Addendum to

AIR QUALITY MODELING STUDY FOR THE FOUR CORNERS REGION

Additional Ozone Source Apportionment and Ozone Sensitivity Modeling Analyses

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TABLE OF CONTENTS

Page

PREFACE **1**

OZONE SOURCE APPORTIONMENT ANALYSIS **1**

Methodology 2
Results 3

CALCULATION OF OZONE SENSITIVITIES VIA HDDM **10**

Methodology 10
Results 11

REFERENCES **21**

APPENDICES

Appendix A: Additional Ozone Source Apportionment Results
Appendix B: Osat Tabular Results

TABLES

Table 1. Definitions of source groups used in 2018 base case ozone source apportionment runs 2
Table 2. Definitions of the eleven source categories used in the OSAT time series plots (Figures 1 and 2) 6
Table 3. Number of 8-hour running averages during the year with ozone greater than indicated threshold 7
Table 4. Source groups used in ozone sensitivity (HDDM) runs 11
Table 5. Number of days with afternoon 8-hour average ozone greater than indicated threshold (shading indicates combinations for which too few days are available from which to compute average sensitivities) 11

FIGURES

Figure 1. Ozone source apportionment results (running 8-hour averages) at Mesa Verde during April (top) and July (bottom) 4
Figure 2. Ozone source apportionment results (running 8-hour averages) at Navajo Lake during April (top) and July (bottom) 5

Figure 3. OSAT source contributions: average over all 8-hour periods with predicted ozone exceeding 65 ppb (contributions from initial and boundary conditions not included); table shows percent contribution to total (values for each monitoring site sum to 100%) 8

Figure 4. Comparison of ozone source contributions averaged over all 8-hour periods exceeding 65 ppb and 70 ppb at Mesa Verde (top) and Navajo Lake (bottom) 9

Figure 5. Average ozone sensitivities at Navajo Lake to changes in VOC and NOx emissions from anthropogenic sources in the 12 km modeling domain (outside the 4 km domain) on afternoons of high ozone days in July. Results based on average over all 11:00 – 19:00 MST 8-hour periods exceeding 65 ppb (top) and 70 ppb (bottom) 12

Figure 6. As in Figure 5 but for average ozone sensitivities at Navajo Lake to changes in VOC and NOx emissions from oil and gas sources in the 4 km modeling domain on afternoons (11:00 – 19:00 MST average) of high ozone days in July as defined by a 65 ppb threshold (top) and a 70 ppb threshold (bottom) 14

Figure 7. As in Figure 5 but for average ozone sensitivities at Navajo Lake to changes in EGU NOx emissions and changes in oil and gas (O+G) VOC emissions in the 4 km modeling domain on afternoons (11:00 – 19:00 MST average) of high ozone days in July as defined by a 65 ppb threshold (top) and a 70 ppb threshold (bottom).....16

Figure 8. As in Figure 5 but for average ozone sensitivities at Navajo Lake to changes in EGU NOx emissions and changes in oil and gas (O+G) NOx emissions in the 4 km modeling domain on afternoons (10:00 – 18:00 MST average) of high ozone days in July as defined by a 65 ppb threshold (top) and a 70 ppb threshold (bottom).....18

Figure 9. As in Figure 5 but for average ozone sensitivities at Mesa Verde on afternoons (10:00 – 18:00 MST average) of high ozone days in April as defined by a 65 ppb threshold to changes in: oil and gas VOC and NOx emissions (top left), EGU NOx and oil and gas VOC emissions (top right) and EGU NOx and oil and gas NOx emissions (bottom left) 19

PREFACE

A detailed photochemical modeling analysis of current and potential future air quality conditions in the Four Corners region was carried out during 2007 – 2009 under the auspices of the Four Corners Air Quality Group (FCAQG). Results of this study, which was funded by the New Mexico Environmental Department using a grant from the U.S. Environmental Protection Agency, were described in a comprehensive final report (*Air Quality Modeling Study for the Four Corners Region*, Stoeckenius et al., 2009[1]). As the Four Corners modeling study was nearing completion, the FCAQG decided it would be useful to perform some additional ozone source apportionment and ozone sensitivity modeling to expand upon the results presented in the final study report. BP America Production Co. agreed to fund the additional work which is described in this addendum to the above referenced report. Only brief mention is made here of the background, methodology and results of the Four Corners modeling study; readers are urged to become familiar with the Stoeckenius et al. report prior to reading this addendum.

OZONE SOURCE APPORTIONMENT ANALYSIS

As described by Stoeckenius et al. (2009), source apportionment modeling was conducted on the 2018 base case scenario to assist with understanding the contributions of different source groups to ozone and PM impacts. These analyses were prepared using ozone and PM source apportionment technology (OSAT and PSAT, respectively), in which precursor emissions are stratified by source category and by source region; tracers are used to tag emissions from each category-region pair and track transport, chemical evolution, and removal. In OSAT, NOx and VOC tracers are run to apportion total ozone throughout the grid to NOx and VOC precursor source categories and regions. NOx and VOC are attributed to ozone formation according to local NOx- or VOC-limited chemical conditions along the transport route. When interpreting results from an OSAT or PSAT run, it is important to understand that the apportionment of ozone and PM in this manner is defined by the particular emission scenario used in the OSAT/PSAT simulation (in this case the 2018 base case scenario). Use of a different emission scenario would result in a different set of relative source contributions as non-linear chemistry changes the source apportionment matrix. It should also be noted that source apportionment is not the same as conducting *source reduction sensitivity tests* such as the HDDM sensitivity analyses described in a later section of this addendum. Source reduction sensitivity tests are used specifically to understand how changes in emissions for a certain source type/location impact chemistry and ultimately ozone and PM concentration patterns. Thus, a source reduction sensitivity test is not an attribution or apportionment of ozone or PM, but more of a measure of how sensitive ozone or PM formation chemistry is to emission changes for the source being tested under a given emission scenario. The difference between emission sensitivity and source apportionment is the non-linear chemistry. The definitions of source sensitivity and source apportionment would be equivalent only if the chemistry component were to be removed (e.g., in a situation involving only inert pollutants). Additional information and a more detailed description of OSAT and PSAT as well as the HDDM methodology is provided in ENVIRON (2008).

[1] Available from http://www.nmenv.state.nm.us/aqb/4C/Modeling.html

Methodology

CAMx was run with OSAT for the full annual 2018 base case described by Stoeckenius et al. (2009). A set of source groups defined as combinations of source types (e.g., electric generating units) and source regions (e.g., portion of Arizona contained within the 4 km modeling domain) were selected for this analysis as shown in Table 1. These source groups differ from those used by Stoeckenius et al. (2009) in that the contributions of biogenic and fire emissions are treated separately in both the 4 km and 12 km modeling domains whereas fire emissions had previously been lumped together with other, non-EGU (Electric Generating Unit) point sources in both the 4 km and 12 km domains and biogenic sources had been lumped together with area sources in the 12 km domain.

Table 1. Definitions of source groups used in 2018 base case ozone source apportionment runs[2]

Source Category/Region	4 km Modeling Domain			12 km Modeling Domain[3]
	Colorado	New Mexico	Arizona & Utah	
Oil & gas combustion sources (compressors, drill rigs, heaters, all other engines)	Area & Point[4]	Area	Area & Point[5]	All Anthropogenic Sources
Oil & gas large point sources in NM	--	Point	--	
Oil & gas non-combustion sources (fugitives, completions, venting)	Area	Area	Area	
Mobile sources (on-road and non-road)	Area	Area	Area	
Other area sources	Area	Area	Area	
Electric Generating Units	Point	Point	Point	
Other (non-EGU, non-O&G) point sources	Point	Point	Point	
Biogenics	Area	Area	Area	Area
Fire	Point	Point	Point	Point

As in Stoeckenius et al. (2009), oil and gas sources were divided into two types: combustion sources such as compressors, etc. which emit primarily NOx along with some other pollutants and non-combustion sources such as completions, blowdowns, pneumatic devices, etc. which release VOC emissions. EGUs were grouped separately from other (non oil and gas) point sources. The "Other area source" group includes all area sources not included in any of the other source groups and includes small, widely distributed sources such as space heating, dry cleaners, etc. In addition to the source groups defined in Table 1, OSAT calculates source contribution estimates for initial conditions and for boundary conditions.

[2] In addition to these source categories, CAMx computed contributions from 1) 12 km domain boundary conditions and 2) initial conditions
[3] Excluding emission sources within the 4 km domain
[4] All NOx sources greater than 2 tons/year included as point sources
[5] Only large NOx sources included as point sources, small sources are included as area sources

Results

Source contributions to 8-hour average ozone during April and July at the Mesa Verde and Navajo Lake monitoring sites are illustrated by the time series in Figures 1 and 2, respectively.[6] Results for additional monitoring sites (Farmington, San Juan, Shamrock, Ignacio and Bondad) are provided in Appendix A. For simplicity, source groups shown in these time series are defined as shown in Table 2 in terms of combinations of the OSAT source groups from Table 1. These time series plots also show the contributions from boundary and initial conditions (BC/IC); initial condition contributions are insignificant since they only impact the results during the first few days of a simulation and are thus largely removed during the simulation spin-up period which occurs prior to the first of the month. Note that the "NonEGUs" source group represents the total "other point source category" for the 4 km domain. These results are consistent with the OSAT time series described by Stoeckenius et al. (2009). Contributions from oil and gas sources and EGUs are evident during many of the peak ozone events. With the fire and biogenic source categories now separated out, it is possible to see that fires occasionally contribute several ppb of ozone (for example just over 8 ppb at Mesa around 19 July) but there is no contribution from fires on several other days with peak ozone as high or higher as on the fire days.[7] An important feature of these results is that anthropogenic sources located in the 12 km domain (outside the 4 km domain) generally contribute more to ozone formation than do 12 km domain fire and biogenic sources. Boundary conditions contribute nearly all of the ozone predicted during April whereas the boundary condition influence is much lower in July. This seasonality in the boundary condition apportionment was discussed in more detail by Stoeckenius et al. (2009).

[6] Source apportionment is for the cell with the maximum ozone concentration in a 7 x 7 cell matrix centered on the grid cell containing the monitoring site. This methodology is consistent with EPA's ozone attainment demonstration guidelines (EPA, 2007).

[7] As per Table 2, fire source contributions shown in Figures 1 and 2 represent the combined contribution of fires in both the 4 km and 12 km modeling domains; separate contributions from fires in these two domains are provided in the source apportionment tabular results included in Appendix B.

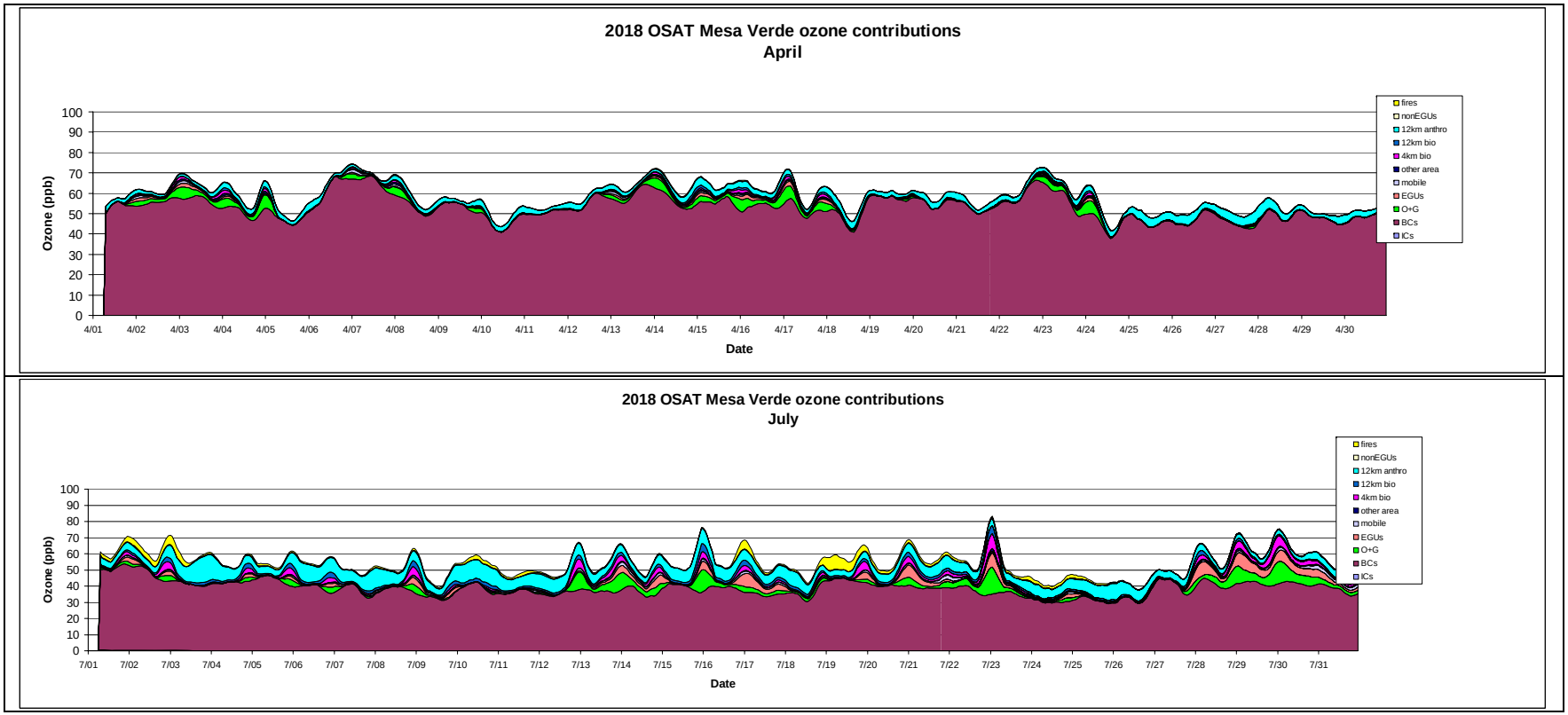


Figure 1. Ozone source apportionment results (running 8-hour averages) at Mesa Verde during April (top) and July (bottom).

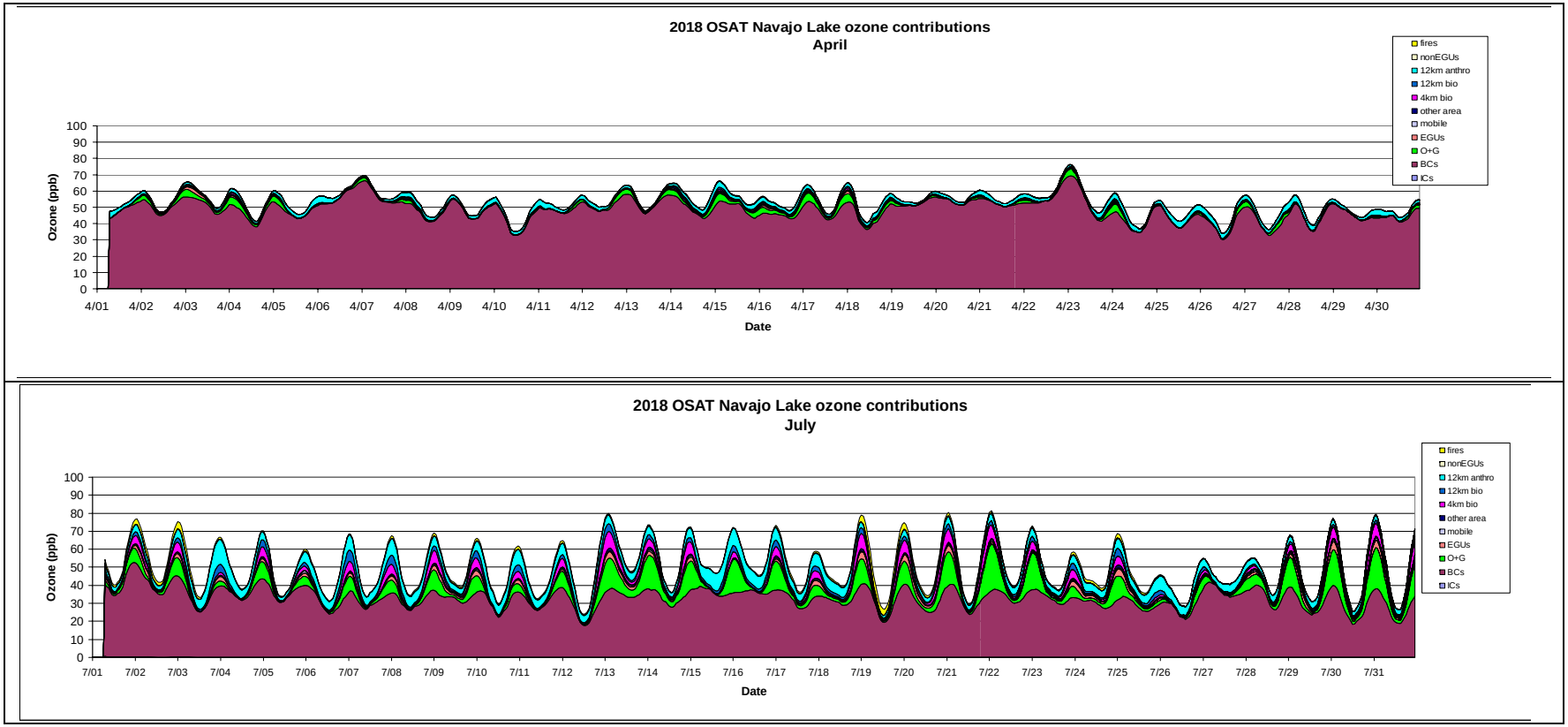


Figure 2. Ozone source apportionment results (running 8-hour averages) at Navajo Lake during April (top) and July (bottom).

Table 2. Definitions of the eleven source categories used in the OSAT time series plots (Figures 1 and 2).[8]

Source Category/Region	4 km Modeling Domain	12 km Modeling Domain[9]
All Oil & gas combustion and non-combustion sources	O+G	All Anthropogenic Point & Area
Other area sources	Other Area	
on-road and non-road mobile sources	Mobile	
Electric Generating Units	EGUs	
Other (non-EGU, non-O&G) point sources	Non-EGUs	
Biogenics	4km bio	12km bio
Fire Emissions	Fire	
Initial Conditions	ICs	
Boundary Conditions	BCs	

Average source contributions to all 8-hour running average periods during the year with 8-hour average ozone levels exceeding selected threshold levels (65 and 70 ppb) were calculated at key monitoring site locations. Use of the 65 and 70 ppb cutoffs serves to focus attention on periods of interest to air quality managers when ozone levels are elevated above background and starting to approach the level of the ozone standard (currently 75 ppb) while maintaining a reasonably large number of events over which to average the results, thus avoiding potentially over focusing on unique combinations of emissions and meteorological conditions which are not sufficiently general for purposes of forming robust conclusions regarding source contributions to ozone formation. Table 3 lists the number of days with 8-hour periods exceeding 65 and 70 ppb at the Mesa Verde and Navajo Lake monitoring sites. Note that some of these 8-hour periods overlap one another and may occur on the same day.

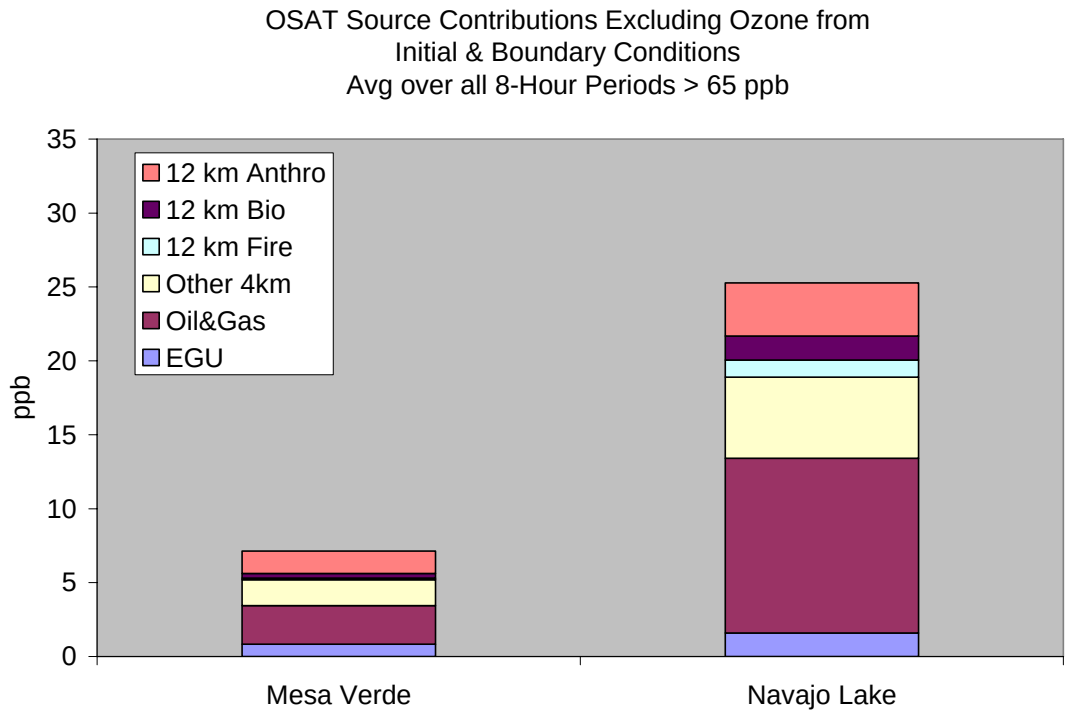
[8] In addition to these 11 source categories, CAMx computed sensitivity coefficients for 1) 12 km domain boundary conditions and 2) initial conditions

[9] Excluding emission sources within the 4 km domain

Table 3. Number of 8-hour running averages during the year with ozone greater than indicated threshold.

	> 65 ppb	> 70 ppb
Mesa Verde	117	13
Navajo	113	38

Detailed tables of OSAT results for source groups as defined in Table 1 are provided in Appendix B. Figure 3 summarizes results for Navajo Lake and Mesa Verde for all 8-hour periods during the year exceeding 65 ppb. Note that contributions from initial and boundary conditions (IC/BC) are not included in this figure so as to better illustrate contributions from other source groups; initial and boundary conditions are the single largest contributors to ozone at both monitoring sites as illustrated in Figures 1 and 2. Also note that the other area, mobile and non-EGU point source groups are combined into an "other 4 km" category in Figure 3. Contributions from all source groups are lower at Mesa Verde as compared to Navajo Lake. Oil and gas sources within the 4 km domain are estimated to contribute an average of 3 ppb of ozone (37% of the total non-IC/BC ozone) at Mesa Verde and 12 ppb (47%) at Navajo Lake. As noted in the discussion of the time series results presented above, 12 km anthropogenic sources contributions are greater than the combined contributions of biogenic and fire emissions in the 12 km domain.



	EGU	Oil&Gas	Other 4km	12 km Fire	12 km Bio	12 km Anthro	Initial & Boundary Conditions
Mesa Verde	1.2%	3.9%	2.6%	0.2%	0.5%	2.3%	89.4%
Navajo Lake	2.3%	17.5%	8.1%	1.7%	2.4%	5.3%	62.7%

Figure 3. OSAT source contributions: average over all 8-hour periods with predicted ozone exceeding 65 ppb (contributions from initial and boundary conditions not included in bar chart); table shows percent contribution to total (values for each monitoring site sum to 100%).

Average source contributions for all 8-hour periods exceeding 70 ppb were also calculated for the source groups shown in Figure 3. Comparisons of results obtained using the 65 ppb and 70 ppb cutoffs are shown in Figure 4 in terms of the percent contributions of each source group to the total non-IC/BC ozone at Mesa Verde and Navajo Lake. Overall, the pattern of source contributions are similar under each cutoff level although events exceeding 70 ppb have a slightly higher percentage contribution from oil and gas and other area sources within the 4 km domain. These results demonstrate that the source apportionment is not overly sensitive to the concentration threshold used to represent high ozone events.

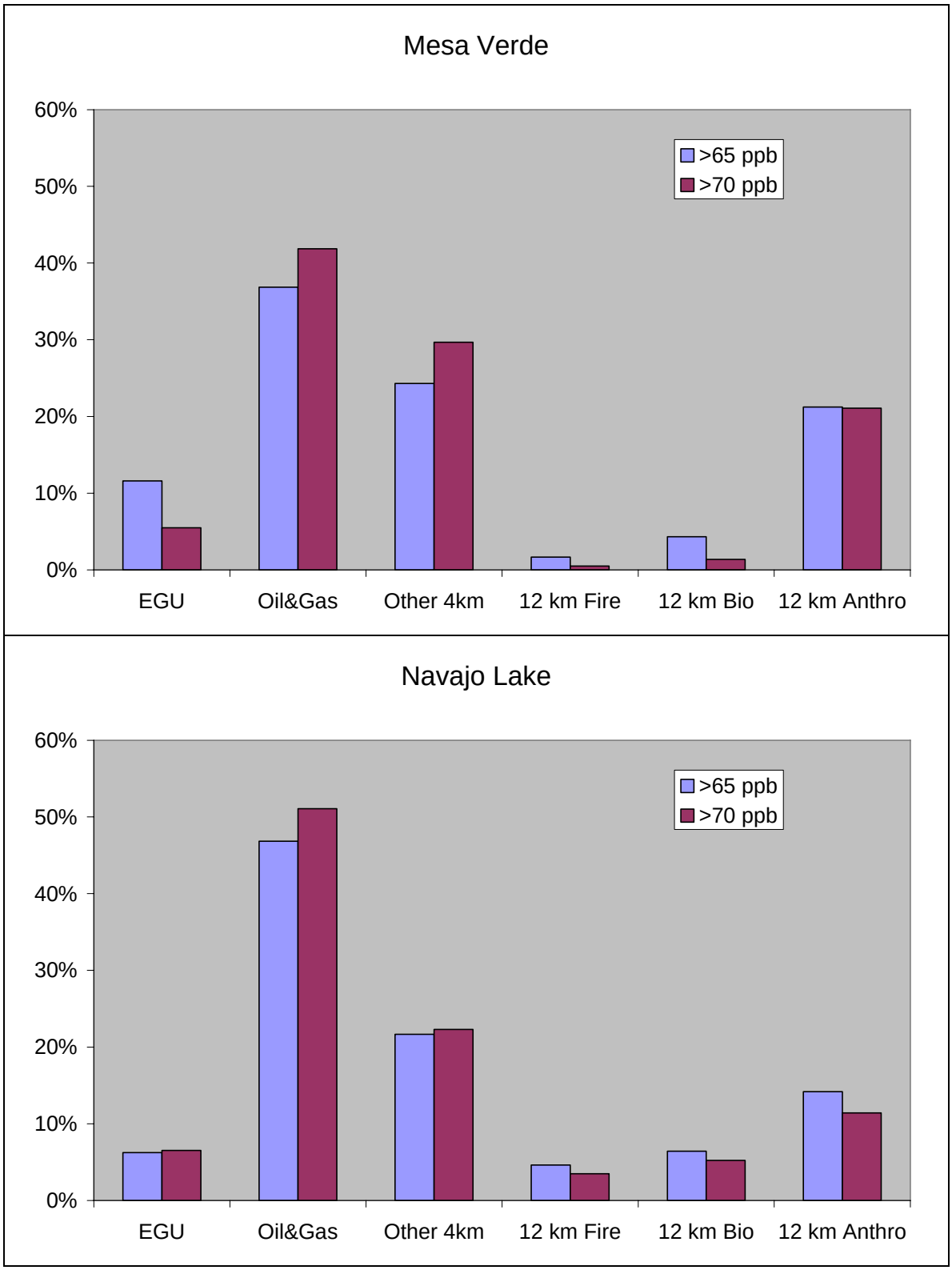


Figure 4. Comparison of ozone source contributions averaged over all 8-hour periods exceeding 65 ppb and 70 ppb at Mesa Verde (top) and Navajo Lake (bottom).

CALCULATION OF OZONE SENSITIVITIES VIA HDDM

Results from the mitigation scenario modeling described by Stoeckenius et al. (2009) suggest that application of what are currently regarded as maximum achievable levels of emission reductions from the two major source groups in the 4 km modeling domain (EGUs and oil and gas) will reduce ozone design values by at most 5 to 10 ppb. Achieving additional ozone reductions would require either additional reductions from sources in the 4 km domain or reducing emissions from sources outside the 4 km domain which the source apportionment results presented above suggest are substantial contributors to ozone in the Four Corners area. However, formulating realistic mitigation scenarios for these sources is a difficult undertaking that falls outside the scope of the Four Corners Air Quality Modeling study. Nevertheless, it is possible to estimate the sensitivity of ozone in the 4 km domain to changes in VOC and NOx emissions from 4 and 12 km domain sources using the Higher-Order Direct Decoupled (HDDM) method (ENVIRON, 2008). Ozone sensitivity coefficients calculated with this method represent an estimate of the change in ozone given a small change in VOC or NO_x emissions individually or a combined change in both VOC and NOx. Similar to the source apportionment analysis presented above, HDDM sensitivities can be calculated for any source group defined by either source category and/or location. Since HDDM computes first and second-order sensitivities, including cross-sensitivities, nonlinearities in ozone formation chemistry are treated to second order and it is thus feasible to generate diagrams that show the approximate change in ozone corresponding to different combinations of VOC and NO_x emission reductions (or increases) from each source group.

Methodology

CAMx was run with HDDM for the months of April and July using the source groups shown in Table 4. Results are summarized in terms of so-called EKMA diagrams which illustrate how ozone concentrations change at key locations as a function of changes in VOC and NOx emissions (either alone or in combination) from one or more selected source groups. Sensitivities were calculated at locations of the Navajo Lake and Mesa Verde ozone monitoring sites. As sensitivities vary from hour to hour in response to changes in emissions and meteorological conditions, it is useful to summarize the sensitivities in terms of averages over the high ozone periods that are of most interest. Results are therefore presented here as average sensitivities on afternoons of high ozone days. The 8-hour period 11:00 – 19:00 MST was used to represent the afternoon period in July (10:00 – 18:00 MST was used for results in April) and sensitivity coefficients were averaged over all days for which this 8-hour average ozone exceeded 65 ppb or 70 ppb. Table 5 lists the number of days exceeding each threshold at Navajo Lake and Mesa Verde during April and July. Shaded cells in this table indicate combinations for which there are an insufficient number of days from which to calculate average sensitivities.

Table 4. Source groups used in ozone sensitivity (HDDM) runs.

Source Category/Region	4 km Modeling Domain	12 km Modeling Domain[10]
Oil & gas	Area & Point[11]	All Anthropogenic Point & Area
Other area sources including on-road and non-road mobile sources and windblown dust	Area	
Electric Generating Units	Point	
Other (non-EGU, non-O&G) point sources	Point	
Biogenics	Area	Area
Fire Emissions	Point	Point

Table 5. Number of days with afternoon 8-hour average ozone greater than indicated threshold (shading indicates combinations for which too few days are available from which to compute average sensitivities).

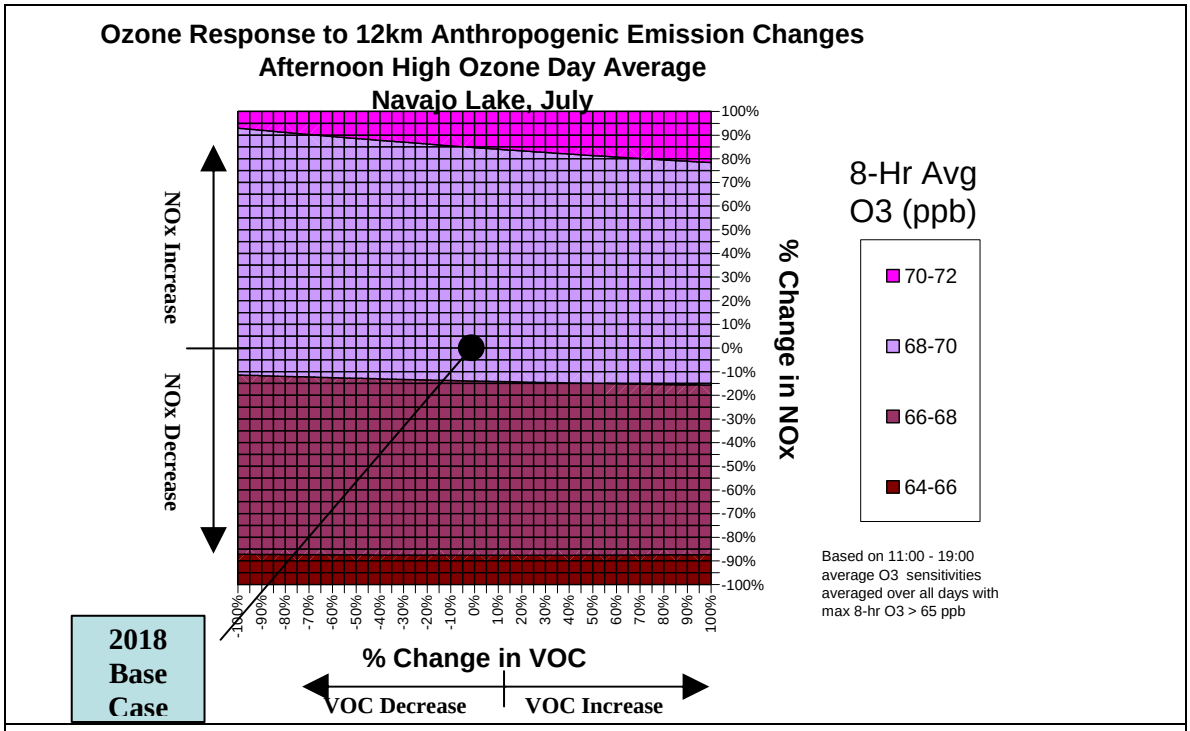
	April[a]		July[b]	
	> 65 ppb	> 70 ppb	> 65 ppb	> 70 ppb
Mesa Verde	5	1	0	0
Navajo	1	0	14	5

[a]Based on 10:00 – 18:00 MST average of predicted value in grid cell covering the monitoring site location; note that the daily maximum 8-hour average may occur during a different 8-hour period.
[b]Based on 11:00 – 19:00 MST average of predicted value in grid cell covering the monitoring site location; note that the daily maximum 8-hour average may occur during a different 8-hour period.

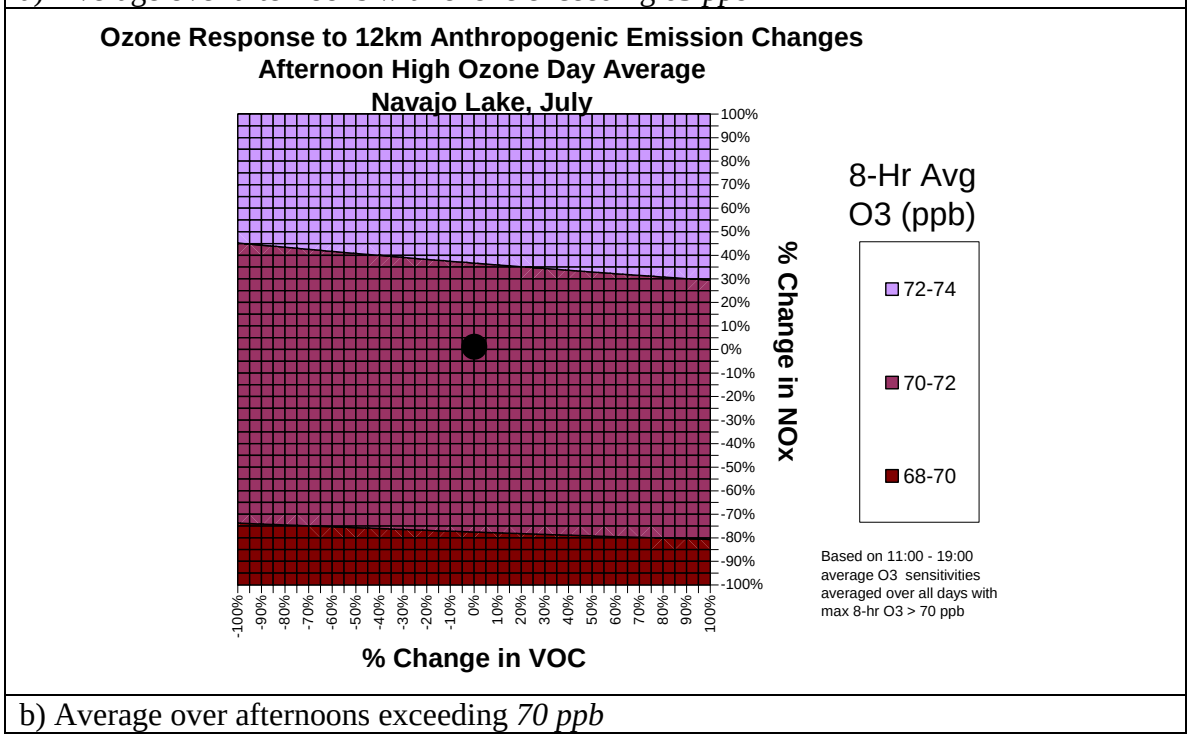
Results

Sensitivities at Navajo Lake during July averaged in the manner described above to changes in 12 km domain anthropogenic VOC and NOx emissions are presented in Figure 5. Sensitivity to both increases and decreases in emissions are shown, with the 2018 base case represented by the (0,0) point in the center of the EKMA diagram. As these results show, ozone on afternoons of high ozone days at Navajo Lake is not sensitive to changes in 12 km domain anthropogenic VOC emissions but does exhibit some sensitivity to changes in 12 km domain anthropogenic NOx emissions. Eliminating NOx emissions from this source group (i.e., a 100% reduction) is predicted to result in approximately a 3 ppb reduction in ozone. Note that this 3 ppb estimate cannot be compared directly with the source apportionment results presented above for reasons previously discussed.

[10] Excluding emission sources within the 4 km domain
[11] All NOx sources greater than 2 tons/year included as point sources in CO; only larger NOx sources included as point sources in NM, AZ and UT; small sources are included as area sources



a) Average over afternoons with ozone exceeding *65 ppb*

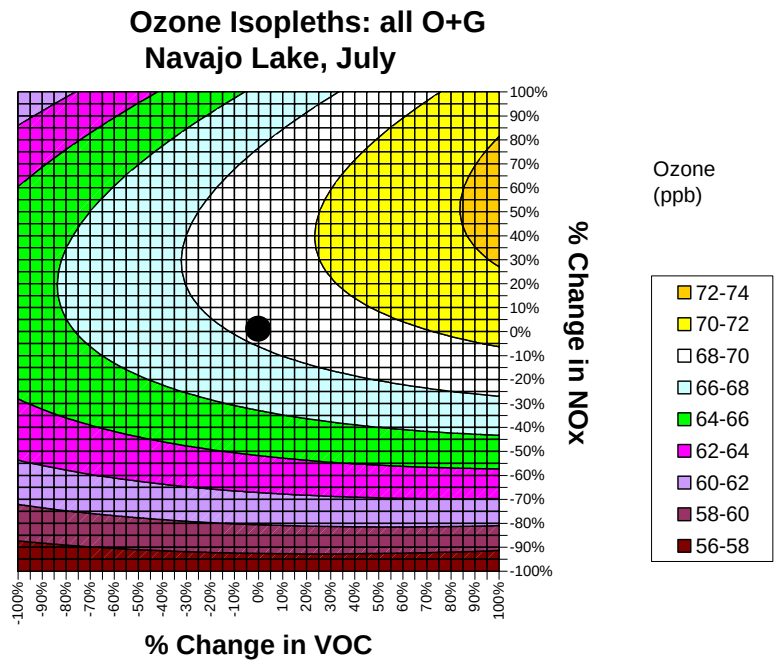


b) Average over afternoons exceeding *70 ppb*

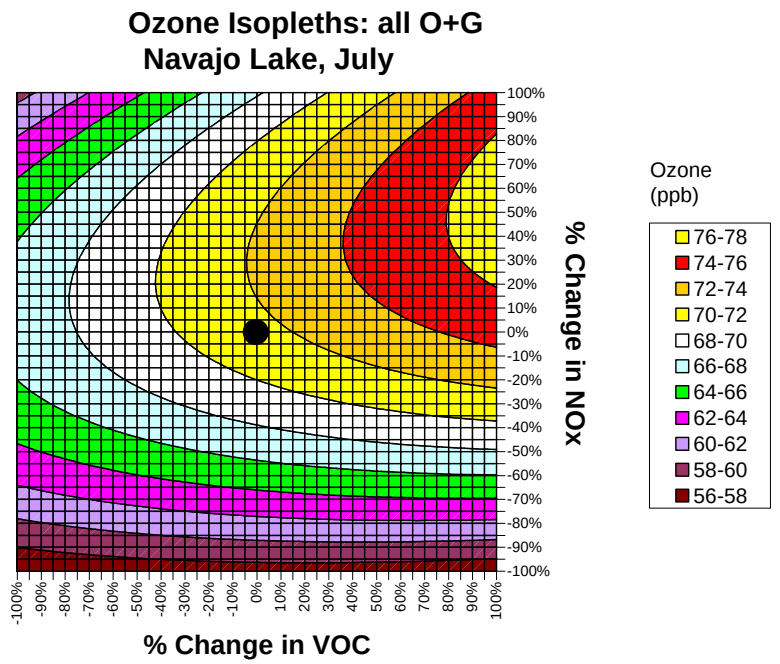
Figure 5. Average ozone sensitivities at Navajo Lake to changes in VOC and NOx emissions from anthropogenic sources in the 12 km modeling domain (outside the 4 km domain) on afternoons of high ozone days in July. Results based on average over all 11:00 – 19:00 MST 8-hour periods exceeding 65 ppb (top) and 70 ppb (bottom).

HDDM results were summarized in a similar manner to display sensitivities at Navajo Lake to changes in emissions from oil and gas sources within the 4 km domain (Figure 6a). These results suggest that summer afternoon peak ozone at Navajo Lake is more sensitive to NOx reductions from oil & gas sources than to VOC reductions: VOC reductions alone are estimated to result in at most a 4 ppb ozone reduction below the 2018 base case level. Achieving additional ozone reductions via controls on oil & gas sources would require NOx reductions. Furthermore, as NOx is reduced, VOC reductions become progressively less effective.

As one would expect, ozone above the 70 ppb threshold exhibits a greater sensitivity to emission reductions than is the case for the 65 ppb threshold but the relative importance of NOx vs VOC emission changes (i.e., the shape of the isopleths) remains the approximately same, with ozone showing a somewhat greater sensitivity to NOx reductions as compared to VOC reductions.



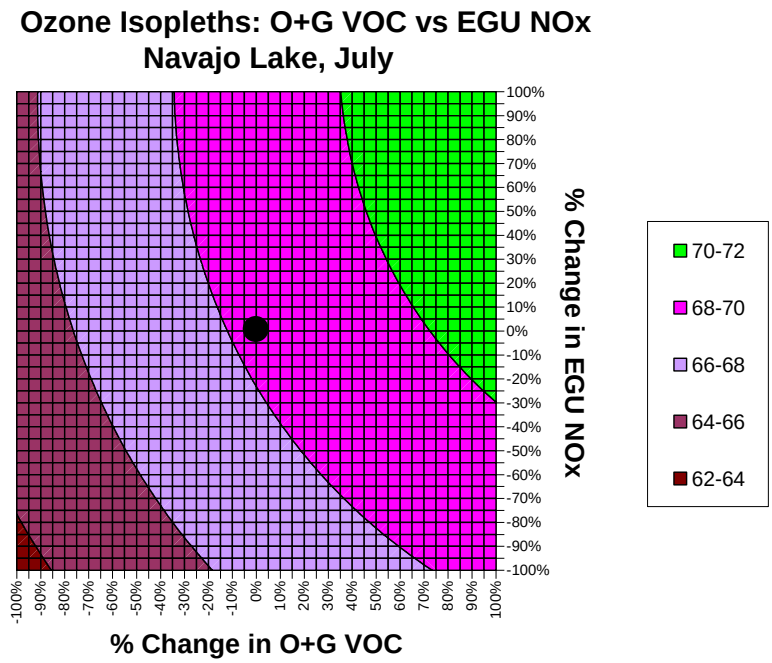
a) Average over afternoons with ozone exceeding *65 ppb*



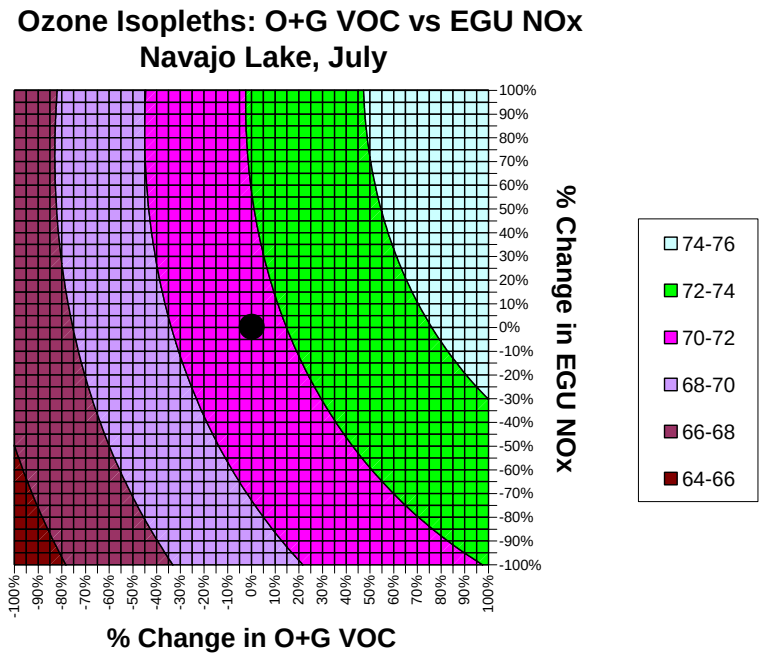
b) Average over afternoons exceeding *70 ppb*

Figure 6. As in Figure 5 but for average ozone sensitivities at Navajo Lake to changes in VOC and NOx emissions from oil and gas sources in the 4 km modeling domain on afternoons (11:00 – 19:00 MST average) of high ozone days in July as defined by a 65 ppb threshold (top) and a 70 ppb threshold (bottom).

A potential consideration in designing an emission control program is the relative sensitivity of ozone to changes in VOC and NOx emissions from different source categories. In keeping with the focus on oil and gas and EGU sources, HDDM results were used to compare sensitivities to changes in EGU NOx emissions in conjunction with changes in oil and gas NOx emissions and with changes in oil and gas VOC emissions. Figure 7 illustrates average sensitivities at Navajo Lake to joint changes in oil and gas VOC emissions and EGU NOx emissions on high ozone afternoons in July using both a 65 ppb threshold (Figure 7a) and a 70 ppb threshold (Figure 7b) to identify the high ozone days. For averages based on both threshold levels, there is a greater sensitivity to oil and gas VOC emission changes as compared to EGU NOx emission changes. This is consistent with the relatively large contribution of oil and gas sources to ozone at Navajo Lake as compared to EGU sources as found in the source apportionment results presented in the preceding section. Nevertheless, there is some ozone reduction predicted under EGU NOx reduction scenarios.



a) Average over afternoons with ozone exceeding *65 ppb*



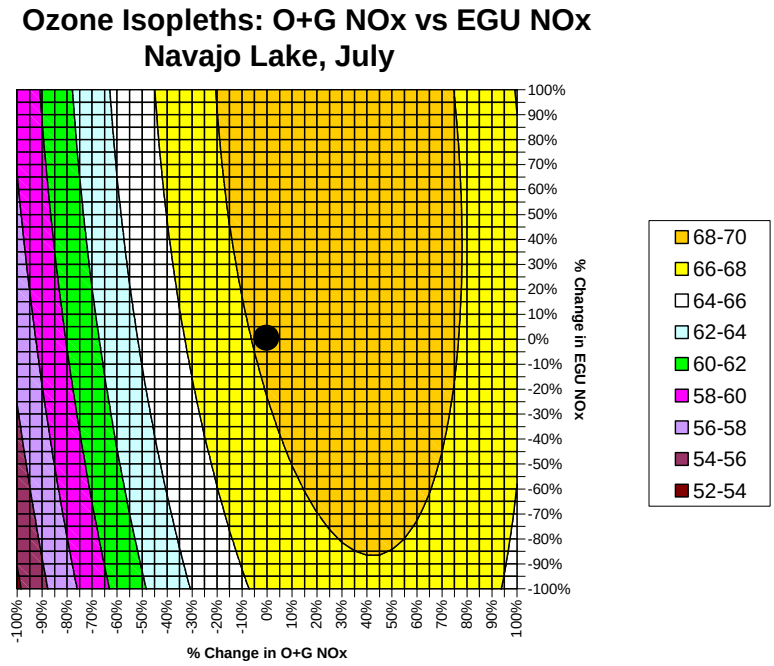
b) Average over afternoons exceeding *70 ppb*

Figure 7. As in Figure 5 but for average ozone sensitivities at Navajo Lake to changes in EGU NOx emissions and changes in oil and gas (O+G) VOC emissions in the 4 km modeling domain on afternoons (11:00 – 19:00 MST average) of high ozone days in July as defined by a 65 ppb threshold (top) and a 70 ppb threshold (bottom).

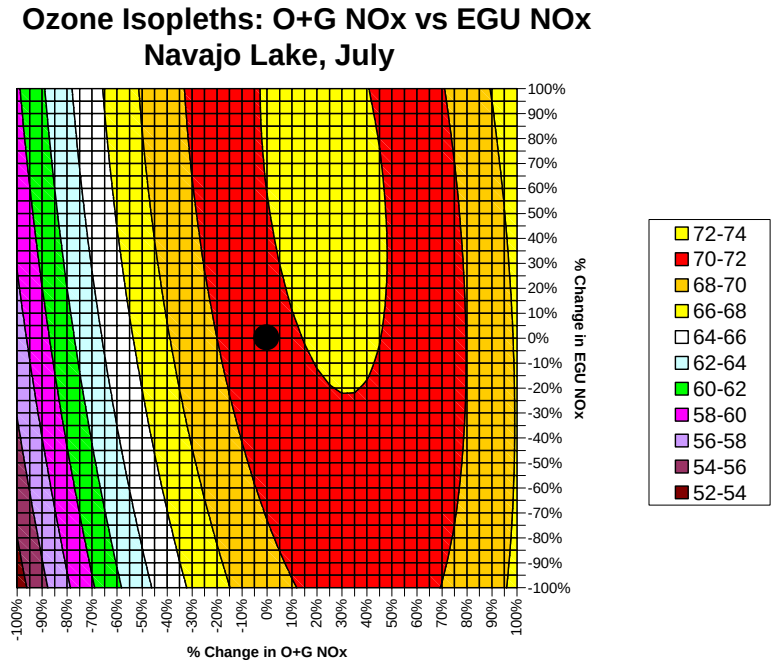
Figure 8 presents joint sensitivities to changes in EGU NOx emissions and oil and gas NOx emissions averaged over July afternoons exceeding 65 ppb (top) and 70 ppb (bottom). These figures deviate from the "boomerang" shape typical of ozone isopleths in NOx vs VOC plots such as Figure 6 because they are comparing NOx reductions only from two different source groups. Isopleth shapes are similar under both the 65 ppb and 70 ppb cutoffs used to define high afternoon ozone days. Consistent with the greater impact from oil and gas sources at Navajo Lake, ozone is much more sensitive to NOx reductions from oil and gas sources as compared to EGU sources, resulting in isopleths that are nearly parallel to the y-axis. Nevertheless, there is some ozone reduction predicted under EGU NOx reduction scenarios, consistent with results in Figure 7. Another interesting feature of these results is that the 2018 base case (which falls at the (0,0) point in the center of each plot) is within 2 ppb of the ozone maximum predicted under all emission changes considered. NOx increases beyond this maximum point are predicted to result in ozone reductions as a result of the NOx disbenefit effect. Thus, ozone increases more than 2 ppb above the 2018 base case are only predicted to occur if there are other emission increases. In particular, higher ozone levels are predicted if oil and gas VOC emissions were to increase, as shown in Figure 6. In other words, July afternoon high ozone days at Navajo Lake are predicted to be very near the dividing line between a NOx limited and a VOC limited ozone formation regime. This is also consistent with the results shown in Figure 6.

In considering the implications of the HDDM results presented above, it is important to keep in mind that they represent an average over a limited number of afternoons during a single month (July 2005 meteorological conditions) at one location (Navajo Lake). Model runs based on additional months/years of meteorological data and calculation of sensitivities at multiple geographic locations would be needed to more fully evaluate the potential implications of these results for future regulatory decisions.

Ozone isopleth diagrams were also generated from HDDM results for grid cells centered on the Mesa Verde monitoring site for elevated ozone afternoons during April (Figure 9). Only averages over afternoons exceeding 65 ppb could be calculated since only one April afternoon exceeded 70 ppb at this location. As indicated by the OSAT results presented above (see Figure 1, local sources do not contribute heavily to ozone at Mesa Verde during April and therefore the sensitivities shown in Figure 9 are weak with changes resulting from emission reductions below the 2018 base case levels predicted to be less than 2 ppb. Results were not prepared for July at Mesa Verde because no July afternoon (11:00 – 19:00 MST) 8-hour averages were predicted to exceed 65 ppb.



a) Average over afternoons with ozone exceeding *65 ppb*



b) Average over afternoons exceeding *70 ppb*

Figure 8. As in Figure 5 but for average ozone sensitivities at Navajo Lake to changes in EGU NOx emissions and changes in oil and gas (O+G) NOx emissions in the 4 km modeling domain on afternoons (10:00 – 18:00 MST average) of high ozone days in July as defined by a 65 ppb threshold (top) and a 70 ppb threshold (bottom).

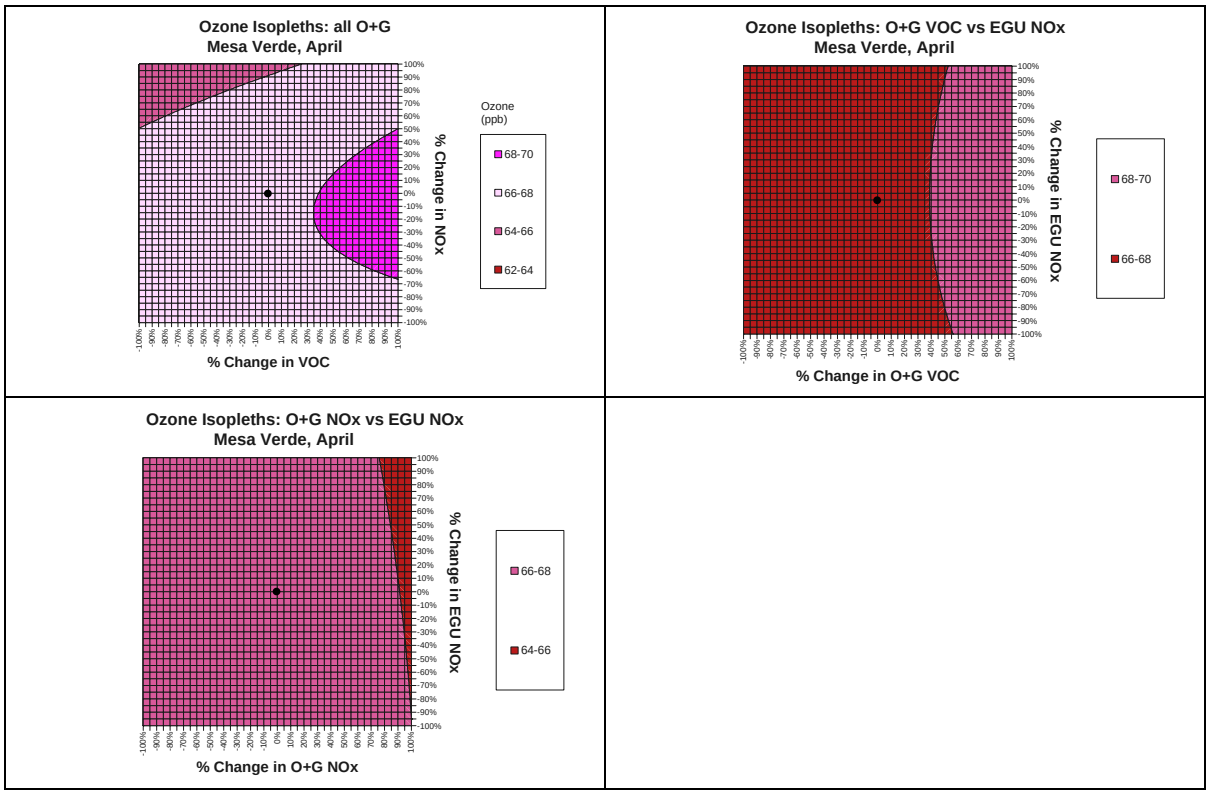


Figure 9. As in Figure 5 but for average ozone sensitivities at Mesa Verde on afternoons (10:00 – 18:00 MST average) of high ozone days in April as defined by a 65 ppb threshold to changes in: oil and gas VOC and NOx emissions (top left), EGU NOx and oil and gas VOC emissions (top right) and EGU NOx and oil and gas NOx emissions (bottom left).

SUMMARY

Ozone source apportionment and ozone sensitivity analyses were conducted using the CAMx OSAT and HDDM probing tools, respectively as a supplement to the previously reported Four Corners modeling results, which included a limited set of OSAT results but no HDDM results. Source categories were realigned for these analyses from those previously used so as to identify the contributions of, and sensitivities to, emissions from fires and biogenics in both the 4 km and 12 km modeling domains and to lump the oil and gas sources into a single category for the HDDM sensitivity run.

Key additional findings from the new OSAT results presented here which were not previously reported include:

- Fires occasionally contribute up to several ppb of ozone but not always on the highest predicted ozone days.
- Anthropogenic sources in the 12 km domain (outside of the 4 km domain) generally contribute more to ozone formation than do 12 km domain fire and biogenic sources.
- Anthropogenic sources in the 12 km domain contribute 1.5 ppb of ozone (21% of the total non-IC/BC ozone) at Mesa Verde and 3.6 ppb (14%) at Navajo Lake when

contributions are averaged over all 8-hour periods predicted to exceed 65 ppb. Source contribution patterns differ by only a few percentage points when averaged over all 8-hour periods exceeding 70 ppb.

Key findings from the ozone sensitivity (HDDM) analysis *based on average sensitivities during afternoons of high ozone days at Navajo Lake during July* include:

- Ozone is more sensitive to reductions in NOx emissions than reductions in VOC emissions under the 2018 base case scenario. VOC reductions from oil and gas sources of 50% are predicted to result in a 1.4 ppb ozone reduction assuming no other changes in emissions. This increases to a 4.9 ppb drop in ozone if the 50% VOC reduction is coupled with a 50% NOx reduction.
- Ozone is somewhat sensitive to NOx reductions from 12 km domain anthropogenic sources: eliminating NOx emissions from this source group is predicted to result in approximately a 3 ppb reduction in ozone. Ozone is not sensitive to changes in 12 km domain anthropogenic VOC emissions.
- Ozone at Navajo Lake is much more sensitive to reductions in oil & gas NOx emissions than reductions in EGU NOx emissions but combining EGU NOx reductions with oil and gas VOC reductions is predicted to result in ozone reductions (for example, a 50% EGU NOx reduction coupled with a 50% oil and gas VOC reduction is estimated to result in a 2.2 ppb ozone reduction).
- Ozone sensitivities to different combinations of emissions changes are similar in a relative sense whether a 65 ppb or a 70 ppb ozone concentration threshold is used to define a high ozone day.

Significant caution is needed when considering the implications of the above ozone sensitivity analysis results as they represent an average over a limited number of afternoons during a single month (July 2005 meteorological conditions) at one location (Navajo Lake). Model runs based on additional months/years of meteorological data and calculation of sensitivities at multiple geographic locations would be needed to more fully evaluate the potential implications of these results for future regulatory decisions.

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ENVIRON, 2008. CAMx User's Guide: Comprehensive Air Quality Model with Extensions, ENVIRON International Corp., Novato, CA, May.

Stoeckenius, T.E., C.A. Emery, T.P. Shah, J.R. Johnson, L.K. Parker and A.K. Pollack, 2009. Air Quality Modeling Study For the Four Corners Region. ENVIRON International Corp., Revised Report, August.

U.S. EPA, 2007. Guidance on the Use of Models and Other Analyses for Demonstrating Attainment of Air Quality Goals for Ozone, PM2.5, and Regional Haze. EPA -454/B-07-002, U.S. Environmental Protection Agency, April.

APPENDIX A

ADDITIONAL OZONE SOURCE APPORTIONMENT RESULTS

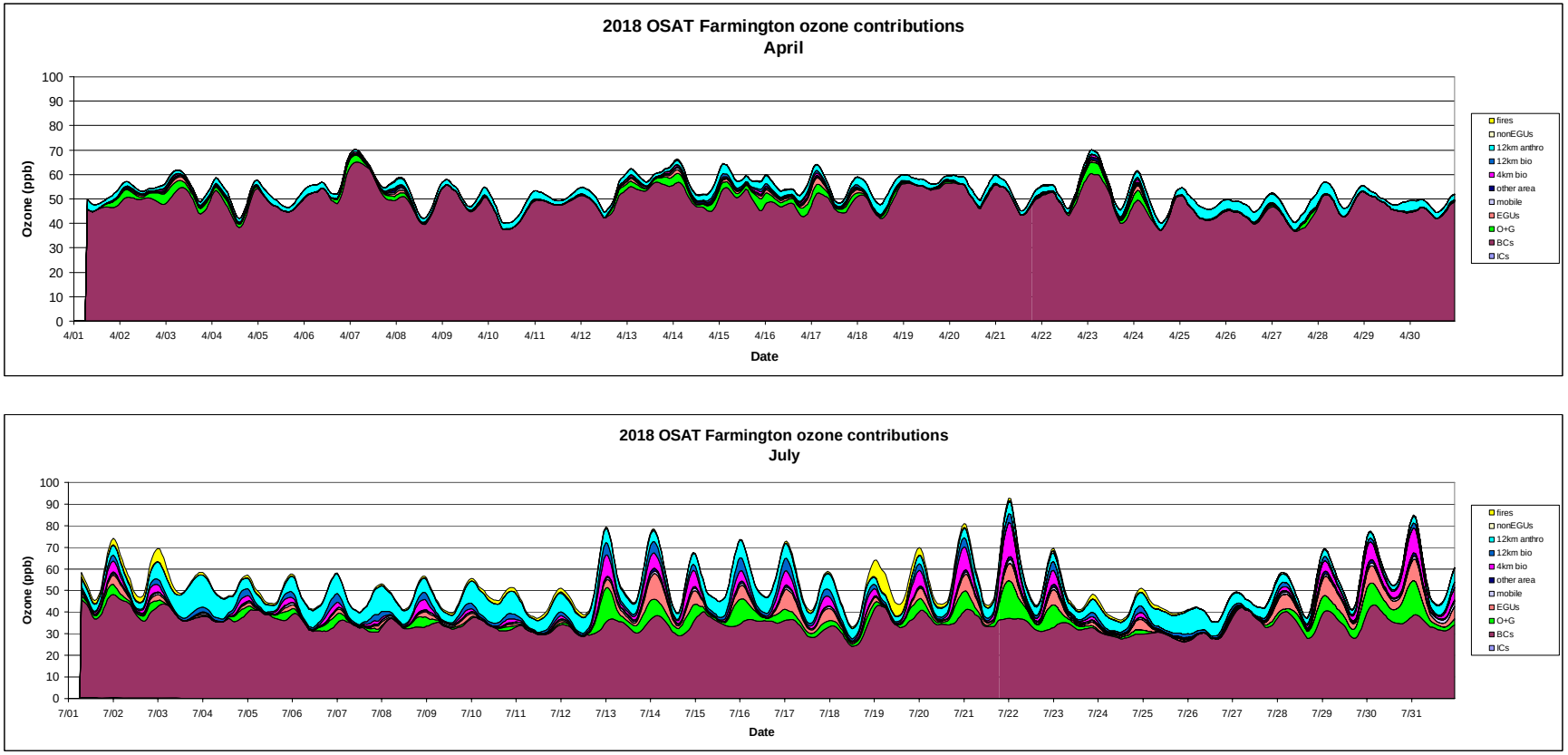

Figure A-1. Ozone source apportionment results (running 8-hour averages) at Farmington, NM during April (top) and July (bottom).

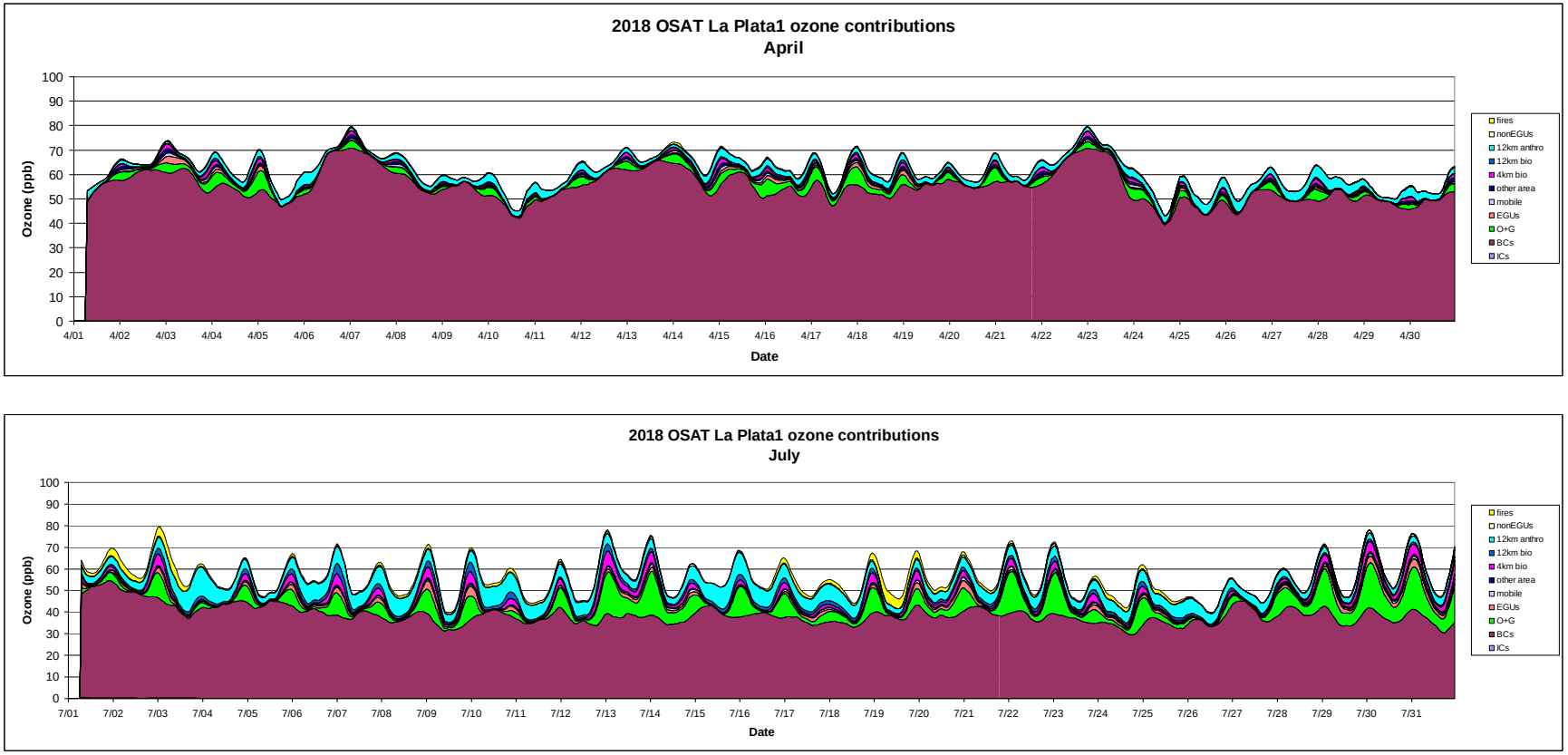

Figure A-2. Ozone source apportionment results (running 8-hour averages) at Ignacio (La Plata1) in La Plata County, CO during April (top) and July (bottom).

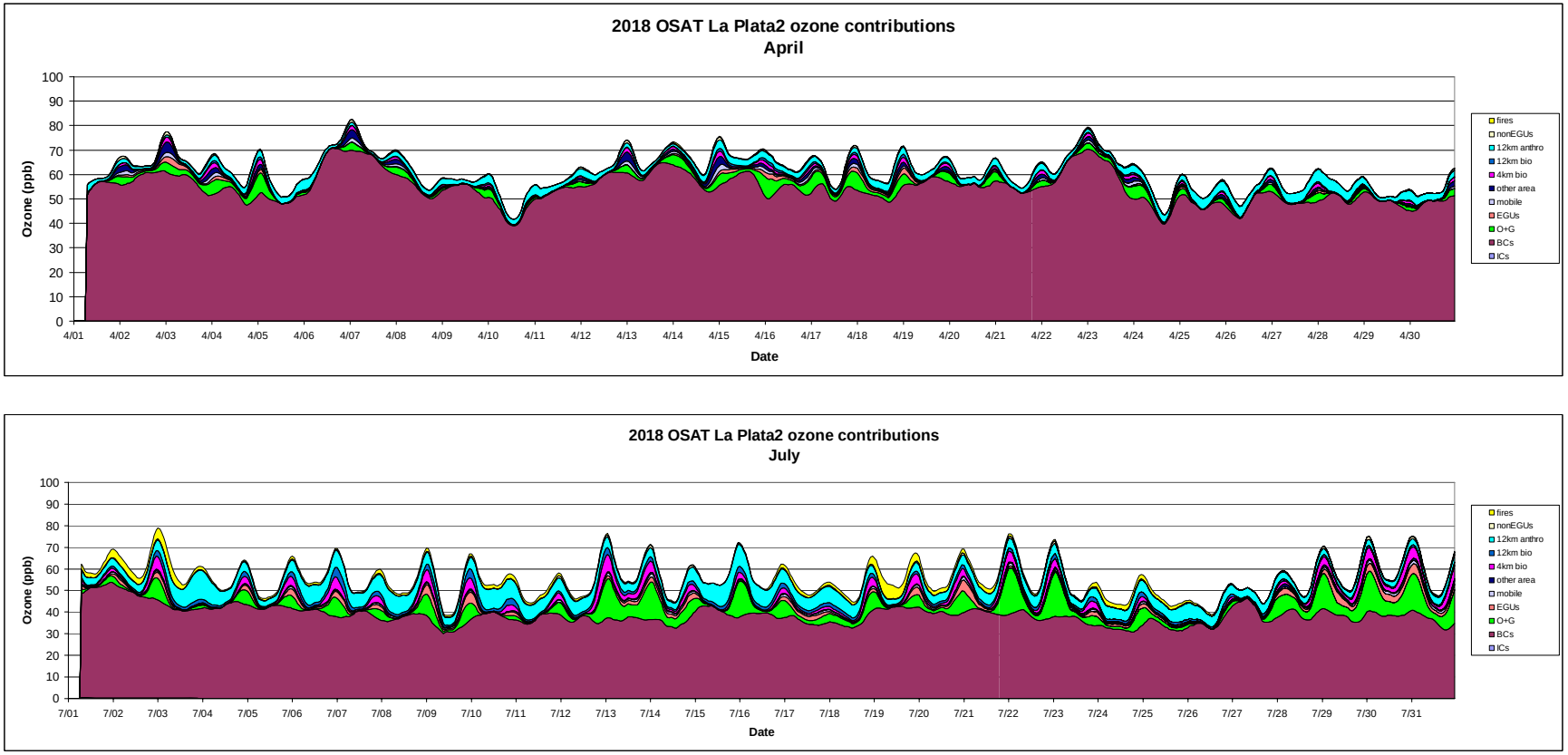

Figure A-3. Ozone source apportionment results (running 8-hour averages) at Bondad (La Plata2) in La Plata County, CO during April (top) and July (bottom).

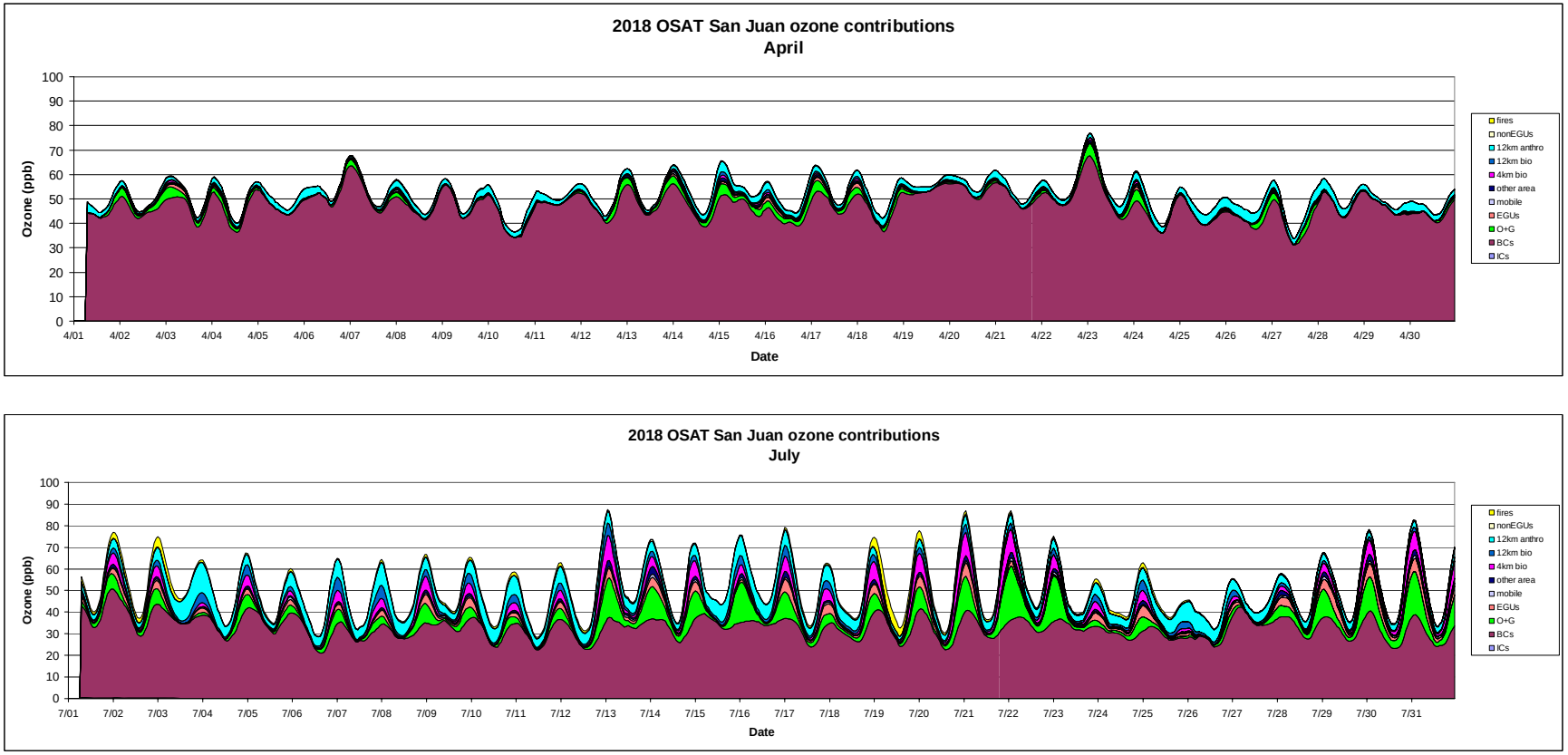

Figure A-4. Ozone source apportionment results (running 8-hour averages) at San Juan Substation monitor near Waterflow, NM during April (top) and July (bottom).

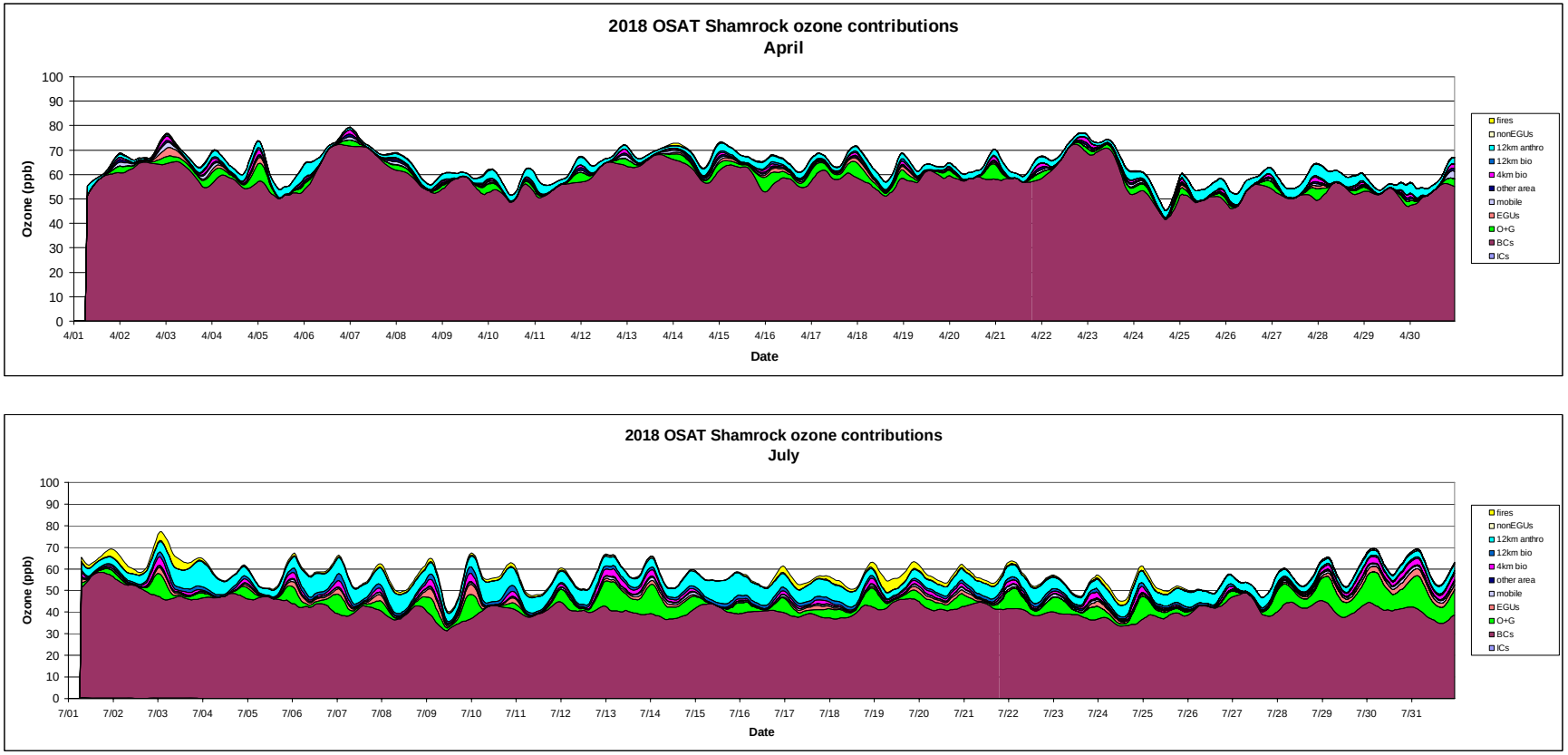

Figure A-5. Ozone source apportionment results (running 8-hour averages) at Shamrock, CO during April (top) and July (bottom).

APPENDIX B

OSAT TABULAR RESULTS

Table B-1. Average ozone source contributions calculated by OSAT at the Mesa Verde monitoring location for all running 8-hour periods with average ozone greater than 65 ppb (top) and greater than 70 ppb (bottom).

Mesa Verde hourly O3 contributions for 8-hr O3 average > 65 ppb

			Oil & Gas combustion			Oil & Gas non-combustion			Oil & Gas NM large points										
	IC	BC	O3_NOx	O3_VOC	O3_total	O3_NOx	O3_VOC	O3_total	O3_NOx	O3_VOC	O3_total	EGUs	nonEGUs	mobile	other 4km area	fires	biogenic	all anthro	Region Totals
New Mexico			0.87	0.26	1.12	0.00	0.54	0.54	0.31	0.13	0.43	0.83	0.06	0.16	0.21	0.00	0.45	3.35	**3.80**
Colorado			0.40	0.11	0.51	0.00	0.01	0.01				0.00	0.03	0.31	0.13	0.05	0.30	0.99	**1.34**
AZ & UT			0.01	0.00	0.01	0.00	0.00	0.00				0.00	0.00	0.01	0.00	0.00	0.03	0.02	**0.05**
12km																0.12	0.31	1.52	**1.95**
IC	0.00																		**0.00**
BC		59.93																	**59.93**
Grand Total	**0.00**	**59.93**	**1.28**	**0.37**	**1.64**	**0.00**	**0.55**	**0.55**	**0.31**	**0.13**	**0.43**	**0.83**	**0.09**	**0.48**	**0.34**	**0.17**	**1.09**	**5.88**	**67.07**

Mesa Verde hourly O3 contributions for 8-hr O3 average > 70 ppb

			Oil & Gas combustion			Oil & Gas non-combustion			Oil & Gas NM large points										
	IC	BC	O3_NOx	O3_VOC	O3_total	O3_NOx	O3_VOC	O3_total	O3_NOx	O3_VOC	O3_total	EGUs	nonEGUs	mobile	other 4km area	fires	biogenic	all anthro	Region Totals
New Mexico			0.73	0.19	0.92	0.00	0.43	0.43	0.17	0.07	0.24	0.32	0.03	0.08	0.07	0.01	0.15	2.09	**2.25**
Colorado			0.74	0.10	0.84	0.00	0.01	0.01				0.00	0.12	0.63	0.24	0.09	0.31	1.84	**2.24**
AZ & UT			0.00	0.00	0.00	0.00	0.00	0.00				0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
12km																0.03	0.08	1.23	**1.34**
IC	0.00																		**0.00**
BC		64.63																	**64.63**
Grand Total	**0.00**	**64.63**	**1.47**	**0.29**	**1.76**	**0.00**	**0.44**	**0.44**	**0.17**	**0.07**	**0.24**	**0.32**	**0.15**	**0.71**	**0.31**	**0.13**	**0.54**	**5.16**	**70.46**

Table B-2. Average ozone source contributions calculated by OSAT at the Navajo Lake monitoring location for all running 8-hour periods with average ozone greater than 65 ppb (top) and greater than 70 ppb (bottom).

Navajo Lake hourly O3 contributions for 8-hr O3 average > 65 ppb

			Oil & Gas combustion			Oil & Gas non-combustion			Oil & Gas NM large points										
	IC	BC	O3_NOx	O3_VOC	O3_total	O3_NOx	O3_VOC	O3_total	O3_NOx	O3_VOC	O3_total	EGUs	nonEGUs	mobile	other 4km area	fires	biogenic	all anthro	Region Totals
New Mexico			5.15	1.08	6.22	0.00	2.39	2.39	1.93	0.57	2.50	1.57	0.12	0.30	0.42	0.01	2.83	13.52	**16.36**
Colorado			0.54	0.13	0.66	0.00	0.02	0.02				0.00	0.05	0.17	0.06	0.01	1.07	0.96	**2.04**
AZ & UT			0.04	0.00	0.04	0.00	0.00	0.00				0.01	0.02	0.10	0.01	0.00	0.31	0.18	**0.49**
12km																1.17	1.63	3.59	**6.39**
IC	0.04																		**0.04**
BC		42.41																	**42.41**
Grand Total	**0.04**	**42.41**	**5.73**	**1.21**	**6.92**	**0.00**	**2.41**	**2.41**	**1.93**	**0.57**	**2.50**	**1.58**	**0.19**	**0.57**	**0.49**	**1.19**	**5.84**	**18.25**	**67.73**

Navajo Lake hourly O3 contributions for 8-hr O3 average > 70 ppb

			Oil & Gas combustion			Oil & Gas non-combustion			Oil & Gas NM large points										
	IC	BC	O3_NOx	O3_VOC	O3_total	O3_NOx	O3_VOC	O3_total	O3_NOx	O3_VOC	O3_total	EGUs	nonEGUs	mobile	other 4km area	fires	biogenic	all anthro	Region Totals
New Mexico			7.05	1.34	8.39	0.00	3.02	3.02	2.55	0.62	3.17	1.96	0.16	0.43	0.50	0.00	3.54	17.63	**21.17**
Colorado			0.64	0.13	0.77	0.00	0.03	0.03				0.00	0.06	0.20	0.06	0.01	1.24	1.12	**2.37**
AZ & UT			0.06	0.00	0.06	0.00	0.00	0.00				0.01	0.02	0.13	0.02	0.00	0.37	0.24	**0.61**
12km																1.05	1.58	3.45	**6.08**
IC	0.05																		**0.05**
BC		41.21																	**41.21**
Grand Total	**0.05**	**41.21**	**7.75**	**1.47**	**9.22**	**0.00**	**3.05**	**3.05**	**2.55**	**0.62**	**3.17**	**1.97**	**0.24**	**0.76**	**0.58**	**1.06**	**6.73**	**22.44**	**71.49**

Table B-3. Average ozone source contributions calculated by OSAT at the Farmington monitoring location for all running 8-hour periods with average ozone greater than 65 ppb (top) and greater than 70 ppb (bottom).

Farmington hourly O3 contributions for 8-hr O3 average > 65 ppb

			Oil & Gas combustion			Oil & Gas non-combustion			Oil & Gas NM large points										
	IC	BC	O3_NOx	O3_VOC	O3_total	O3_NOx	O3_VOC	O3_total	O3_NOx	O3_VOC	O3_total	EGUs	nonEGUs	mobile	other 4km area	fires	biogenic	all anthro	Region Totals
New Mexico			1.92	1.09	3.00	0.00	2.06	2.06	0.85	0.53	1.38	4.75	0.10	0.37	0.61	0.01	3.39	12.27	**15.67**
Colorado			0.78	0.33	1.11	0.00	0.06	0.06				0.00	0.07	0.26	0.12	0.01	2.28	1.62	**3.91**
AZ & UT			0.12	0.00	0.13	0.00	0.00	0.00				0.02	0.03	0.23	0.03	0.00	0.73	0.44	**1.17**
12km																0.81	1.89	3.23	**5.93**
IC	0.04																		**0.04**
BC		41.34																	**41.34**
Grand Total	**0.04**	**41.34**	**2.82**	**1.42**	**4.24**	**0.00**	**2.12**	**2.12**	**0.85**	**0.53**	**1.38**	**4.77**	**0.20**	**0.86**	**0.76**	**0.83**	**8.29**	**17.56**	**68.06**

Farmington hourly O3 contributions for 8-hr O3 average > 70 ppb

			Oil & Gas combustion			Oil & Gas non-combustion			Oil & Gas NM large points										
	IC	BC	O3_NOx	O3_VOC	O3_total	O3_NOx	O3_VOC	O3_total	O3_NOx	O3_VOC	O3_total	EGUs	nonEGUs	mobile	other 4km area	fires	biogenic	all anthro	Region Totals
New Mexico			3.19	1.73	4.93	3.32	0.00	3.32	1.36	0.78	2.14	6.38	0.18	0.60	0.89	0.02	5.33	18.44	**23.79**
Colorado			1.14	0.50	1.64	0.09	0.00	0.09				0.00	0.11	0.35	0.16	0.00	3.61	2.35	**5.96**
AZ & UT			0.15	0.00	0.16	0.00	0.00	0.00				0.04	0.02	0.21	0.03	0.00	0.78	0.46	**1.24**
12km																0.61	2.28	3.49	**6.38**
IC	0.00																		**0.00**
BC		35.69																	**35.69**
Grand Total	**0.00**	**35.69**	**4.48**	**2.23**	**6.73**	**3.41**	**0.00**	**3.41**	**1.36**	**0.78**	**2.14**	**6.42**	**0.31**	**1.16**	**1.08**	**0.63**	**12.00**	**24.74**	**73.06**

Table B-4. Average ozone source contributions calculated by OSAT at the Ignacio (La Plata1) monitoring location for all running 8-hour periods with average ozone greater than 65 ppb (top) and greater than 70 ppb (bottom).

La Plata1 hourly O3 contributions for 8-hr O3 average > 65 ppb

			Oil & Gas combustion			Oil & Gas non-combustion			Oil & Gas NM large points										
	IC	BC	O3_NOx	O3_VOC	O3_total	O3_NOx	O3_VOC	O3_total	O3_NOx	O3_VOC	O3_total	EGUs	nonEGUs	mobile	other 4km area	fires	biogenic	all anthro	Region Totals
New Mexico			1.42	0.30	1.72	0.00	0.63	0.63	0.34	0.14	0.48	0.70	0.04	0.11	0.15	0.00	0.58	3.83	**4.41**
Colorado			0.97	0.24	1.22	0.00	0.02	0.02				0.00	0.07	0.30	0.22	0.07	0.71	1.83	**2.61**
AZ & UT			0.02	0.00	0.02	0.00	0.00	0.00				0.00	0.01	0.05	0.01	0.00	0.11	0.09	**0.20**
12km																0.42	0.44	1.82	**2.68**
IC	0.02																		**0.02**
BC		57.84																	**57.84**
Grand Total	**0.02**	**57.84**	**2.41**	**0.54**	**2.96**	**0.00**	**0.65**	**0.65**	**0.34**	**0.14**	**0.48**	**0.70**	**0.12**	**0.46**	**0.38**	**0.49**	**1.84**	**7.57**	**67.76**

La Plata1 hourly O3 contributions for 8-hr O3 average > 70 ppb

			Oil & Gas combustion			Oil & Gas non-combustion			Oil & Gas NM large points										
	IC	BC	O3_NOx	O3_VOC	O3_total	O3_NOx	O3_VOC	O3_total	O3_NOx	O3_VOC	O3_total	EGUs	nonEGUs	mobile	other 4km area	fires	biogenic	all anthro	Region Totals
New Mexico			0.71	0.16	0.88	0.00	0.34	0.34	0.20	0.07	0.28	0.31	0.01	0.04	0.06	0.00	0.37	1.92	**2.29**
Colorado			1.12	0.40	1.52	0.00	0.02	0.02				0.00	0.12	0.40	0.43	0.02	0.78	2.49	**3.29**
AZ & UT			0.01	0.00	0.01	0.00	0.00	0.00				0.00	0.01	0.04	0.00	0.00	0.10	0.06	**0.16**
12km																0.59	0.45	1.69	**2.73**
IC	0.03																		**0.03**
BC		63.26																	**63.26**
Grand Total	**0.03**	**63.26**	**1.84**	**0.56**	**2.41**	**0.00**	**0.36**	**0.36**	**0.20**	**0.07**	**0.28**	**0.31**	**0.14**	**0.48**	**0.49**	**0.61**	**1.70**	**6.16**	**71.76**

Table B-5. Average ozone source contributions calculated by OSAT at the Bondad (La Plata2) monitoring location for all running 8-hour periods with average ozone greater than 65 ppb (top) and greater than 70 ppb (bottom).

La Plata2 hourly O3 contributions for 8-hr O3 average > 65 ppb

			Oil & Gas combustion			Oil & Gas non-combustion			Oil & Gas NM large points										
	IC	BC	O3_NOx	O3_VOC	O3_total	O3_NOx	O3_VOC	O3_total	O3_NOx	O3_VOC	O3_total	EGUs	nonEGUs	mobile	other 4km area	fires	biogenic	all anthro	Region Totals
New Mexico			1.60	0.29	1.89	0.00	0.60	0.60	0.42	0.13	0.55	0.65	0.04	0.13	0.18	0.01	0.61	4.04	**4.66**
Colorado			0.95	0.24	1.19	0.00	0.02	0.02				0.00	0.13	0.41	0.40	0.02	0.76	2.15	**2.93**
AZ & UT			0.01	0.00	0.02	0.00	0.00	0.00				0.00	0.01	0.05	0.01	0.00	0.12	0.09	**0.21**
12km																0.55	0.56	2.23	**3.34**
IC	0.02																		**0.02**
BC		56.66																	**56.66**
Grand Total	**0.02**	**56.66**	**2.56**	**0.53**	**3.10**	**0.00**	**0.62**	**0.62**	**0.42**	**0.13**	**0.55**	**0.65**	**0.18**	**0.59**	**0.59**	**0.58**	**2.05**	**8.51**	**67.82**

La Plata2 hourly O3 contributions for 8-hr O3 average > 70 ppb

			Oil & Gas combustion			Oil & Gas non-combustion			Oil & Gas NM large points										
	IC	BC	O3_NOx	O3_VOC	O3_total	O3_NOx	O3_VOC	O3_total	O3_NOx	O3_VOC	O3_total	EGUs	nonEGUs	mobile	other 4km area	fires	biogenic	all anthro	Region Totals
New Mexico			0.40	0.13	0.53	0.00	0.26	0.26	0.14	0.06	0.21	0.29	0.01	0.03	0.05	0.00	0.28	1.38	**1.66**
Colorado			0.97	0.30	1.27	0.00	0.02	0.02				0.00	0.17	0.60	0.66	0.00	0.67	2.72	**3.39**
AZ & UT			0.01	0.00	0.01	0.00	0.00	0.00				0.00	0.01	0.03	0.00	0.00	0.08	0.05	**0.13**
12km																0.47	0.35	1.67	**2.49**
IC	0.02																		**0.02**
BC		64.02																	**64.02**
Grand Total	**0.02**	**64.02**	**1.38**	**0.43**	**1.81**	**0.00**	**0.28**	**0.28**	**0.14**	**0.06**	**0.21**	**0.29**	**0.19**	**0.66**	**0.71**	**0.47**	**1.38**	**5.82**	**71.71**

Table B-6. Average ozone source contributions calculated by OSAT at the San Juan Substation monitor near Waterflow, NM for all running 8-hour periods with average ozone greater than 65 ppb (top) and greater than 70 ppb (bottom).

San Juan hourly O3 contributions for 8-hr O3 average > 65 ppb

			Oil & Gas combustion			Oil & Gas non-combustion			Oil & Gas NM large points										
	IC	BC	O3_NOx	O3_VOC	O3_total	O3_NOx	O3_VOC	O3_total	O3_NOx	O3_VOC	O3_total	EGUs	nonEGUs	mobile	other 4km area	fires	biogenic	all anthro	Region Totals
New Mexico			3.98	1.12	5.11	0.00	2.22	2.22	1.95	0.68	2.64	2.21	0.15	0.36	0.89	0.00	3.31	13.58	**16.89**
Colorado			0.55	0.21	0.76	0.00	0.04	0.04				0.00	0.05	0.18	0.08	0.02	1.48	1.11	**2.61**
AZ & UT			0.04	0.00	0.04	0.00	0.00	0.00				0.01	0.02	0.11	0.01	0.00	0.43	0.19	**0.62**
12km																1.12	1.96	3.61	**6.69**
IC	0.04																		**0.04**
BC		41.85																	**41.85**
Grand Total	**0.04**	**41.85**	**4.57**	**1.33**	**5.91**	**0.00**	**2.26**	**2.26**	**1.95**	**0.68**	**2.64**	**2.22**	**0.22**	**0.65**	**0.98**	**1.14**	**7.18**	**18.49**	**68.70**

San Juan hourly O3 contributions for 8-hr O3 average > 70 ppb

			Oil & Gas combustion			Oil & Gas non-combustion			Oil & Gas NM large points										
	IC	BC	O3_NOx	O3_VOC	O3_total	O3_NOx	O3_VOC	O3_total	O3_NOx	O3_VOC	O3_total	EGUs	nonEGUs	mobile	other 4km area	fires	biogenic	all anthro	Region Totals
New Mexico			5.75	1.39	7.14	0.00	2.82	2.82	2.61	0.74	3.35	2.36	0.18	0.47	1.12	0.01	4.20	17.44	**21.65**
Colorado			0.70	0.23	0.93	0.00	0.04	0.04				0.00	0.07	0.25	0.09	0.01	2.08	1.38	**3.47**
AZ & UT			0.04	0.00	0.04	0.00	0.00	0.00				0.01	0.03	0.11	0.01	0.00	0.43	0.20	**0.63**
12km																0.94	2.21	3.69	**6.84**
IC	0.02																		**0.02**
BC		40.03																	**40.03**
Grand Total	**0.02**	**40.03**	**6.49**	**1.62**	**8.11**	**0.00**	**2.86**	**2.86**	**2.61**	**0.74**	**3.35**	**2.37**	**0.28**	**0.83**	**1.22**	**0.96**	**8.92**	**22.71**	**72.64**

Table B-7. Average ozone source contributions calculated by OSAT at the Shamrock monitoring location for all running 8-hour periods with average ozone greater than 65 ppb (top) and greater than 70 ppb (bottom).

Shamrock hourly O3 contributions for 8-hr O3 average > 65 ppb

			Oil & Gas combustion			Oil & Gas non-combustion			Oil & Gas NM large points										
	IC	BC	O3_NOx	O3_VOC	O3_total	O3_NOx	O3_VOC	O3_total	O3_NOx	O3_VOC	O3_total	EGUs	nonEGUs	mobile	other 4km area	fires	biogenic	all anthro	Region Totals
New Mexico			0.46	0.17	0.62	0.00	0.35	0.35	0.16	0.09	0.25	0.46	0.03	0.07	0.10	0.00	0.22	1.88	**2.10**
Colorado			0.38	0.08	0.46	0.00	0.01	0.01				0.00	0.03	0.24	0.10	0.05	0.30	0.84	**1.19**
AZ & UT			0.01	0.00	0.01	0.00	0.00	0.00				0.00	0.00	0.02	0.00	0.00	0.04	0.03	**0.07**
12km																0.20	0.23	1.55	**1.98**
IC	0.01																		**0.01**
BC		62.36																	**62.36**
Grand Total	**0.01**	**62.36**	**0.85**	**0.25**	**1.09**	**0.00**	**0.36**	**0.36**	**0.16**	**0.09**	**0.25**	**0.46**	**0.06**	**0.33**	**0.20**	**0.25**	**0.79**	**4.30**	**67.71**

Shamrock hourly O3 contributions for 8-hr O3 average > 70 ppb

			Oil & Gas combustion			Oil & Gas non-combustion			Oil & Gas NM large points										
	IC	BC	O3_NOx	O3_VOC	O3_total	O3_NOx	O3_VOC	O3_total	O3_NOx	O3_VOC	O3_total	EGUs	nonEGUs	mobile	other 4km area	fires	biogenic	all anthro	Region Totals
New Mexico			0.16	0.03	0.19	0.00	0.06	0.06	0.05	0.01	0.06	0.09	0.01	0.02	0.03	0.00	0.05	0.46	**0.51**
Colorado			0.30	0.07	0.37	0.00	0.00	0.00				0.00	0.05	0.22	0.11	0.04	0.16	0.75	**0.95**
AZ & UT			0.00	0.00	0.00	0.00	0.00	0.00				0.00	0.00	0.01	0.00	0.00	0.01	0.01	**0.02**
12km																0.09	0.09	0.08	**0.26**
IC	0.00																		**0.00**
BC		68.56																	**68.56**
Grand Total	**0.00**	**68.56**	**0.46**	**0.10**	**0.56**	**0.00**	**0.06**	**0.06**	**0.05**	**0.01**	**0.06**	**0.09**	**0.06**	**0.25**	**0.14**	**0.13**	**0.31**	**1.30**	**70.30**