UPPER GREEN RIVER OZONE INVESTIGATION
(O3i)

OZONE SPATIAL DISTRIBUTION SURVEY

02/22/2009 AND 06/03/2009

DATA SUMMARIES AND PLOTS

Prepared for

WYOMING DEPARTMENT OF ENVIRONMENTAL QUALITY
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1.0 INTRODUCTION

The University of Wyoming's (UW) Atmospheric Science Department (ATSC) designed and implemented two ozone spatial distribution surveys. A winter survey was performed in February 2009 and a summer survey was performed in June 2009. This ozone spatial distribution survey exercise was conducted through a contract with the Wyoming Department of Environmental Quality, Air Quality Division with the support of the UW School of Energy Resources. This report describes work performed for each of the two surveys.

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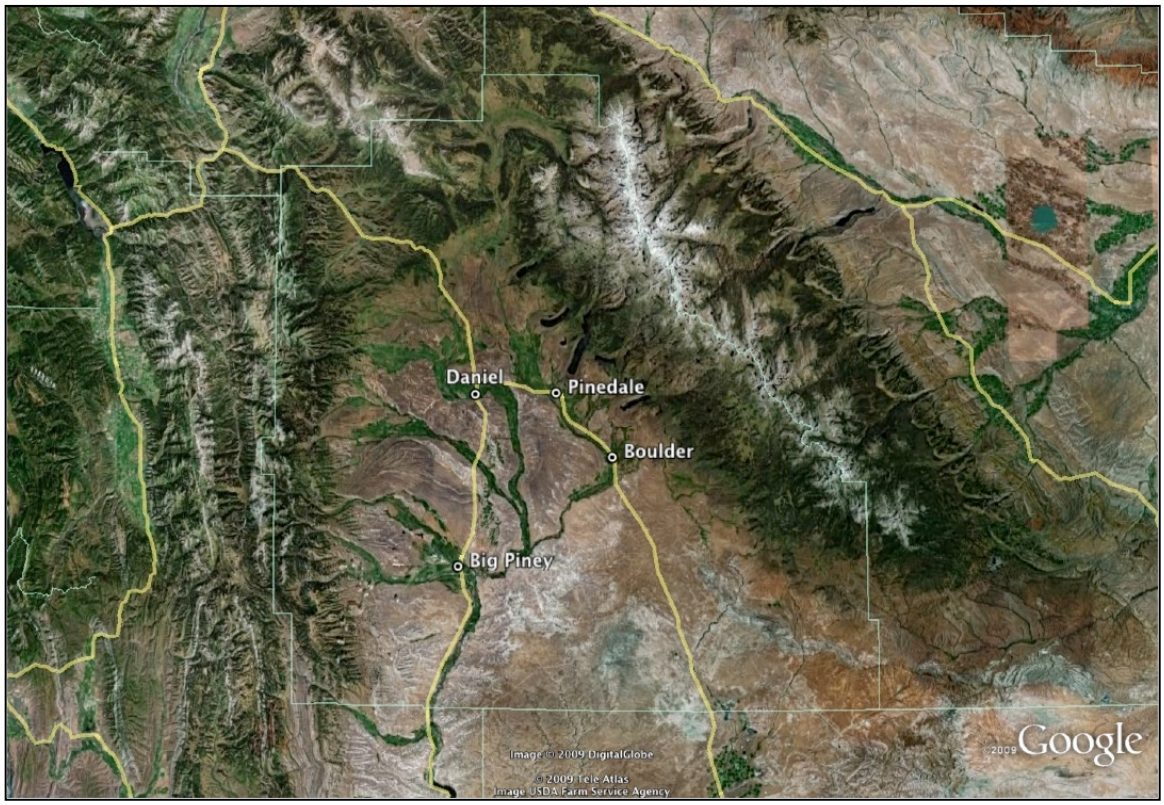
1.1 Background

A spatial survey using passive sampling enables an assessment of pollutant distribution over relatively extensive geographical areas. This approach has great utility for a number of purposes but most often to determine regions with elevated pollution levels. When monitoring data from spatial surveys are interpolated into iso-concentration contour maps pollution behavior can be revealed. Such maps have great utility to determine regions associated with both higher and lower pollution exposure. Iso-concentration contour maps are also used to evaluate placement of monitoring stations. A further important benefit of passive sampling approaches is the ease of use for direct assessment of human exposure as passive samplers are lightweight and easy to wear on the outer layer of clothing. For the purpose of O3i objective 2, fifty ambient sites were selected that represented different positions relative to the Pinedale Anticline Development Area (PAPA) and Jonah development. Figure 1-1 gives the location of each of these monitoring sites. In a small sample of approximately twenty, human exposure volunteers wore samplers at the same time as the ambient survey. The survey of spatial distribution of, and human exposure to, ambient ozone levels throughout Sublette County, Wyoming was conducted using samplers supplied by Ogawa & Company. The simultaneous spatial and human exposure surveys were conducted for eight hours on February 23, 2009 (winter) and June 03, 2009 (summer).

Figure 1-1 provides an overview of the study area with population centers indicated.

Figure 1-1. Map showing overview of the study area.



2.0 METHODOLOGY

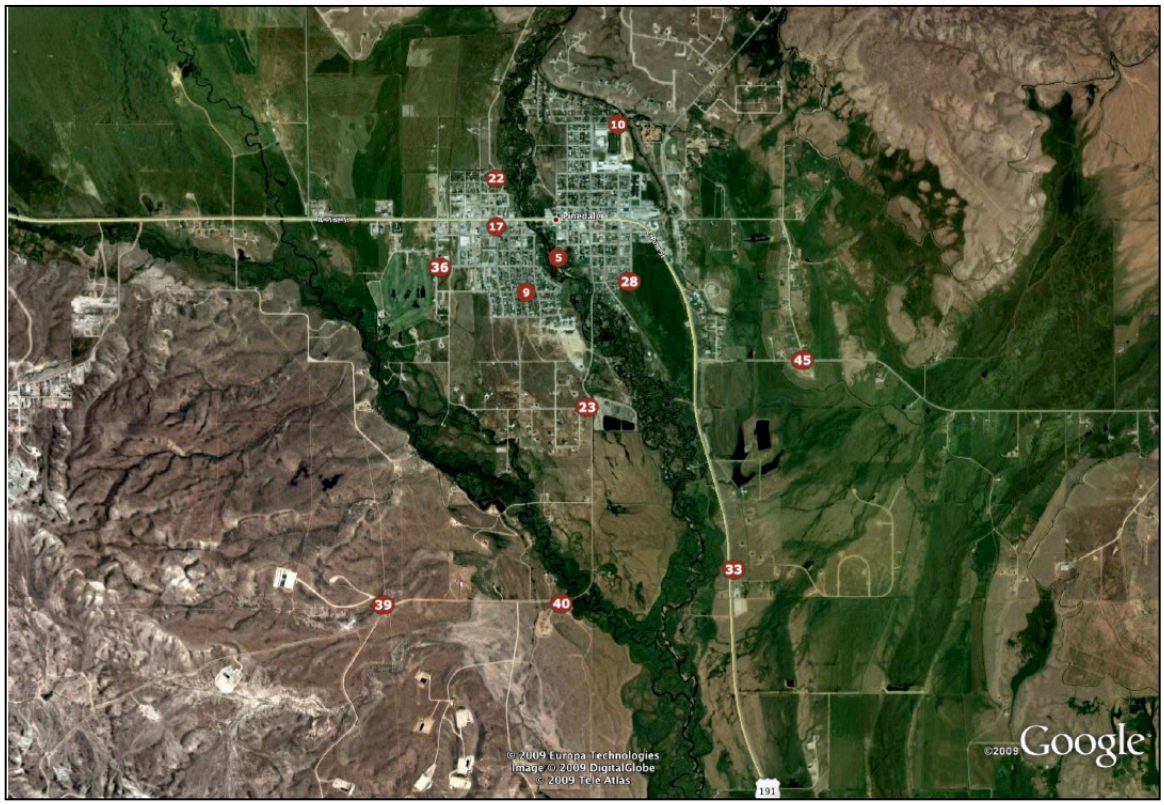
2.1 Monitoring Site Selection

Fifty sites were used for the ozone spatial survey study conducted as part of the UW ATSC O3i project. Sites were selected through the use of a simple ten by ten grid that was overlaid on a map of the study area. Based on this grid, approximately 108 possible sites were located. These sites were selected with the use of a real time GPS location software while driving on roads ranging from US highways to oil and gas development dirt roads. The final fifty site locations were determined based upon selection criteria of accessibility, representativeness, and safety. While many sites were selected close to roadways, the open nature of the region minimized the influence of the possibility of high levels of oxides of nitrogen interfering with the local level of ambient ozone. These sites are shown in Figure 2-1.

Figure 2-1. Map showing locations of spatial survey sites.

As evident from Figure 2-1 the highest density of samplers was at Pinedale. At the time of the set-up of the survey the WDEQ-AQD had not yet installed a continuous monitoring station in Pinedale. A high density of samplers was deemed important since monitoring at Pinedale had been limited up to this point. Furthermore elevated ozone had been reported close to the satellite community of Boulder. A close up of the Pinedale locations is given in Figure 2-2.

Figure 2-2. Map showing close up of Pinedale locations.



Each spatial site was equipped with an Ogawa O_3 ambient air passive sampler and an Ogawa O_3 protective shelter mounted on gray PVC pipe. Figure 2-3 presents both a photograph of a typical passive sampling site and a photograph of the Ogawa O_3 ambient air passive sampler system.

2.2 Volunteer Selection

A request for volunteers was performed in Sublette County. This was achieved through media requests with both newspaper and radio interviews. This approach was supplemented by direct contact with organizations and individuals who had interest regarding air quality in the region. Interested individuals that responded were offered the opportunity to participate; if able to receive sampler training, sign a waiver and generally be available during the anticipated monitoring timeframe. For the winter survey a pool of volunteers were trained with respect to sampler protocols as indicated below. The volunteers were then called and included if available. For the summer survey a different approach was taken with the collaboration of a science class from Pinedale High School. Volunteers were either students or employees of the school. This approach required the approval of the UW Institutional Research Board, as minors were part of the survey. For the summer survey a further difference was the addition of extra ambient samplers within the school grounds as well as indoor samplers inside of the school buildings.

Figure 2-3. Ogawa O3 protective shelter mounted on gray PVC pipe and an Ogawa O3 ambient air passive sampler.

2.3 Sampler Protocols

Prior to the survey a number of interested organizations and individuals were approached to assist with sampler placement and collection. This was essential as the samplers needed to be placed and collected within twenty minutes of each other. This was to ensure that the monitoring period was similar, from 9:00 to 5:00, for example, plus or minus 15 minutes. Each sampler placement team was asked to be at their first site at the same time. UW previously tested each sampling route. This testing was performed to make sure that each route was of broadly equal duration. Each team was provided with a sampler route and map. Placement of samplers was facilitated with the cooperation of fourteen teams, representing Local, State, and Federal Governments, the University, Industry, and local citizenry. A full list of all participants is contained in the acknowledgement section at the end of this report.

The complementary assessment of human exposure to ozone was facilitated with the cooperation of thirty-four individuals. These individuals consisted of two groups of eighteen and sixteen for the February and June exercises, respectively. Volunteers included individuals representing Local, State, and Federal Governments, and local citizenry, including Pinedale High School students and employees. Participants of the human exposure study were asked to start and end their sampler at the same time as for the spatial survey. The sampling protocol, supplied to each individual when they were trained in the use of the sampler, is given elsewhere in the Quality Assurance Project Plan (QAPP).

Team members and individuals participated in a training session before they took part in the sampler placement exercise. During this training session, they were instructed as to the use and placement of passive samplers, as well as instruction as to the location of assigned sampling sites. Volunteers participated in either a group or individual training session before they took part in the personal exposure assessment. During the training session, they were instructed as to the use of passive samplers, as well as basic information regarding proper handling of samplers. Each volunteer was required to complete a movement and activity diary. This diary required volunteers to track the location they were in, and how they moved about throughout the day.

Samplers were stored in a controlled environment in original packaging until the day before the planned survey. Several hours before distribution, sampler bodies and pre-coated ozone collection pads were assembled and prepared for use, according to protocols supplied by Ogawa and given in the quality assurance project plan.

Samplers were distributed to teams and individuals the evening before the sampler placement exercise. Participants stored samplers overnight in a cool dry place in a container provided to them and placed samplers the day of the sampling operation starting at 9 am. Placement of samplers was completed within a thirty-minute time frame. Each team retrieved samplers approximately eight hours later, at 5 pm. During sampler placement, teams completed a log that specified placement time, and whether or not they encountered any problems.

Samplers were collected and prepared for analysis immediately upon receipt from sampler placement teams or human exposure subjects. Samplers were kept refrigerated within an insulated cooler overnight. Samplers were shipped in an insulated container next day, via air-mail to the analysis laboratory.

Samplers were analyzed by RTI International, using standard protocols supplied by Ogawa, USA. RTI International supplied a spreadsheet with a mass loading for each sampler. UW then converted the mass loading for each sample to a final ambient ozone concentration using a standard uptake rate with blank correction. Travel blanks were used for approximately ten percent of the total number of samplers for the surveys. A correction factor was also applied for the ambient temperature and pressure.

2.4 Field Validation

Since passive sampling is a scoping methodology samplers were co-located with two types of ozone monitors in the study area. Table 2-1 presents site numbers, names, and operator of co-located sites.

Table 2-1. Location and site numbers of co-located sites.

University of Wyoming Spatial Ozone Survey Co-located Site Locations		
Site Number	**Site Name**	**Operator**
2	Buckhorn / CASTNET	Other
3	DEQ Jonah	WDEQ-AQD
4	Big Piney High School	UW
9	Pinedale Town Park	UW
12	Bargerville	Other
14	DEQ Boulder	WDEQ-AQD
22	DEQ Pinedale	WDEQ-AQD
32	Warbonnet	Other
37	Speedway	Other
46	DEQ Daniel	WDEQ-AQD

This comparison was undertaken to check the precision of the passive samplers, in particular since they were operated for relatively short time periods. The first type of co-located site is a Regulatory Equivalent Method (REM) site, and includes sites operated by DEQ-AQD and the University of Wyoming MAQML. The second type of co-located is a non-REM site contracted by DEQ-AQD for wintertime ozone monitoring.

3.0 RESULTS

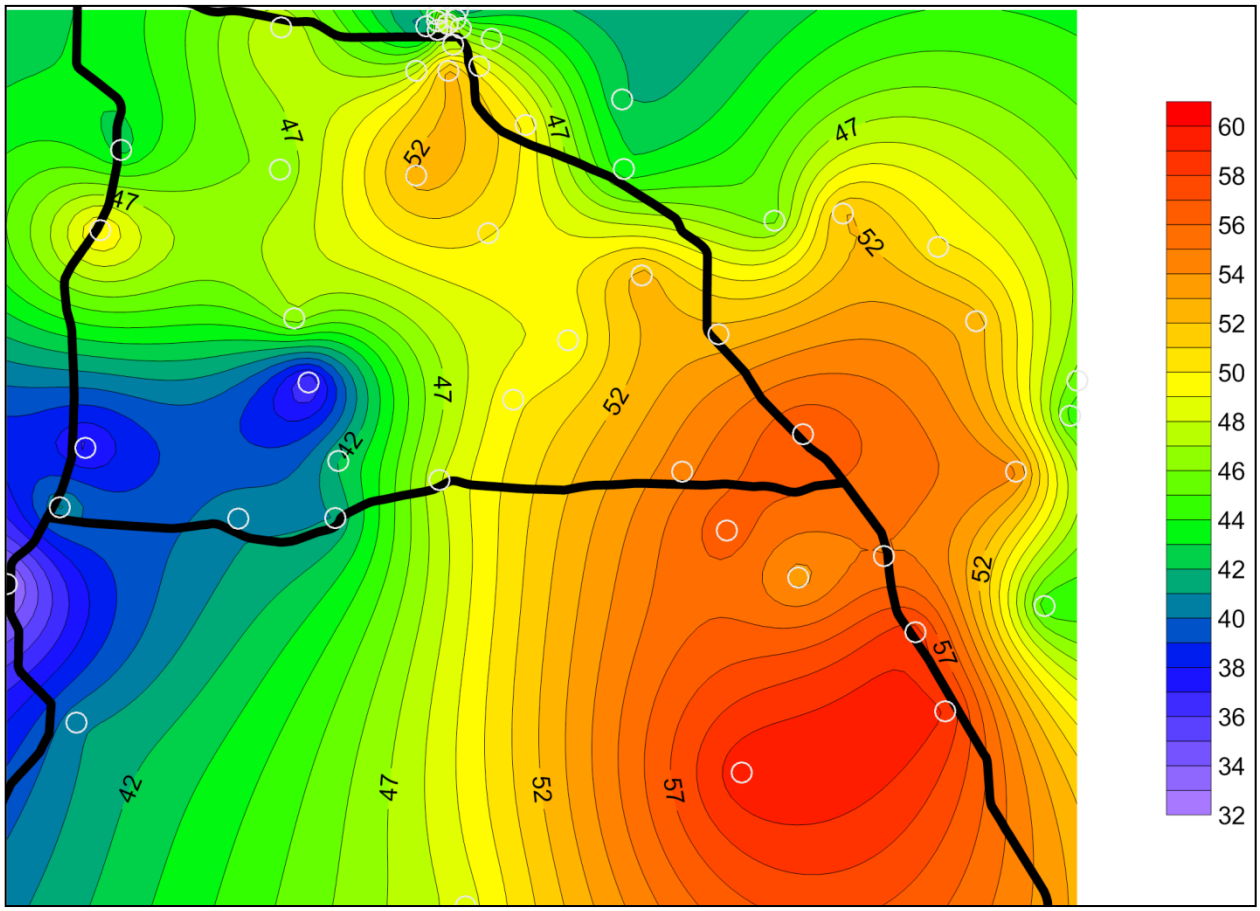
A table of the complete list of results for each ambient sampler is given in Appendix A. This information is presented for each ambient spatial survey. While the listed concentrations are useful the main purpose of the ambient survey was to consider the spatial distribution of ozone in the survey area. As such the figures presented in this section are color coded to allow for direct comparison between the two surveys. It should be noted however that each survey is for a particular day and as such represents a snapshot of the conditions for that day. It is known that during the wintertime, ozone conditions are critically dependent upon meteorological conditions. While the summer survey date was set many weeks in advance the exact date of the winter survey was not known until a few days prior to sampling. The exact date was determined according to a review of the meteorological conditions and was set in consultation with WDEQ-AQD.

3.1 Winter Survey Ambient Ozone February 2009

Figure 3-1 is an iso-concentration contour map constructed using data from the ambient sampling performed on February 22nd 2009. In order to orientate the contours the main highways are also placed on the map, namely US 189, US 351 and US 191. The exact location of each sampler is indicated with a white circle. It should be noted that a slight difference between the concentration indicated by the relevant circle and the map is anticipated due to the interpolation calculation employed by the surfer software used to generate the map.

During the monitoring period wind speeds at Big Piney were relatively low, 1.4 m/s, with Easterly wind directions dominant as indicated by Figure 3-2. It is interesting to note that the figure indicates a gradient of ozone concentrations with lowest concentrations to the West with highest concentrations to the South East.

Figure 3-1. Spatial map showing results of February 22, 2009 passive ozone survey.



To place the quality of these measurements in context of other monitoring that was performed at the same time, Table 3-1 compares data from the passive samplers with that measured over the same timeframe by continuous analyzers. This table also presents a ratio that can be used as an indicator of the relative bias between the passive samplers and the other various analyzers.

Figure 3-2. Wind rose for Big Piney February 22, 2009 8:30 to 17:30.

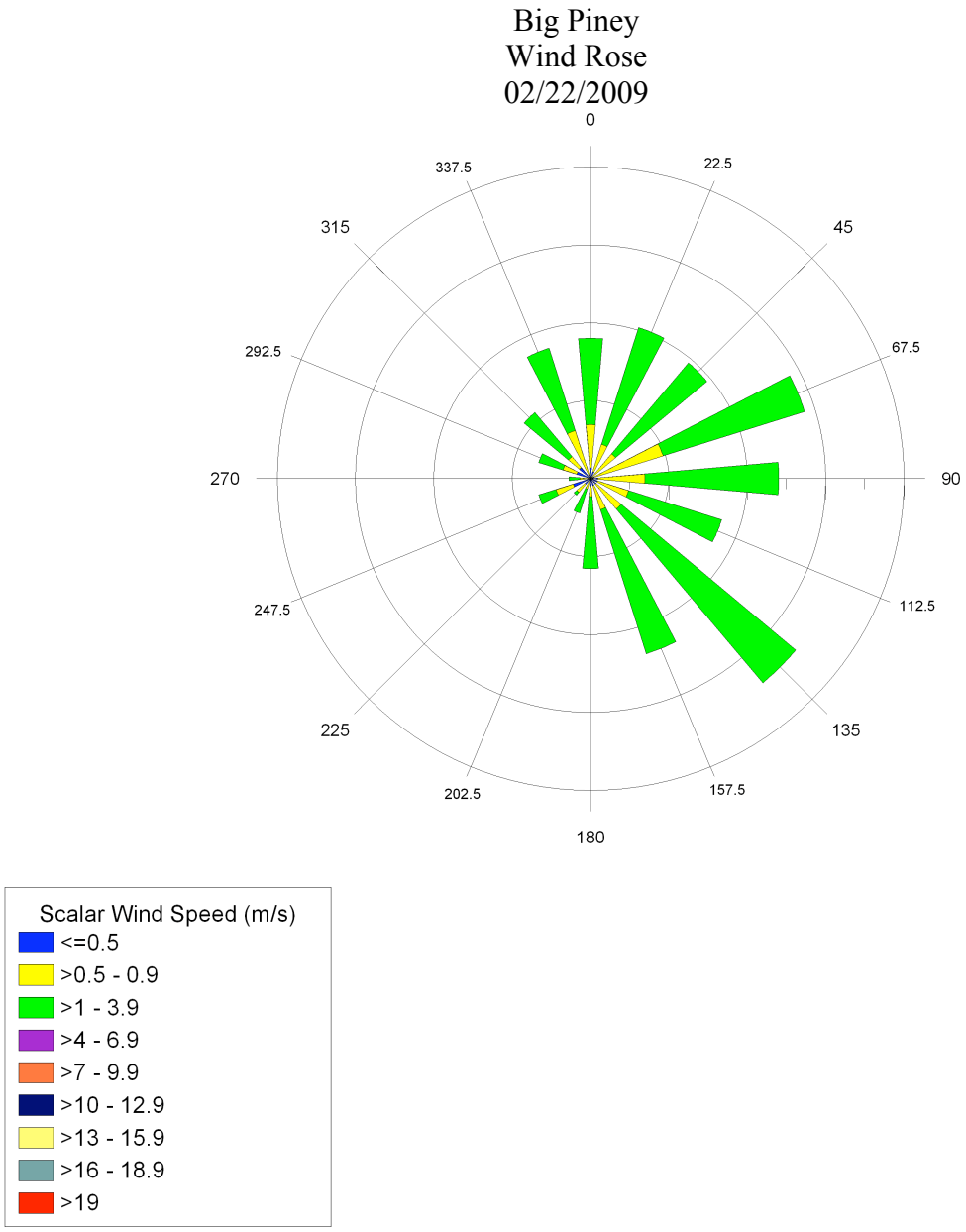


Table 3-1. Comparison of measurements at co-located sites February 22nd 2009.

University of Wyoming Spatial Ozone Survey Co-located Site Values				
Site Number	**Site Name**	**Passive (ppb)**	**FEM (ppb)**	**Ratio %**
3	Jonah	60	63	95
14	Boulder	53	56	95
22	Pinedale	47	47	100
46	Daniel	43	49	88

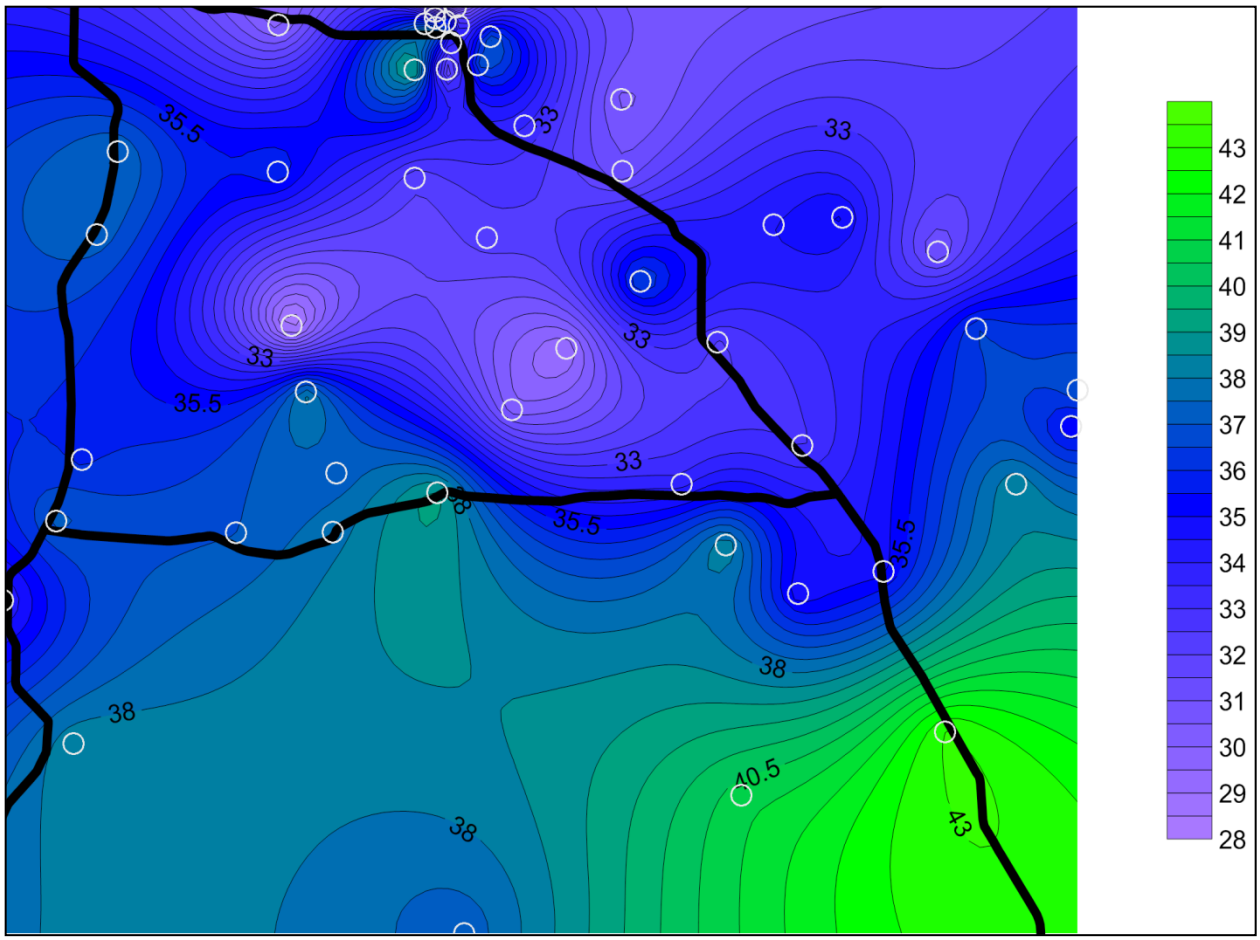
The comparison in Table 3-1 shows good agreement between the two methodologies. Only data from Federal Equivalent Methodology (FEM) sites are shown. There is no significant difference and as such for this survey the results can be considered to be equivalent with a difference of approximately 5%.

3.2 Summer Survey Ambient Ozone June 2009

Figure 3-3 is an iso-concentration contour map constructed using data from the ambient sampling performed on June 3rd 2009. In order to orientate the contours the main highways are also placed on the map, namely US 189, US 351 and US 191. The exact location of each sampler is indicated with a white circle. It should be noted that a slight difference between the concentration indicated by the relevant circle and the map is anticipated due to the interpolation calculation employed by the surfer software used to generate the map.

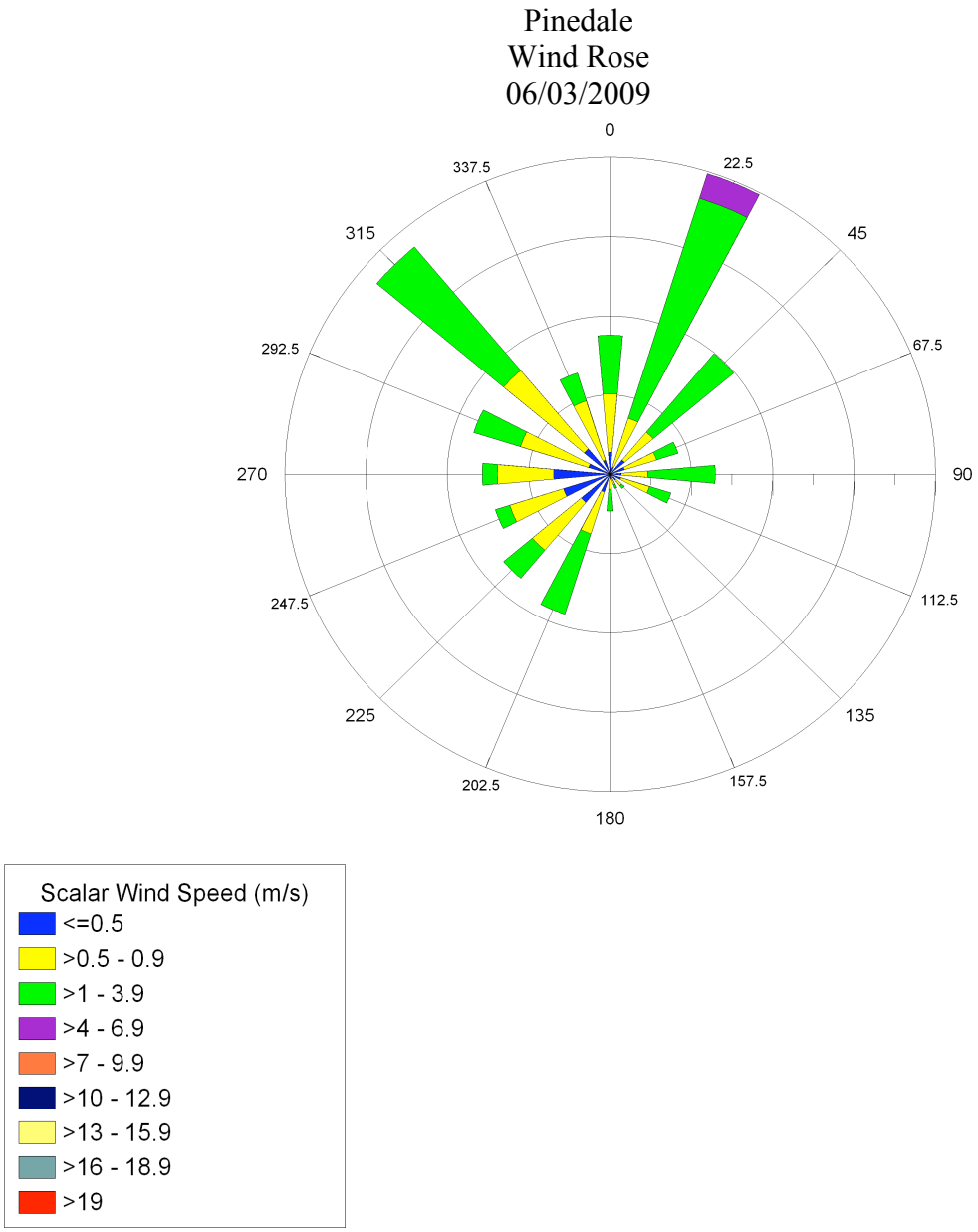
During the monitoring period wind speeds at Pinedale were low, 1.1 m/s, with a range of wind directions, with NW and NNE having the greatest representation as indicated by Figure 3-4. It is interesting to note that while ozone concentrations are low the figure indicates a gradient of ozone concentrations with lowest concentrations to the West and highest concentrations to the South East.

Figure 3-3. Spatial map showing results of June 3, 2009 passive ozone survey.



To place the quality of these measurements in context of other monitoring that was performed at the same time Table 3-2 compares data from the passive samplers with that measured over the same timeframe by continuous analyzers. This table also presents a ratio that can be used as an indicator of the relative bias between the passive samplers and the other various analyzers.

Figure 3-4. Wind Rose for Pinedale June 3, 2009 8:00 to 17:00.



Data from four FEM sites was available for the comparison. As indicated by Table 3-2 the passive samplers are lower than continuous analyzers by approximately 15%. The ratios evident from this table should be considered along with the conditions of the comparison. The amount of pollutant collected was low as the exposure time of the samplers was shorter than that usually applied for such the devices. Often these samplers are used for 24 to 172 hours with conditions including ozone concentrations in excess of 100 ppb.

Table 3-2. Comparison of measurements at co-located sites June 3rd 2009.

University of Wyoming Spatial Ozone Survey Co-located Site Values				
Site Number	**Site Name**	**Passive (ppb)**	**Analyzer (ppb)**	**Ratio**
14	Boulder	37	46	80
46	Daniel	38	43	88
22	Pinedale	30	36	84
2	Castnet Pinedale	37	44	87

3.3 Winter Survey Human Exposure to Ozone February 2009

Table 3-3 gives the results for each of the human exposure samplers along with the time that was spent inside structures, most commonly buildings, breathing indoor air and the time spent outside breathing ambient air.

Table 3-3. Human exposure results for the winter survey.

University of Wyoming Spatial Ozone Survey Human exposure participants			
Sampler Number	**Ozone ppb**	**% Time indoors**	**% Time outdoors**
68	0.1	100	0
63	2.4	97	3
61	1.1	94	6
55	3.3	91	9
67	6.2	89	11
60	3.6	88	12
52	4.2	84	16
64	5.9	82	18
62	23.6	81	19
57	17.3	80	20
53	13.2	79	21
66	15.7	78	22
54	6.8	76	24
65	9.2	70	30
58	30.3	59	41
51	44.5	28	72
59	19.1	20	80

There is a clear relationship between the time spent indoors and outdoors and the actual exposure value of the participant to ozone. Since the sample size was less than twenty participants Table 3-4 pools the data into three different classes; namely indoors, mixed and mainly outdoors, in terms of time spent outdoors.

Table 3-4. Human exposure and time spent indoors for the winter survey.

University of Wyoming Spatial Ozone Survey Human exposure participant classes		
Class (time spent outdoors)	**n**	**Ozone ppb**
Indoors (0 to 12%)	6	2.8
Mixed (16 to 30%	8	12.0
Outdoors (>40%)	3	31.3

Generally, the more time that is spent outdoors, the higher the exposure level.

3.4 Summer Survey Human Exposure to Ozone June 2009

Table 3-5 gives the results for each of the human exposure samplers along with descriptions of the type and class of participant and the time that was spent inside structures, most commonly buildings, breathing indoor air and the time spent outside breathing ambient air.

Table 3-5. Human exposure results for the summer survey.

University of Wyoming Spatial Ozone Survey Human exposure participants					
Sampler Number	**Participant**	**Class**	**Ozone ppb**	**% Time indoors**	**% Time outdoors**
56	Office Staff	At school	8.2	100	0
71	Office Staff	At school	4.9	96	4
63	Teacher	At school	7.1	88	12
65	Teacher	At school	2.6	100	0
57	Student	At school	4.0	100	0
76	Student	Hybrid	13.0	58	42
70	Student	Hybrid	10.6	58	42
51	Student	Hybrid	12.9	58	42
53	Student	Hybrid	13.6	58	42
60	Student	Field trip	29.3	5	95
66	Student	Field trip	16.6	5	95
68	Student	Field trip	33.1	5	95
69	Student	Field trip	21.3	5	95
55	Student	Field trip	37.4	5	95
59	Student	Field trip	26.2	5	95
61	Student	Field trip	37.9	5	95
64	Student	Field trip	31.3	5	95

Table 4-6 summarizes the information presented in Table 4-5 by participant class. At school is predominately indoors. Hybrid is a mixed category with significant time spent both indoors and outdoors. Field trip is predominately outdoors.

Again, the more time that is spent outdoors, the higher the exposure level.

Table 3-6. Human exposure and time spent indoors for the summer survey.

University of Wyoming Spatial Ozone Survey Human exposure participant classes		
Class (time spent outdoors)	**N**	**Ozone ppb**
At school (0 to 15%)	5	5.4
Hybrid (40 to 50%)	4	12.5
Outdoors (>90%)	8	29.1

It should be noted that the field trip for the students that morning was spent close to the Forest Service remote air quality monitoring station north of Pinedale. The afternoon was spent in the center of Pinedale at Town Park. The data for the human exposure participants is supplemented by further sampling at a number of indoor and outdoor locations on the Pinedale High School property. This data is given in Table 3-7.

Table 3-7. Pinedale High School indoor and outdoor sampling.

University of Wyoming Spatial Ozone Survey Indoor and outdoor sampling		
Sampler	**Location**	**Ozone ppb**
54	Tennis court	38.7
74	Front lawn sculpture	45.5
79	Pool vent	64.6
78	Next to running track	36.6
67	Office*	11.2
52	Gym	5.7
62	Classroom	11.7
58	Cafeteria	9.3

* Sampler was located close to photocopier

Table 3-7 also indicates that levels of ozone are higher outdoors than indoors. Three of the samplers report comparable concentrations to those from the ambient survey for Pinedale. One of the outdoor samplers, pool vent, was located at exit of the ventilation system of the ozonator for the swimming pool. This sampler was housed on the vent at a height consistent with the other outdoor samplers. Another potential source of ozone is electronic equipment. Photocopiers have been identified to produce ozone. One sampler that was located close to photocopier did not appear to indicate a significant elevation, in

particular since dispersion of air is often much slower indoors than outdoors. The office staff indicated in Table 3-5, who work close to the office indicated above, also had low levels of exposure to ozone.

6.0 DISCUSSION

The approach employed for the ozone spatial distribution survey was successful in terms of both implementation and data generation. The work presented in the proceeding sections demonstrates that the original objective of performing a scoping study of the distribution of ambient ozone concentrations in Sublette County was achieved. In the planning phase it was the original intention to run more winter surveys. It was anticipated that the weather conditions would be similar to previous years and as such monitoring would be performed during ozone advisories. The winter of 2009 had few periods of stagnant air and relatively low snowfall. While poor dispersion conditions and build-up of ozone was reported on a few occasions, there were no significant longer-term ozone episodes, and as such there were few ozone advisories and no 8-hour average ozone concentrations greater than the NAAQS during the winter of 2009. While being ready to perform further winter surveys, the required conditions did not present themselves and WDEQ-AQD did not request a second winter survey. It should be noted that the results presented here are complementary to those of the WDEQ-AQD Winter Ozone Study. A summer ozone spatial survey was performed as a contrast to the winter conditions for both the operation of the samplers as well as the ambient and exposure conditions. Since the summer survey was less relevant for checking higher levels of human exposure to ozone UW decided to collaborate with a science class from Pinedale High School. This collaboration as a further community outreach aspect of the project was important as an educational component for the school as well as meeting the outreach mission of UW.

7.0 CONCLUSIONS

- Passive sampling of ozone to derive an understanding of spatial distribution over large geographical areas is feasible, even in winter conditions such as those experienced in the Upper Green River Basin.

- Passive sampling surveys have good utility as a scoping tool to determine pollutant distribution.

- Ozone concentrations from passive samplers were comparable to those reported for WDEQ-AQD regulatory equivalent monitoring analyzers.

- For the two days sampled, winter-time ozone concentrations had greater variation and higher absolute levels than those in the summer-time.

- Lowest ozone concentrations were interpolated towards the West and the North of the study area.

- Highest ozone concentrations were interploated for the South East of the study area downwind of PAPA and in the region of the Jonah development.

- Elevated ozone concentrations in the winter-time map do not appear to be a result of transport into the study area, indicating the likelihood of local production.

- Human exposure to ozone is strongly influenced by the relative time spent indoors and outdoors.

- Ozone levels indoors are generally much lower than outdoors.

- An unusual outdoor source of ozone was identified at Pinedale High School; namely the vent from the ozonator used to clean swimming pool water.

APPENDIX A

Results for the Winter and Summer Ozone Surveys

University of Wyoming Spatial Ozone Survey Site Values				
Site Number	**Site Name**	**Winter**	**Site Name**	**Summer**
1	Route 2 Citizen	40.8	Route 2 Citizen	38.4
2	Route 12 BP	48.5	Route 5 FS CASTNET	37.1
3	Route 12 BP	59.8	Route 12 BP	40.8
4	Route 1 UW 1 lab	32.2	Route 1 UW 1	33.8
5	Route 9 Town Pinedale	49.7	Route 9 Town Pinedale	38.3
6	Route UW 2	55.0	Route UW 2	34.8
7	Route 4 SCCD	52.5	Route 4 SCCD	36.5
8	Route 10 Questar	52.5	Route 10 Questar	32.1
9	Route 9 Town Pinedale	46.6	Route UW 2 Lab	37.4
10	Route 9 Town Pinedale	40.1	Route 9 Town Pinedale	29.1
11	Route 10 Questar	50.0	Route 10 Questar	32.3
12	Route 8 DEQ	42.1	Route 8 DEQ	30.4
13	Route 1 UW 1	50.4	Route 1 UW 1	37.4
14	Route 10 Questar	52.6	Route 10 Questar	36.8
15	Route UW 2	57.0	Route UW 2	32.9
16	Route 4 SCCD	44.4	Route 4 SCCD	34.9
17	Route BLM 2	46.9	Route BLM 2	33.5
18	Route BLM 2	48.1	Route BLM 2	29.7
19	Route 11 Shell	53.4	Route 11 Shell	34.6
20	Route 3 BLM 1	46.8	Route 3 BLM 1	27.8
21	Route 5 FS	52.2	Route 5 FS	35.1
22	Route BLM 2	46.6	Route BLM 2	29.5
23	Route SCHD	46.9	Route SCHD	32.9
24	Route 3 BLM 1	42.2	Route 3 BLM 1	37.1
25	Route BLM2	40.8	Route 2 Citizen	37.0
26	Route 2 Citizen	35.6	Route 2 Citizen	38.2
27	Route 2 Citizen	46.1	Route BLM2	36.0
28	Route 13 CURED 1	46.5	Route 13 Town Pinedale II	33.2
29	Route 5 FS	50.2	Route 5 FS	30.9
30	Route 11 Shell	49.8	Route 11 Shell	30.2
31	Route 1 UW 1	36.6	Route 1 UW 1	35.9
32	Route 11 Shell	56.6	Route 11 Shell	38.5
33	Route 13 CURED 1	49.1	Route 13 Town Pinedale II	36.8
34	Route 5 FS	45.6	Route 5 FS	34.5
35	Route 3 BLM 1	41.0	Route 3 BLM 1	37.7
36	Route 9 Town Pinedale	39.6	Route 9 Town Pinedale	37.5
37	Route 4 SCCD	45.6	Route 4 SCCD	37.0
38	Route 3 BLM 1	48.0	Route 3 BLM 1	39.3

39	Route SCHD	47.8	Route SCHD	39.6
40	Route SCHD	52.7	Route SCHD	30.9
41	Route 1 UW 1	41.2	Route 1 UW 1	37.2
42	Route UW 2	52.3	Route UW 2	32.4
43	Route 10 Questar	49.0	Route 10 Questar	29.0
44	Route 11 Shell	54.6	Route 11 Shell	33.8
45	Route 13 CURED 1	45.9	Route 13 Town Pinedale II	37.1
46	Route 1 UW 1	42.5	Route 1 UW 1	37.5
47	Route 8 DEQ	49.8	Route 8 DEQ	33.5
48	Route 8 DEQ	43.2	Route 8 DEQ	31.1
49	Route 4 SCCD	54.3	Route 4 SCCD	38.5
50	Route 12 BP	59.0	Route 12 BP	43.1

ACKNOWLEDGEMENTS

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- Sublette County Health District (Keith Raney)
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- USFS (Ted Porwoll and Ed Sherman),
- Citizens United for Responsible Energy Development (Bev and Sam Sharp, Perry Walker, Tina Rock and Mary Lynn Worl)
- WDEQ-AQD (Jennifer Frazier)
- Town of Pinedale (Mayor Steve Smith, Assistant Mayor Mary Hogarty, Patty and Dave Racich and Kate Grimes)
- Shell (Jim Sewell, David Osborn, Charles Travis, Bill Cook and Levi Ackland)
- British Petroleum (Don Brooks, Todd Morgan)
- Questar (Kevin Williams)
- Big Piney High School Students and Employees (Steven Nelson)
- Pinedale High School Students and Employees (Elizabeth David)

Furthermore we would like to thank the citizens of Sublette county and students of Pinedale High School who wore samplers for our human exposure surveys. Your participation was essential to meet the aims of O3i. We would like to thank the management of the Rock Rabbit Café who allowed us to train volunteers and use their premises as the center of operations on survey days.

We appreciate the effort of UW Institutional Research Board to approve the use of human subjects in this survey. We gratefully acknowledge the financial support of WDEQ-AQD and the UW School of Energy Resources, without funding this study would not have been possible.