900	0.05	0.17	0.22
7/30	2100	0.02	0.11	0.13
7/31	900	0.10	0.36	0.46
7/31	2100	0.05	0.19	0.24
8/ 1	900	0.03	0.02	0.05
8/ 1	2100	0.04	0.09	0.13
8/ 2	900	0.03	0.05	0.08
8/ 2	2100	0.04	0.22	0.26
8/ 3	900	0.22	0.60	0.82
8/ 3	2100	0.05	0.11	0.16
8/ 4	900	0.03	0.04	0.07
8/ 4	2100	0.02	0.04	0.06
8/ 5	900	0.06	0.19	0.25
8/ 5	2100	0.20	0.07	0.27
8/ 6	900	0.04	0.62	0.66
8/ 6	2100	0.05	0.18	0.23
8/ 7	900	0.18	0.30	0.48
8/ 7	2100	0.07	0.33	0.40
8/ 8	900	0.05	0.09	0.14
8/ 8	2100	0.04	0.30	0.34
8/ 9	900	0.18	0.56	0.74
8/ 9	2100	0.04	0.19	0.23
8/10	900	0.17	0.46	0.63
8/10	2100	0.05	0.16	0.21
8/11	900	0.17	0.41	0.58
8/11	2100	0.06	0.18	0.24
8/12	900	0.24	0.21	0.45
8/12	2100	0.08	0.14	0.22
8/13	900	0.21	0.13	0.34
8/13	2100	0.03	0.27	0.30
8/14	900	0.06	0.16	0.22
8/14	2100	0.02	0.09	0.11
8/15	900	0.00	0.00	0.00
8/15	2100	0.13	0.14	0.27
8/16	900	0.37	0.37	0.74
8/16	2100	0.16	0.10	0.26
8/17	900	0.20	0.27	0.47
8/17	2100	0.05	0.34	0.39
8/18	900	0.19	0.11	0.30
8/18	2100	0.02	0.05	0.07
8/19	900	0.27	0.23	0.50
8/19	2100	0.03	0.19	0.22
8/20	900	0.18	0.30	0.48
8/20	2100	0.03	0.23	0.26
8/21	900	0.48	0.30	0.78
8/21	2100	0.06	0.20	0.26
8/22	900	0.30	0.26	0.56
8/22	2100	0.05	0.39	0.44
8/23	900	0.41	0.64	1.05

Station 4 - Glacier Park
(µg/m³)

8/23	2100	0.05	0.42	0.47
8/24	900	0.09	0.08	0.17
8/24	2100	0.05	0.04	0.09
8/25	900	0.10	0.13	0.23
8/25	2100	0.02	0.12	0.14
8/26	900	0.23	0.32	0.55
8/26	2100	0.02	0.11	0.13
8/27	900	0.12	0.27	0.39
8/27	2100	0.02	0.08	0.10
8/28	900	0.14	0.29	0.43
8/28	2100	0.02	0.45	0.47
8/29	900	0.08	0.16	0.24
8/29	2100	0.02	0.04	0.06
8/30	900	0.25	0.41	0.66
8/30	2100	0.03	0.17	0.20
8/31	900	0.13	0.12	0.25
8/31	2100	0.05	0.02	0.07
9/ 1	900	0.12	0.15	0.27
9/ 1	2100	0.02	0.06	0.08
9/ 2	900	0.23	0.26	0.49
9/ 2	2100	0.03	0.16	0.19
9/ 3	900	0.09	0.00	0.00
9/ 3	2100	0.00	0.00	0.00
9/ 4	900	0.09	0.21	0.30
9/ 4	2100	0.02	0.02	0.04
9/ 5	900	0.18	0.13	0.31
9/ 5	2100	0.09	0.11	0.20
9/ 6	900	0.12	0.13	0.25
9/ 6	2100	0.03	0.03	0.06
9/ 7	900	0.08	0.32	0.40
9/ 7	2100	0.05	0.12	0.17
9/ 8	900	0.08	0.11	0.19
9/ 8	2100	0.04	0.12	0.16
9/ 9	900	0.16	0.33	0.49
9/ 9	2100	0.02	0.03	0.05
9/10	900	0.09	0.16	0.25
9/10	2100	0.04	0.06	0.10
9/20	900	0.12	0.26	0.38
9/20	2100	0.01	0.02	0.03
9/21	900	0.16	0.49	0.65
9/21	2100	0.04	0.04	0.08
9/22	900	0.02	0.05	0.07
9/22	2100	0.02	0.03	0.05
9/23	900	0.04	0.08	0.12
9/23	2100	0.01	0.25	0.26
9/24	900	0.20	0.46	0.66
9/24	2100	0.02	0.23	0.25
9/25	900	0.20	0.59	0.79
9/25	2100	0.03	0.15	0.18
9/26	900	0.00	0.51	0.00
9/26	2100	0.02	0.12	0.14
9/27	900	0.13	0.57	0.70
9/27	2100	0.02	0.21	0.23
9/28	900	0.12	0.38	0.50
9/28	2100	0.02	0.39	0.41
10/16	900	0.00	0.00	0.00
10/16	2100	0.02	1.33	1.35
10/17	900	0.03	0.12	0.15
10/17	2100	0.02	0.08	0.10
10/18	900	0.06	1.12	1.18
10/18	2100	0.05	0.55	0.60
10/19	900	0.04	0.16	0.20
10/19	2100	0.02	0.02	0.04
10/20	900	0.03	0.10	0.13
10/20	2100	0.09	0.27	0.36
10/21	900	0.02	0.02	0.04
10/21	2100	0.04	0.30	0.34

Station 17 - Glacier Park
(µg/m³)

8/17	900	0.00	0.00	0.00
8/17	2100	0.15	0.41	0.56
8/18	900	0.20	0.45	0.65
8/18	2100	0.08	0.06	0.14
8/19	900	0.64	0.53	1.17
8/19	2100	0.20	0.42	0.62
8/20	900	0.78	0.60	1.38
8/20	2100	0.23	0.69	0.92
8/21	900	3.65	1.11	4.76
8/21	2100	0.56	0.38	0.94
8/22	900	1.47	1.51	2.98
8/22	2100	0.36	0.36	0.72
8/23	900	1.53	1.18	2.71
8/23	2100	0.33	0.43	0.76
8/24	900	1.00	0.73	1.73
8/24	2100	0.44	1.05	1.49
8/25	900	0.63	0.93	1.56
8/25	2100	0.48	2.21	2.69
8/26	900	0.59	0.38	0.97
8/26	2100	0.22	0.66	0.88
8/27	900	0.44	0.58	1.02
8/27	2100	1.05	2.41	3.46
8/28	900	0.99	0.59	1.58
8/28	2100	0.02	0.01	0.03
8/29	900	0.97	2.24	3.21
8/29	2100	0.25	0.69	0.94
8/30	900	0.92	0.65	1.57
8/30	2100	0.41	1.12	1.53
8/31	900	0.00	0.00	0.00
8/31	2100	0.55	0.55	1.10
9/ 1	900	0.15	0.02	0.17
9/ 1	2100	0.23	1.37	1.60
9/ 2	900	0.00	0.00	0.00
9/ 2	2100	0.15	1.16	1.31
9/ 3	900	0.34	1.00	1.34
9/ 3	2100	0.12	0.15	0.27
9/ 4	900	0.16	0.12	0.28
9/ 4	2100	0.09	0.06	0.15
9/ 5	900	0.06	0.00	0.00
9/ 5	2100	0.04	0.02	0.06
9/ 6	900	0.02	0.02	0.04
9/ 6	2100	0.03	0.01	0.04
9/ 7	900	0.22	0.32	0.54
9/ 7	2100	0.09	0.88	0.97
9/ 8	900	0.05	0.06	0.11
9/ 8	2100	0.04	0.02	0.06
9/ 9	900	0.02	0.00	0.00
9/ 9	2100	0.08	0.59	0.67
9/10	900	0.32	0.80	1.12
9/10	2100	0.06	0.08	0.14
9/11	900	0.03	0.02	0.05
9/11	2100	0.02	0.02	0.04
9/12	900	0.15	0.00	0.00
9/12	2100	0.02	0.02	0.04
9/13	900	0.72	2.04	2.76
9/13	2100	0.09	0.48	0.57
9/14	900	0.56	2.07	2.63
9/14	2100	0.12	0.85	0.97
9/15	900	0.50	2.15	2.65
9/15	2100	0.12	0.41	0.53
9/16	900	0.30	0.00	0.00
9/16	2100	0.10	0.00	0.00
9/17	900	0.40	0.00	0.00
9/17	2100	0.16	0.00	0.00
9/18	900	0.09	0.06	0.15
9/18	2100	0.07	0.03	0.10
9/20	900	0.06	0.02	0.08
9/20	2100	0.05	0.30	0.35
9/21	900	0.03	0.01	0.04
9/21	2100	0.02	0.02	0.04
9/22	900	0.03	0.02	0.05
9/22	2100	0.02	0.02	0.04
9/23	900	0.05	0.08	0.13
9/23	2100	0.02	0.48	0.50
9/24	900	0.02	0.17	0.19
9/24	2100	0.02	0.48	0.50
9/25	900	0.03	0.12	0.15
9/25	2100	0.05	0.55	0.60
9/26	900	0.29	1.96	2.25
9/26	2100	0.15	0.58	0.73
9/27	900	0.93	2.09	3.02
9/27	2100	0.16	0.92	1.08
9/28	900	0.00	0.00	0.00
9/28	2100	0.26	1.39	1.65
10/17	900	0.00	0.00	0.00
10/17	2100	0.23	1.38	1.61
10/18	900	0.47	1.67	2.14
10/18	2100	0.26	0.30	0.56
10/19	900	0.05	0.04	0.09
10/19	2100	0.11	0.44	0.55
10/20	900	0.44	2.70	3.14
10/20	2100	0.04	0.02	0.06
10/21	900	0.04	0.20	0.24
10/21	~~2100~~	~~0.08~~	~~0.20~~	~~0.28~~