2011 WASHINGTON COUNTY OZONE SATURATION STUDY

Prepared by

Kiera Harper
and
Seth Arens

State of Utah
Department of Environmental Quality
Division of Air Quality
195 North 1950 West
Salt Lake City, Utah 84114-4820
801-536-4000

February 2012
DAQ-AMS-03-2012

TABLE OF CONTENTS

I. EXECUTIVE SUMMARY

Ozone has been monitored in Washington County since 2004. From 2004-2007 ozone was monitored in St. George, and from 2008-Present ozone has been monitored in Santa Clara. The National Park Service began monitoring ozone near Zion National Park in the Dalton Wash in 2004. Several years of ozone data collection from Santa Clara and Dalton Wash showed consistently higher ozone concentrations at the Dalton Wash site, thus raising concerns whether the Santa Clara site is the best location to monitor ozone in Washington County. In 2011, the Utah Division of Air Quality (UDAQ) conducted an ozone saturation study to determine the location of the highest ozone concentrations in Washington County and the most suitable site for a permanent ozone monitoring site. Temporary sites were located in South St. George, St. George, Washington, Hurricane, La Verkin, Virgin, Dalton Wash (collocated with the Dalton Wash monitor), Lytle Ranch, and New Harmony. High ozone was observed at several sites in Washington County; peak 8-hour ozone concentrations of 77 ppb were observed in La Verkin, Lytle Ranch and Virgin. All monitoring sites in Washington County were in compliance with the current National Ambient Air Quality Standard for ozone of 75 ppb. The lowest ozone concentrations in Washington County were observed in Santa Clara with a peak 8-hour ozone concentration of 72 ppb. Using a simple scoring metric, which considered several measures of ozone and logistics, it was determined that the highest ozone was observed at the site in Hurricane. Based on data from the 2011 ozone saturation study in Washington County, UDAQ recommends that a permanent ozone monitoring site should be installed in Hurricane. Several possible sites that meet EPA monitoring site criteria exist in Hurricane and ozone measurements in Hurricane would be representative of human exposure to ozone in Washington County.

Ozone was monitored at a very remote site on the western border of Washington County at Lytle Ranch Nature Preserve. This site was to determine regional background levels of ozone and to assess the impact of potential atmospheric pollution transport. High ozone was monitored at Lytle Ranch with a peak 8-hour concentration of 77 ppb. Based on the analysis of air mass movement, 85% of high ozone days at Lytle Ranch were potentially influenced by emissions from sources in Nevada and California. Given the lack of anthropogenic sources in the area it is likely that ozone or ozone precursor transport and local emission of biogenic volatile organic compounds contributed to high ozone concentrations.

The Utah Division of Air Quality provides a daily service to the public that announces an air quality index (green, yellow, and red days) of ozone concentrations for various areas around the State of Utah, including Washington County. Given that ozone or ozone precursor transport could be occurring, ozone concentrations were analyzed in St. George, Las Vegas, and Los Angeles in an effort to more accurately predict the Air Quality Index for Washington County. During the early spring, ozone values are fairly similar in St. George and Las Vegas. During the summer months, ozone values should

be on average about seven ppb lower than Las Vegas. Little comparison could be done against Los Angeles.

II. INTRODUCTION

1. History of Ozone Monitoring in Washington County

Washington County, located in the southwestern part of Utah, contrasts greatly from the rest of the state in climate, population, and industrial development. Three large canyons lie nearly parallel to each other in the east central part of the county, and slope from north to south dropping nearly 2,000 feet in elevation. The more populous towns and cities of the county, St. George, Washington, Hurricane, Ivins, and Santa Clara, are near the mouths of these canyons and in adjoining valleys. A desert climate contributes to generally clear skies, relatively mild winters, and hot summers in these low lying areas (less than 3,500 feet in elevation). Temperatures vary from wintertime lows around 27°F to summertime highs exceeding 110°F.

Washington County ranked as the second fastest growing area in the U.S. from 1990-2000. According to the US Census Bureau, the St. George Metropolitan Statistical Area experienced an annual growth rate of 6.2% over this period. The County's population was estimated at 137,500 in 2009 with an annual growth rate of 4.2% since 2000.

Due to the rapid population growth, the Utah Division of Air Quality (UDAQ) began monitoring ozone in Washington County. The first monitor was installed in 2004 in St. George (200 South 300 East). The station was operated from 2004 through 2007. Meteorological and air quality parameters were monitored ─ temperature, wind direction and speed, relative humidity, ozone, nitrogen oxides (NO_x), PM_{10}, and $PM_{2.5}$. In 2008, monitoring operations were moved from St. George to Santa Clara, where they have continued through 2012. Seasonal ozone, NO_x, and year-around meteorology (temperature, wind speed and direction, and relative humidity) are measured in Santa Clara. The National Park Service (NPS) has operated a year-round ozone site outside Zion National Park (NP) in the Dalton Wash since January 2004. UDAQ has no authority over operation, maintenance, or QA/QC procedures associated with data collection at this site. Washington County monitoring locations were selected based on logistical, convenience, and cost considerations, and not saturation studies or ozone modeling.

2. Monitoring Comparisons

Ozone data collected from 2008 through 2010 at Santa Clara and Dalton Wash showed consistently higher ozone concentrations at Dalton Wash, thus raising concerns whether the Santa Clara site is the best location to monitor ozone in Washington County. The question was whether UDAQ should move the ozone monitor closer to Dalton Wash where higher ozone concentrations were expected.

To examine differences in ozone from Dalton Wash, Santa Clara, and St. George, several years of ozone data was compared using the Student Paired t-test with a 98% confidence limit (Table 1). From 2004 to 2009, ozone concentrations were significantly higher in Dalton Wash compared to St. George or Santa Clara. Correlations between

ozone data varied from r^2 = 0.48 – 0.88, indicating spatial and annual variability in ozone concentration. Eight-hour average ozone concentrations were 10 to 12 ppb higher at Dalton Wash compared to St. George during 2004 – 2006 and 5-9 ppb higher than Santa Clara during 2008-2009.

Table 1. Mean difference between 8-hour ozone concentrations at the Dalton Wash site and sites in St. George or Santa Clara. A positive difference means that ozone was higher in Dalton Wash.

Compared Station	***Year***	***Mean Difference (ppb)***	***Correlation (r^2)***
St. George	2004	11.2	0.71
St. George	2005	12.4	0.48
St. George	2006	10.4	0.67
Santa Clara	2008	8.9	0.88
Santa Clara	2009	4.9	0.59

Maximum ozone concentrations were higher at Dalton Wash compared to Santa Clara in 2009 – 2011 (Table 2). Peak and fourth highest 8-hour ozone concentrations were significantly higher at Dalton Wash compared to Santa Clara. Dalton Wash experienced more days with ozone > 65 ppb than Santa Clara. Comparisons of ozone data between Dalton Wash and other Washington County sites showed that ozone was highest at the Dalton Wash site.

Table 2. Comparison of the four highest ozone days in Santa Clara (SC) and at Dalton Wash (DW) from 2009 – 2011.

	2009		***2010***		***2011***	
	SC	***DW***	***SC***	***DW***	***SC***	**DW**
1st high	74	78	68	73	71	73
2nd high	68	72	68	73	70	72
3rd high	68	71	68	72	69	72
4th high	66	68	68	72	68	72
Days > 65 ppb	5	6	9	22	11	24

3. Ozone Photochemistry and VOC Emissions

Ozone is a secondary pollutant meaning it does not have a direct emission source; it is formed when ultraviolet radiation initiates a series of complex chemical reactions between Volatile Organic Compounds (VOCs) and Nitrogen oxides (NO_x) (other compounds can participate in the ozone reaction).

$$\text{VOCs} + NO_x + \text{UV radiation} \rightarrow O3$$

Collocated measurements of NO_x, VOCs, and meteorological parameters (i.e. wind, temperature, water, solar radiation, cloud cover) are paramount to understanding

patterns of ozone formation in Washington County. NO_x emission typically come from combustion processes; VOCs are emitted from a variety of sources including oil and natural gas production, liquid fuel or solvent evaporation, incomplete fossil fuel combustion, and biogenic processes.[1] Based on 2002 National Emissions Inventory data, Figure 1 shows criteria pollutants emissions for Washington County. VOC emission accounts for most of the pollutants in Washington County. VOC emissions were allocated to the source categories shown in Figure 2. Approximately 90% of VOC emissions in Washington County originate from biogenic sources. Mobile and area sources accounted for 9% of VOC emissions and very little VOCs were emitted from point sources. Figure 3 shows the VOC emissions in Clark County, NV and were allocated to biogenic and urban sources. Rural biogenic sources accounted for approximately 94% of the VOC emissions in Clark County, NV.

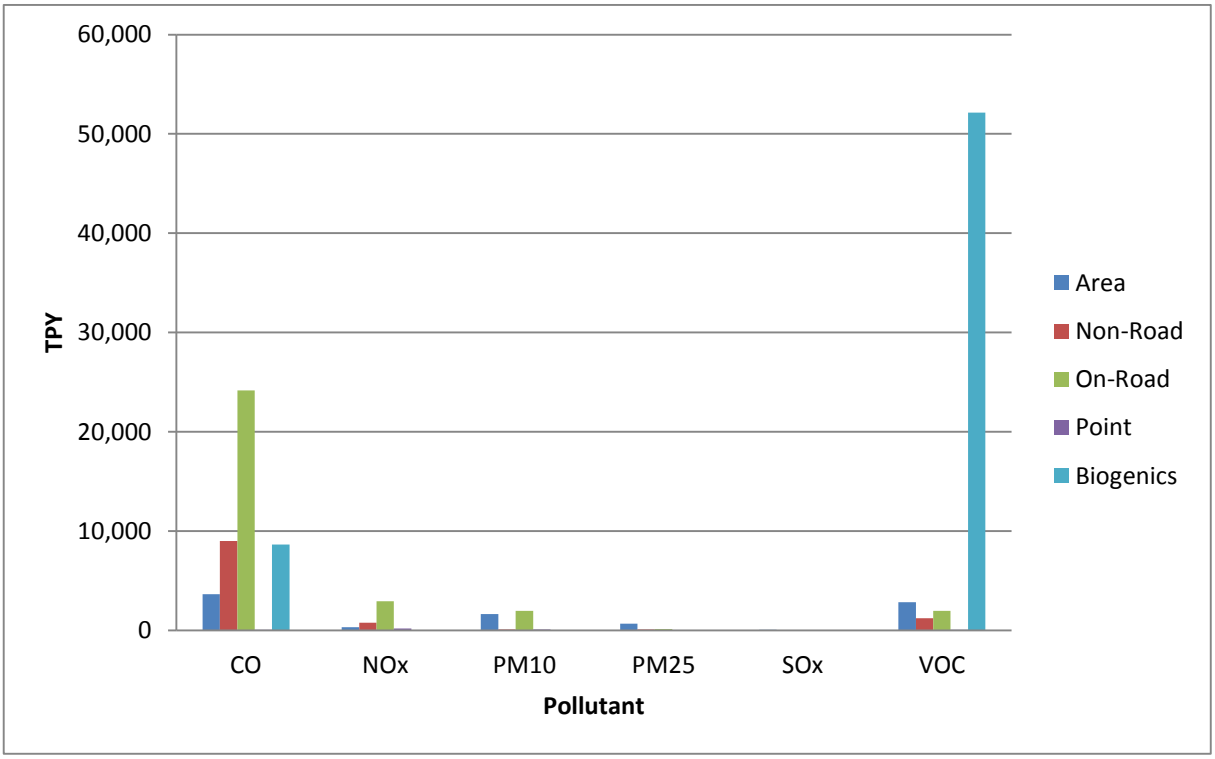

Figure 1. Criteria air pollutants for Washington County. Pollutants were divided into source categories and measured in tons per year (TPY).[2]

[1] Finlayson-Pitts and Pitts, Chemistry of the Upper and Lower Atmosphere, 2000.
[2] 2002 National Emissions Inventory, U.S. Environmental Protection Agency.

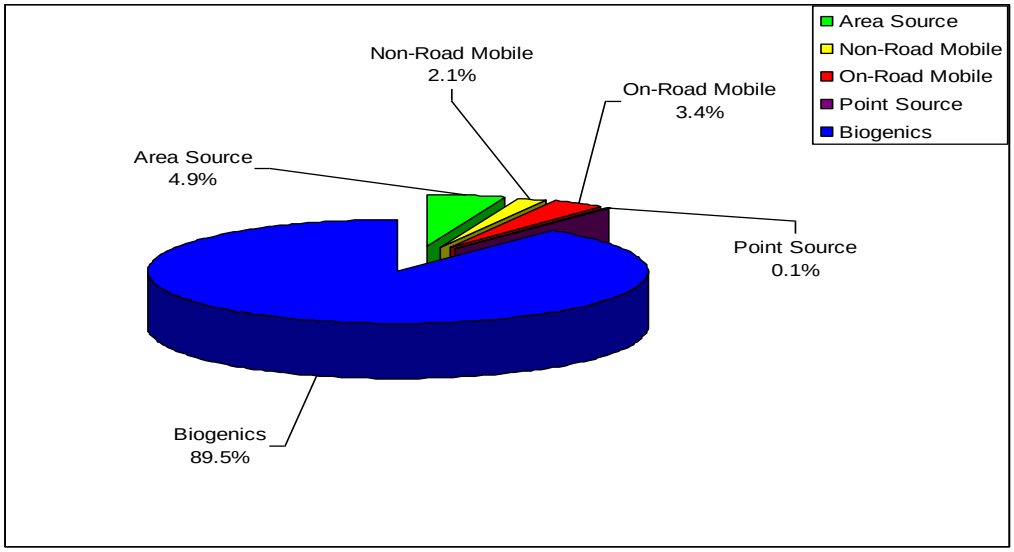

Figure 2. Allocation of volatile organic compound emission in Washington County. [3]

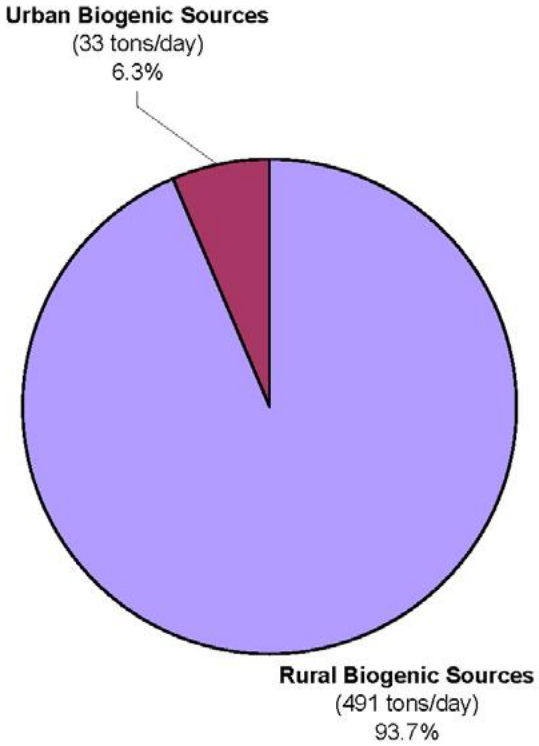

Figure 3. Comparison of rural and urban biogenic emissions of VOCs in Clark County, NV.[4]

Strong vegetative growth occurs in the early spring to early summer months, especially in desert climates when very high temperatures and minimal amounts of water require

[3] VOC source allocation, 2002 National Emissions Inventory, U.S. Environmental Protection Agency.
[4] 2006 Biogenic Emission Inventory for Clark County, NV, Nevada Department of Air Quality

plants to slow metabolism in the latter summer/early fall months as water becomes less available. During spring and early summer emission of biogenic VOCs are typically much higher than in late summer. Figure 4 shows the number of high ozone days (> 67 ppb) by month as observed at Dalton Wash and St. George/Santa Clara sites over the five years. The three-month period between May and July experienced the greatest number of high ozone days. Strong vegetative growth (likely emitting increased VOCs), increased solar radiation, higher ambient temperatures, as well as the potential impact of regional atmospheric transport may account for these higher ozone levels rather than increased VOC formation from local stationary and mobile sources.

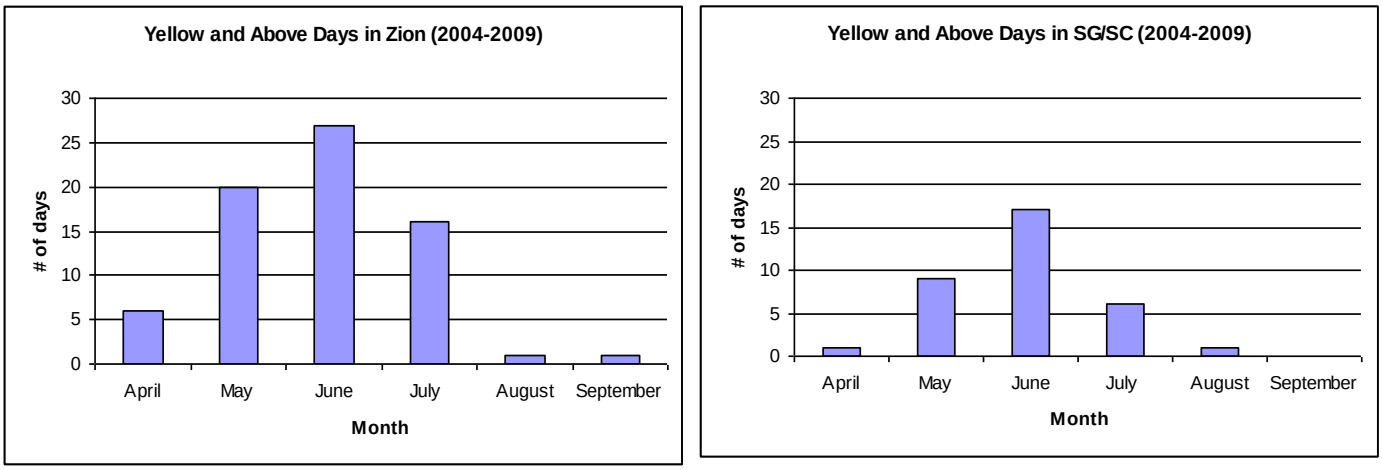

Figure 4. Total number of high ozone days (>67 ppb) by month at Dalton Wash and St. George or Santa Clara. The number of high ozone days for each month is the total from 2004-2009 excluding 2007.

4. Study Objectives

1. Determine the location of highest ozone concentrations in Washington County.
2. Recommend a location for a permanent UDAQ air monitoring site in Washington County.
3. Examine the potential for ozone precursor transport from Las Vegas or Southern California.
4. Provide forecasting help to predict the correct Air Quality Index for Washington County.

III. METHODS and PROCEDURES

1. Southern Utah Winds

To help determine site locations for the ozone saturation study in Washington County, dominant wind patterns at ten sites spread throughout the county, but different from the temporary ozone monitoring sites, were examined. Meteorological data was classified by season ─ winter (11/01/2009 - 2/28/2010), spring (3/01 - 5/31/2010, and summer (6/01 – 8/31/2010). Winds were generally from the south or north during the winter except at Lytle Ranch and St. George Municipal Airport where easterly winds prevailed. Beaver Dam (Arizona), Zion Canyon, and Leeds sites all had prevailing winds from the north to northeast. During spring, the dominant wind direction at most sites shifted to the southwest. Wind patterns at the St. George Municipal Airport, Zion NP, and Leeds during spring were more erratic with winds coming from the north and northeast at times. Specific geographic features appeared to influence dominant wind patterns more strongly in winter and spring. By summer, wind patterns at all sites were dominated by a southwesterly wind.

High ozone in the spring and summer, compared to winter, forms due to a variety of factors, including, warmer ambient temperatures, increased solar radiation and vegetative growth. Prevailing southwest winds tend to push air against the foothills in eastern Washington County; therefore, higher ozone concentrations may be found in towns of northeastern Washington County, such as Hurricane, La Verkin and Virgin. Santa Clara, west of St. George, is bordered by the South Hills to the south and Black Rock Hills to the north. Prevailing winds are from the east and west during spring and summer months at this location. Since Santa Clara is west of St. George and the prevailing winds were from the southwest, it is likely that lower ozone concentrations will be found in Santa Clara.

2. Site Selection and Description

Sites were selected using a combination of Ozone State and Local Air Monitoring Stations (SLAMS) requirements and objectives specific to this ozone saturation study. Site descriptions were recorded by collecting information on location, contacts, power source, sources of air pollutants (point, area, mobile, and dust sources),[5] dominant land use near a site, nearby roads, traffic volume (distance from the road depended on traffic volume per day), airports,[6] topography, distance from trees (site must be ten meters or further from the drip line of trees), obstructions, wind fetch and site photographs. Prior to selecting a specific site, multiple locations within the area were visited to determine

[5] A detailed list of point sources located in Utah and the amount of pollution each source produce was obtained from the Utah's Source # Log.

[6] Comparisons of jet fuel/exhaust vs. automobile fuel/exhaust provided the basis in determining the distance the site should be from the runway/taxi area. Results indicated jet and auto were similar, but caution prevailed and sites were located further away.

which specific locations would best satisfy the selection criteria. Once a location was chosen, ozone and meteorological equipment were installed. Ozone monitoring sites were powered by AC or DC current; some locations included meteorological instrumentation.

Portable ozone monitors were deployed to Washington, La Verkin, and Virgin from April through July 2011 and to Lytle Ranch, South St. George, St. George, Hurricane, and New Harmony from April 2011 through September 2011(Figure 5). An ozone monitor was collocated with the NPS ozone monitor at Dalton Wash for quality control purposes. Most ozone monitoring sites were downwind and northeast of St. George. Monitors were purposely located on a southwest to northeast axis beginning in St. George to see if ozone concentrations increase from St. George to Zion National Park based on increasing cumulative precursor emission. The bowl-shaped topography and diurnal wind patterns of St. George may cause ozone and its precursors to slosh from one side of the valley to the other. Ozone monitors located in South St. George and Lytle Ranch were installed to evaluate the potential role of regional ozone transport from sources to the south and west. All ten ozone monitoring sites are shown in Figure 5. Table 3 shows the date of monitor deployment, number of days of valid data collected and site location.

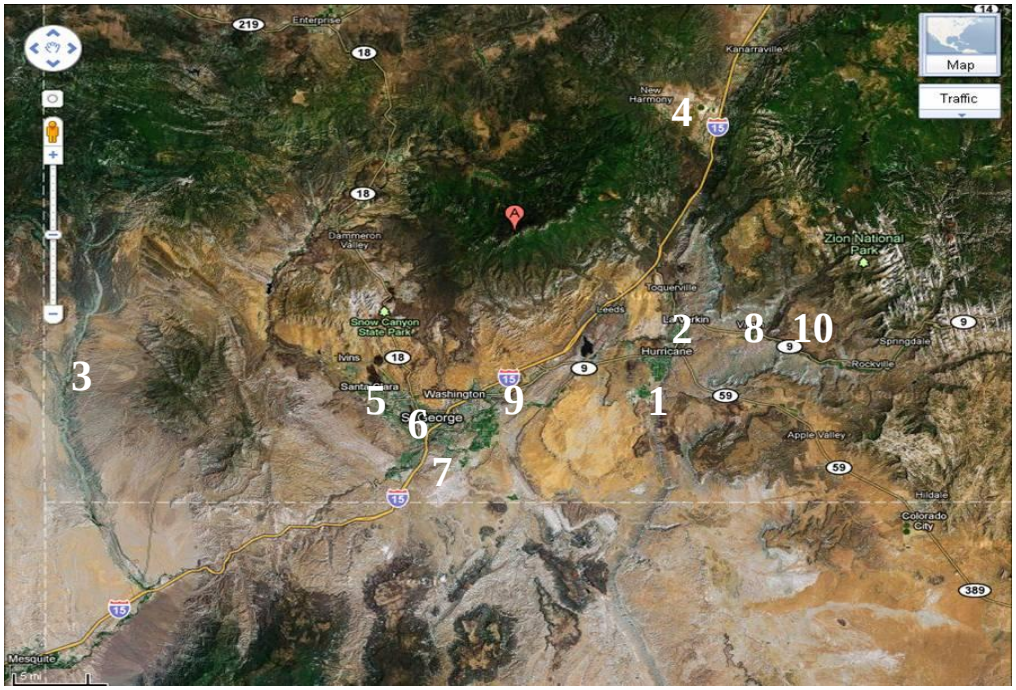

Figure 5. Map of ozone monitoring sites in Washington County: 1) Hurricane, 2) La Verkin, 3) Lytle Ranch, 4) New Harmony, 5) Santa Clara, 6) St. George, 7) South St. George, 8) Virgin, 9) Washington, 10) Dalton Wash.

Table 3. Deployment dates and location of each portable site.

Location	*Deployment dates*	*Number of Days*	*Location*
Hurricane	04/25 – 9/26	174	37.1437° N, 113.3030° W
La Verkin	03/31 – 07/26	118	37.2008° N, 113.2710°W
Lytle Ranch	03/16 – 10/12	211	37.1435° N, 114.0205° W
New Harmony	05/04 – 10/11	161	37.4808° N, 113.2435° W
St. George	03/31 – 10/11	195	37.1052° N, 113.5774° W
South St. George	03/30 – 9/27	182	37.0273° N, 113.5618° W
Virgin	03/30 – 07/26	119	37.2017° N, 113.2141° W
Washington	04/13 – 07/27	106	37.1132° N, 113.4837° W
Dalton Wash	03/29 – 07/26	120	37.1982° N, 113.1506° W

3. *Data Collection Equipment*

Ozone was monitored at the study sites using 2B Technologies Model 205 ozone monitors. In New Harmony, a portable ozone monitoring station (POMS), built by Air Resources Specialists (Fort Collins, CO) was installed. POMS sites measured wind speed and wind direction (via a sonic anemometer), air temperature, relative humidity and pressure in addition to ozone (Figure 6). The inlet for ozone and meteorological variables were measured at a height of two meters. At the other eight sites, ozone monitors were stored in a waterproof case underneath a tripod (Figure 6). Metal conduit was attached to the tripod to protect the inlet for the ozone monitor, which was positioned two meters above the ground. Air temperature was measured at these eight sites and wind speed and direction, along with ozone at three meters height was measured at Hurricane and Virgin (Table 4).

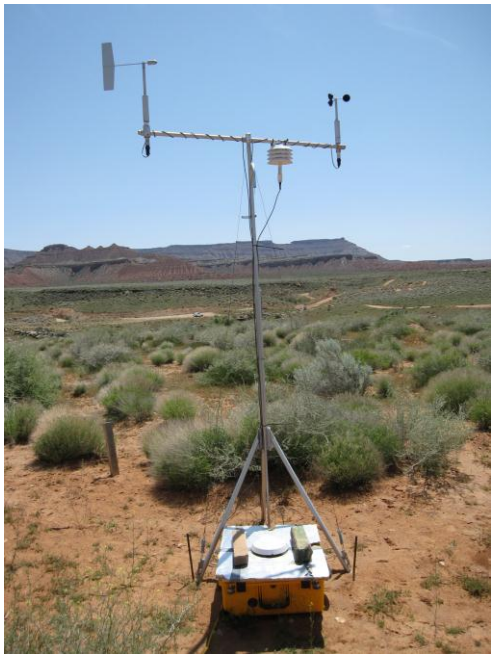

Figure 6. Two types equipment at ozone monitoring equipment used in the Washington County ozone saturation study.

Table 4. Description of nine ozone monitoring sites in Washington County.

Location	***Col-located***	***Power source***	***Wind data source***	***Site Land Use***	***Nearby Land Use***	***Topography***
Hurricane	No	Solar	UDAQ	Airport	Residential/ Desert	Flat Valley
La Verkin	No	AC	Weather bug	Elementary School	Residential	Flat Valley
Lytle Ranch	No	Solar	Mesowest ID: BADU1	Ranch/Nature Preserve	Desert	70' above valley
New Harmony	No	Solar	UDAQ	Fort New Harmony	Residential/ Grassland	Flat Valley
St. George	No	Solar	Mesowest ID: CMP21	UDAQ trailer	Residential/ Parks	Flat Valley
South St. George		AC	Mesowest ID: SGRU1	Production Yard	Industrial/ Desert	Flat Valley
Virgin	No	AC	UDAQ	Residential	Desert	50' above river valley
Washington	No	Solar	Mesowest ID: D5132	Public Works	Residential	20' above valley
Dalton Wash	Yes	AC	NPS	Desert	Desert	400' above valley

During monitoring site setup, ozone monitors were calibrated using a 2B Technologies Model 306 ozone calibration source, which was checked monthly against a state API calibrator. Monitors were set to log five minute averages for approximately 2 weeks. The monitors internally logged date, time, ozone concentrations in ppb, cell temperature, cell pressure, flow, and ambient air temperature. Sites were visited by UDAQ staff every two weeks to download ozone and meteorological data, and run a precision, zero, and span test (PZS). If observed concentrations were +/- 7%, ozone monitors were re-calibrated and the previous two weeks of data was invalidated.

4. Quality Assurance

a. High Temperature

2B Technologies recommends that the internal cell temperatures of the Model 205 ozone monitor remain less than 50°C to ensure receipt of high quality data. During southern Utah's hot summer days, this was extremely difficult to accomplish. Steps taken to alleviate the overheating of ozone monitors included the installation of a fan inside the case, vents on the sides of the case, and a radiation shield to reflect solar radiation. Each ozone monitor was equipped with an internal heater to ensure that air sampled was at a slightly higher temperature than external air. The temperature difference was maintained to reduce humidity of the sampled air. Since summer humidity was very low and temperatures were high, the internal heater was disconnected in early June. In general, the cell temperature of ozone monitors remained below 50°C.

b. Collocated Ozone Monitors

To verify the accuracy and precision of the 2B Technologies Model 205 ozone monitors and to validate data collected at the other Washington County sites, a 2B Technologies Model 205 ozone monitor was collocated at the Dalton Wash site. The Dalton Wash site monitors ozone with an ozone photometer approved as an EPA Federal Reference Method (FRM); the portable ozone monitor was installed on the roof of the monitoring trailer in a waterproof case. The Dalton Wash monitor inlet was approximately 10 meters above the ground, while the UDAQ ozone monitor inlet was approximately 5 meters above the ground. Ozone data collected from the monitors was very strongly correlated ($r^2 = 0.983$) between 3/29 – 7/26/11. Due to this strong correlation between the two ozone monitors, the Model 205 ozone monitor was removed on 7/26/11. A precision of 2.00% was calculated for the collocated ozone monitors using the Environmental Protection Agency's Data Assessment Statistical Calculator.[7] Three months of comparison between a portable ozone model and an FRM ozone monitor showed that 2B Technologies Model 205 ozone monitors produce precise and accurate ozone measurements.

c. Precision and Bias

Precision and bias were calculated for each site using EPA's Data Assessment Statistical Calculator.[5] Ozone data was considered valid if it met EPA standards for precision and bias; each dataset must have precision of 0-7%, a bias of +/- 7% and data completeness of >75%. Values for data precision were < 7% for all sites except La Verkin and Virgin (Table 5). EPA standards for bias and sample size were met at all nine sites.

Table 5. Precision, bias and data completeness for nine sites in Washington County.

Location	***Precision (%)***	***Bias (%)***	***Sample Size***	***Data Completeness (%)***
Hurricane	5.3	+/- 4.3	11	98.8
La Verkin	8.0	+/- 5.9	7	99.6
Lytle Ranch	4.2	+/- 3.2	13	93.3
New Harmony	6.3	+/- 4.7	10	81.9
St. George	5.8	+/- 4.6	14	99.6
South St. George	6.2	+/- 5.0	15	99.1
Washington	6.2	+/- 4.6	8	99.3
Virgin	8.0	+/- 6.0	9	95.3
Dalton Wash	4.2	+ 3.7	9	99.6

[7] Environmental Protection Agency, Data Assessment Statistical Calculator , http://www.epa.gov/ttn/amtic/qareport.html.; accessed 12/10/11.

IV. RESULTS and DISCUSSION

1. Saturation Study

The primary goal of the 2011 Washington County ozone saturation study was to determine the area of highest ozone concentrations and to find a suitable location for a new UDAQ air monitoring site. Nine temporary sites and one permanent site were used to find the highest ozone concentrations and to determine the boundary of high ozone in Washington County. High ozone was observed at several sites, and ozone concentrations at Santa Clara were the lowest observed in Washington County. To resolve the differences in similarly high ozone concentrations observed at several sites, ozone data is presented as the four highest 8-hour ozone days, the number of high ozone days, and mean daily maximum 8-hour ozone concentration. Finally, a scoring metric was used to provide a quantitative determination of the highest ozone site in Washington County since several sites observed similarly high ozone. The highest 8-hour ozone concentrations were observed at La Verkin, Lytle Ranch, and Virgin (Table 6).

Table 6. The five highest 8-hour ozone concentrations at Washington County sites in 2011.

Site	***1st highest 8-hour ozone***	***2nd highest 8-hour ozone***	***3rd highest 8-hour ozone***	***4th highest 8-hour ozone***	***5th highest 8-hour ozone***
Hurricane	76 (5/6)	74 (4/29)	74 (5/7)	74 (6/15)	72 (6/16)
La Verkin	77 (4/29)	74 (5/7)	74 (5/6)	71 (6/1)	70 (4/13)
Lytle Ranch	77 (6/16)	74 (6/1)	72 (6/12)	72 (6/8)	71 (6/15)
New Harmony	70 (5/7)	67 (6/1)	66 (6/2)	65 (6/3)	64 (5/23)
Santa Clara	72 (8/25)	70 (6/1)	70 (6/16)	69 (6/15)	68 (5/6)
St. George	75 (6/16)	74 (6/1)	74 (6/15)	71 (6/2)	71 (6/11)
S. St. George	72 (6/16)	71 (6/15)	70 (5/6)	69 (5/7)	68 (8/27)
Washington	73 (5/7)	72 (5/6)	72 (6/15)	72 (6/16)	71 (6/1)
Virgin	77 (4/29)	74 (5/7)	74 (5/6)	72 (5/23)	72 (5/16)
Dalton Wash	75 (4/29)	75 (6/15)	74 (5/6)	73 (6/1)	73 (6/16)

Peak ozone concentrations at Hurricane, St. George, and Dalton Wash were 76, 75, and 75 ppb, respectively. The lowest ozone concentrations were observed at the current UDAQ site in Santa Clara and in South St. George. All sites were in compliance with the current ozone NAAQS. If the ozone NAAQS were lowered to 70 ppb, then all sites in Washington County, except Santa Clara and South St. George, would be in

violation of the ozone standard. Hurricane was the site closest to violating the current ozone NAAQS with a 4th highest 8-hour ozone concentration of 74 ppb.

While the Washington County site did not violate the NAAQS, all sites except New Harmony experienced at least one day when ozone was above 70 ppb. At the Dalton Wash site, there were seven days when ozone was greater than 70 ppb. There were six days of ozone > 70 ppb in St. George and Virgin and five days with ozone > 70 ppb in Hurricane, Lytle Ranch, and Washington. Dalton Wash experienced the greatest number of days of ozone > 65 ppb (32 days); while sites in Hurricane, La Verkin, Lytle Ranch, St. George, Washington, and Virgin observed between 20 and 25 days of ozone > 65 ppb (Figure 7).

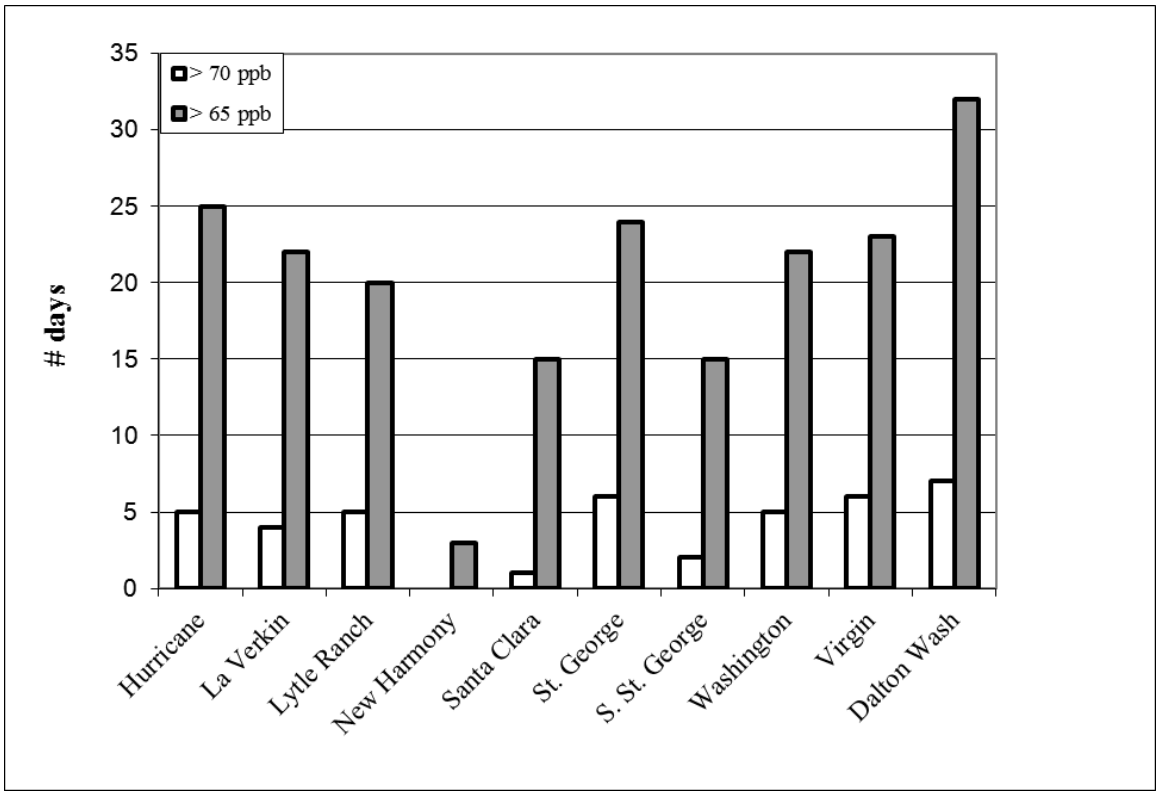

Figure 7. The number of days with ozone > 70 ppb (white bars) and > 65 ppb (gray bars) at ten sites in Washington County.

The highest mean daily maximum 1-hour ozone concentration was observed at Dalton Wash at 63.0 ppb. Mean daily 1-hour ozone concentrations of 62-62.5 ppb were observed in Washington, Hurricane, and Virgin (Figure 8). There was substantially more variance in the mean daily minimum 1-hour ozone concentration with the lowest value occurring in St. George and the highest value occurring at Dalton Wash. Differences in nighttime ozone concentration were likely correlated to the concentrations of NO_x gases present. It was likely that substantially higher concentrations of NO_x were present in urban St. George compared to the rural location of the Dalton Wash site. Higher nighttime concentrations can often lead to higher 8-hour concentrations of ozone, but were not necessarily related to peak 1-hour concentrations of ozone. Mean

daily minimum 1-hour ozone concentrations were 20 ppb lower in St. George compared to Dalton Wash and likely contributed to lower 8-hour ozone concentrations in St. George.

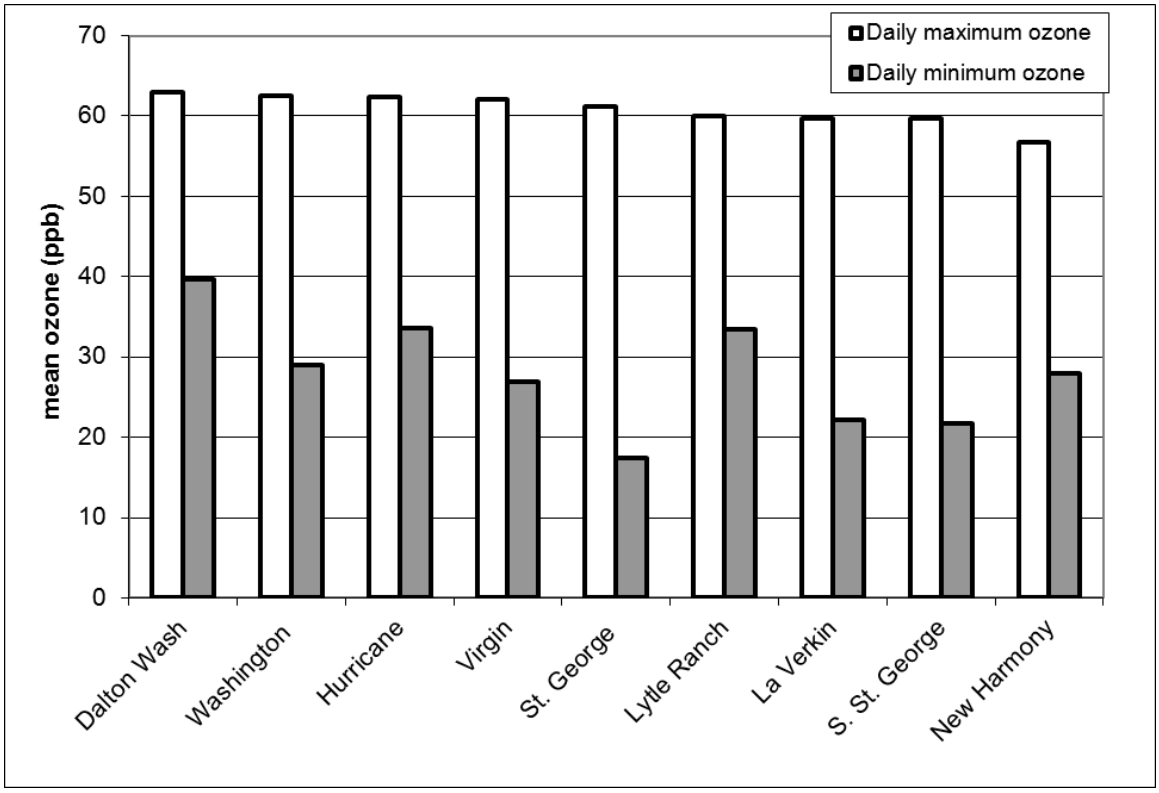

Figure 8. The mean daily 1-hour maximum and minimum ozone concentrations at ten Washington County sites. Data used was from 4/1 – 7/25/11.

Based on the data it is clear that there are several locations in Washington County experiencing high ozone. None of the five measures (peak ozone presented, peak ozone, 4th highest 8-hour ozone, the number of days with ozone > 70 and > 65 ppb, and mean daily maximum 1-hour ozone concentration) by themselves clearly indicate the location of the highest maximum ozone in Washington County. To provide an integrated quantitative analysis of the five measures of high ozone a simple scoring metric was developed. Logistical considerations (population representativeness and ease of locating a suitable site), were also included in the scoring metric. Table 7 shows the results of the scoring metric. Each site was given a score of 1-7 based on the rank of each site for each measure of high ozone and logistics. For example, the site with the highest 8-hour ozone concentration received a score of 7 points and the site with the 7th highest ozone concentration received 1 point. Ties were resolved by taking the average of the points awarded for all sites with the same value; for example if three sites all had the greatest number of days > 70 ppb, then each of the three sites would receive 6 points {(7 +6 + 5)/3}. The site with the highest total score was considered the highest ozone site with the best logistics in Washington County. The results of the scoring metric indicate that Hurricane was the location of highest ozone and best logistics in Washington County. Given that each measure of high ozone and

logistics indicated a different site as the "suitable ozone site," the scoring metric shown in Table 7 provides a simple, but effective analysis and determination of the location of highest ozone and best logistics in Washington County.

Table 7. Results of the scoring metric used to determine the location of highest ozone in Washington County. Seven sites were included in the analysis of five measures of high ozone.

Measure of high ozone & logistics	***Hurri-cane***	***Dalton Wash***	***St. George***	***Virgin***	***Wash-ington***	***La Verkin***	***Lytle Ranch***
Highest 8h ozone	4	2.5	2.5	6	1	6	6
4th highest 8h ozone	7	6	1.5	4	4	1.5	4
Days > 70 ppb	3	7	5.5	5.5	3	1	3
Days > 65 ppb	6	7	5	4	2.5	2.5	1
Mean daily 1h maximum	5	7	3	4	6	1	2
Population representativeness	5	2	7	3	6	4	1
Location selection ease	7	2	6	3	5	4	1
Total score	**37**	**33.5**	**30.5**	**29.5**	**27.5**	**20**	**18**

2. A Closer Look at Potential Ozone/Ozone Precursor Transport

a. Lytle Ranch Nature Preserve

To gain a better understanding of regional background ozone levels and the potential for ozone precursor transport, a remote site in western Washington County, in the far southwestern corner of the state of Utah, was established. In the Beaver Dam Wash, a portable ozone monitor was placed at the Lytle Ranch Nature Preserve. Lytle Ranch is a very remote location with only two people living in the area year-round. The site is 24 miles west of St. George, 50 miles NE of Reid Gardner Power Station (Reid Gardner is a 4 unit, 550 net MW coal fired power plant located on 480 acres in Moapa Valley, Nevada), 90 miles NE of Las Vegas, and 330 miles NE of Los Angeles. Surprisingly, given its remoteness to sources, ozone levels were higher than expected at Lytle Ranch. Lytle experienced an 8-hour average max of 77 ppb, and a 4th-highest 8-hour average max of 72 ppb. There was one day at Lytle Ranch when ozone concentrations exceeded 75 ppb and seven days that exceeded 70 ppb. Given the remote location of Lytle Ranch you would expect ozone values to be more similar to Santa Clara. NOAA HYSPLIT back trajectory analysis was used to track the history of synoptic air masses present at Lytle Ranch on days greater than 70 ppb and days greater than 65 ppb, but less than 70 ppb (Figure 9). All back trajectories were calculated at 1000 meters and were 48 hours out. All days that were above 70 ppb originated from the southwest, passing over or near a potential emission source, including Reid Gardner power station,

Las Vegas, southern California, or San Francisco. The days that were above 65 ppb, but less than 70 ppb, were largely from the southwest as well, with 12 of the16 back trajectories from the southwest, passing over or near a potential emission source. The four that did not originate from the southwest, had slightly lower ozone concentrations.

Given the higher than expected ozone values at Lytle Ranch, it is possible that ozone values from Lytle Ranch may be anomalous. Lytle Ranch is located in the Beaver Dam Wash and in an area with many cottonwood trees and other vegetation. With the sudden change in vegetation from the barren desert plants to an area of cottonwoods, Lytle Ranch may be a possible "hotspot" of ozone, with a possible increase in VOCs, leading to higher ozone values.

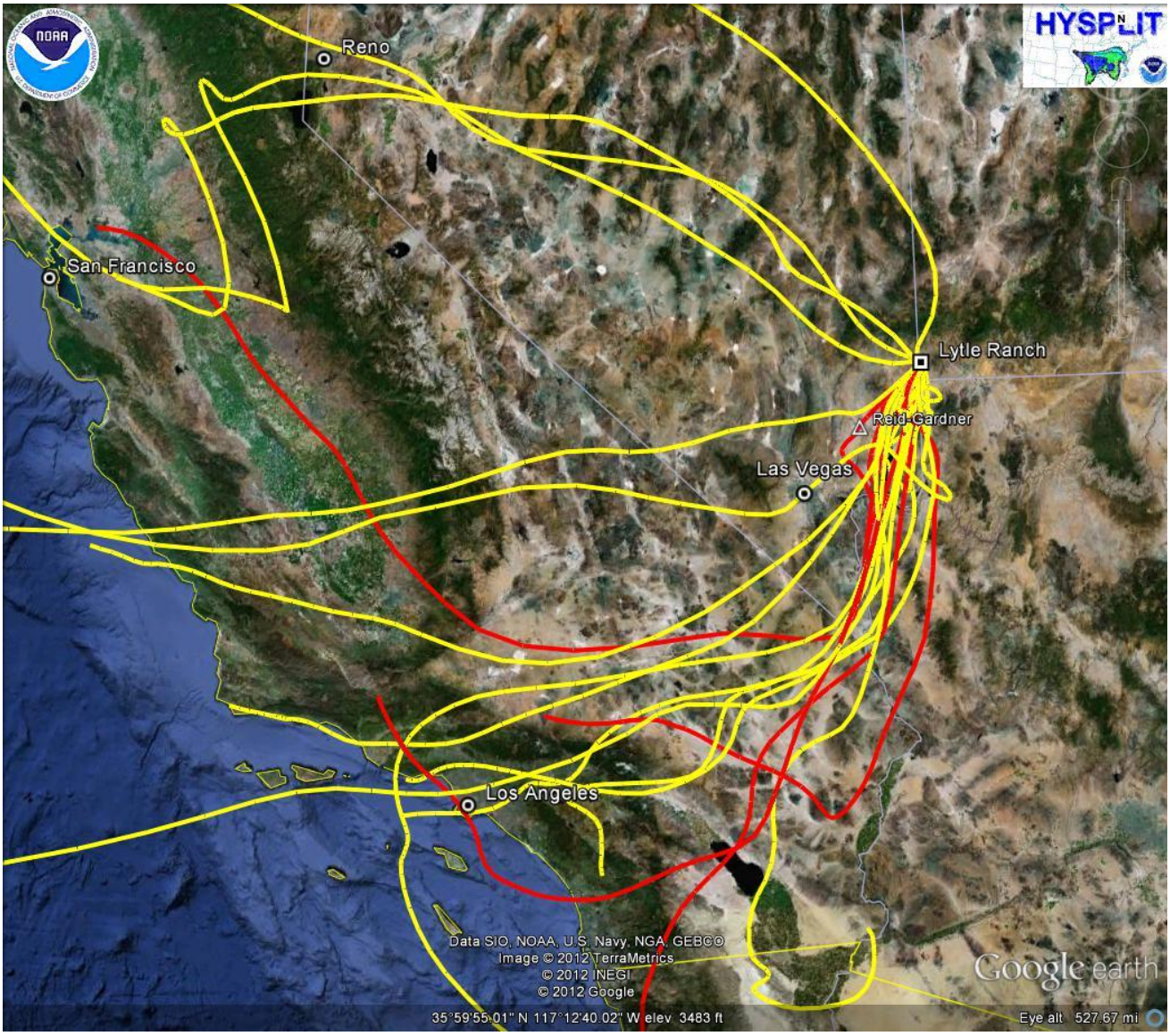

Figure 9. NOAA HYSPLIT back trajectories for Lytle Ranch. Trajectories with 8-hour average ozone >70 ppb are in red. Trajectories with 8-hour average ozone >65 ppb, but <70 ppb are in yellow.

Surface winds were also analyzed at Lytle Ranch. Lytle Ranch was not equipped with its own wind sensing equipment, but wind information was gathered from a Bureau of Land Management (BLM) meteorology site at Badger Spring. Badger Spring is 4 miles NE of Lytle Ranch with an elevation increase of 300 meters. During the time frame of April – September, surface winds were averaged over a 24 hour period. Given the days that were greater than 65 ppb, 80% of the time winds were from 170-270 degrees. Of the days that were greater than 70 ppb, 100% of the time winds were from 170-270 degrees. During the entire period 45% of the time winds were from 170-270 degrees at Badger Spring. Lytle Ranch is down in the Beaver Dam Wash and in somewhat of a canyon and may have more winds from the south than Badger Spring due to the funneling of the winds through the canyon. A map of surface winds showcasing the summer winds for the Washington County area and NE Nevada can be seen in Figure 10. The winds are shown by wind roses, which display the direction the wind is coming from, and the magnitude of the wind. Looking closely at the surface winds in Nevada, winds near Moapa Valley, which is the location of the Reid Gardner power station, there are strong (approximately half of the time winds are greater than 25 mph) winds from the south, south-southwest. Given the topography and the meteorology, a strong south or southwest wind would possibly transport emissions from the power plant to the location of Lytle Ranch. Upwind of the power plant would be Las Vegas. Analyzing the surface winds at Mesquite, NV winds are primarily from the southwest, west-southwest which should be the air mass that is reaching the St. George area. Also, upwind of Mesquite is Las Vegas.

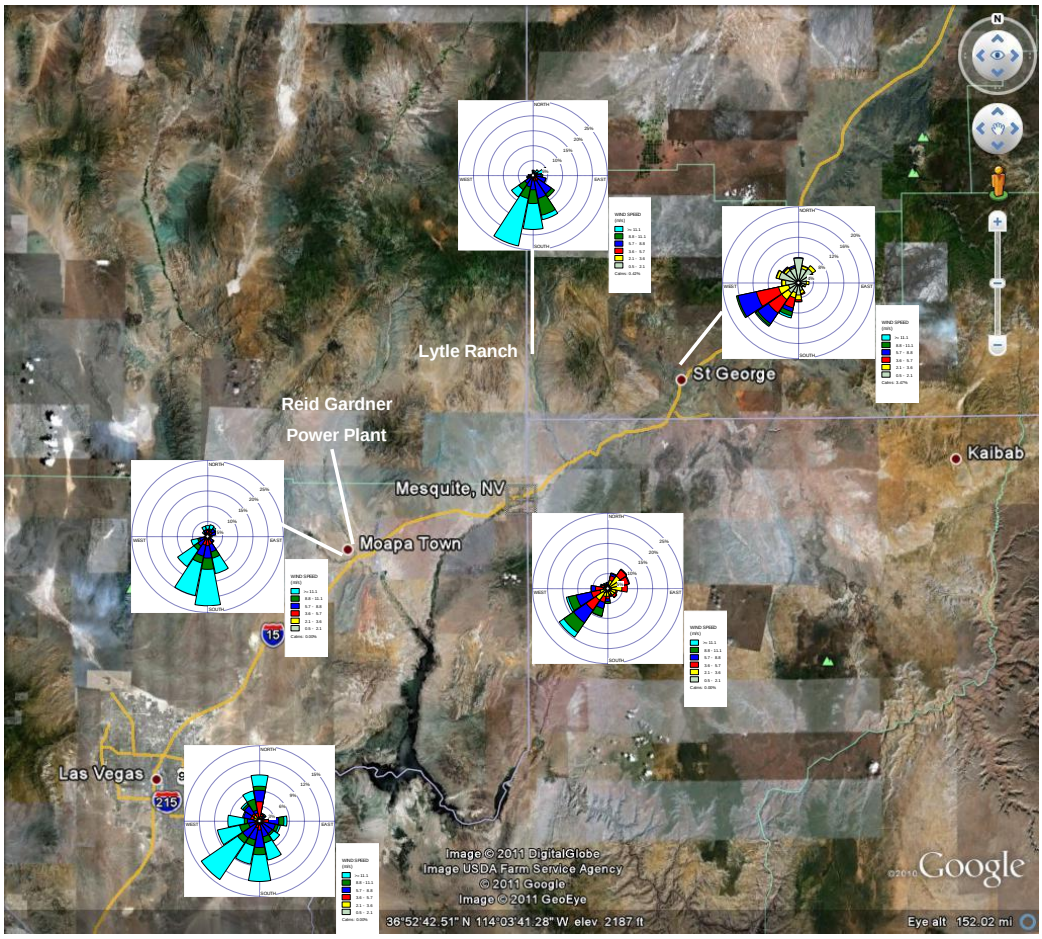

Figure 10. Wind roses showcasing summertime winds at Lytle Ranch, St. George, Reid Gardner power station, Mesquite, NV, and Las Vegas, NV. Winds were generally from the S/SW during the summer months.

b. Great Basin National Park, NV

Back trajectories were also analyzed at Great Basin National Park, NV. Great Basin National Park and the Lytle Ranch site are similar to each other in climate, vegetation, and remoteness. The nearest upwind emission sources are Reid Gardner power plant (135 miles) and Las Vegas (190 miles). The National Park Service has been monitoring ozone at the park since 1993 and has experienced some relatively high ozone values over the years. During the 2011 ozone season it had an 8-hour average max of 76 ppb and a 4th-highest 8-hour average max of 72 ppb. The site logged one day above 75 ppb and seven days above 70 ppb. NOAA HYSPLIT back trajectories were also used to analyze the history of the synoptic air masses at Great Basin National Park (Figure 11). All trajectories were at 1000 meters and 48 hours out. All days that had ozone concentrations above 70 ppb originated from the southwest, passing over or near a potential emission source including Reid Gardner power plant, Las Vegas, and southern California. Six of the thirteen days that were greater than 65 ppb, but less than 70 ppb originated from the southwest, with an additional three originating from the west near San Francisco, CA.

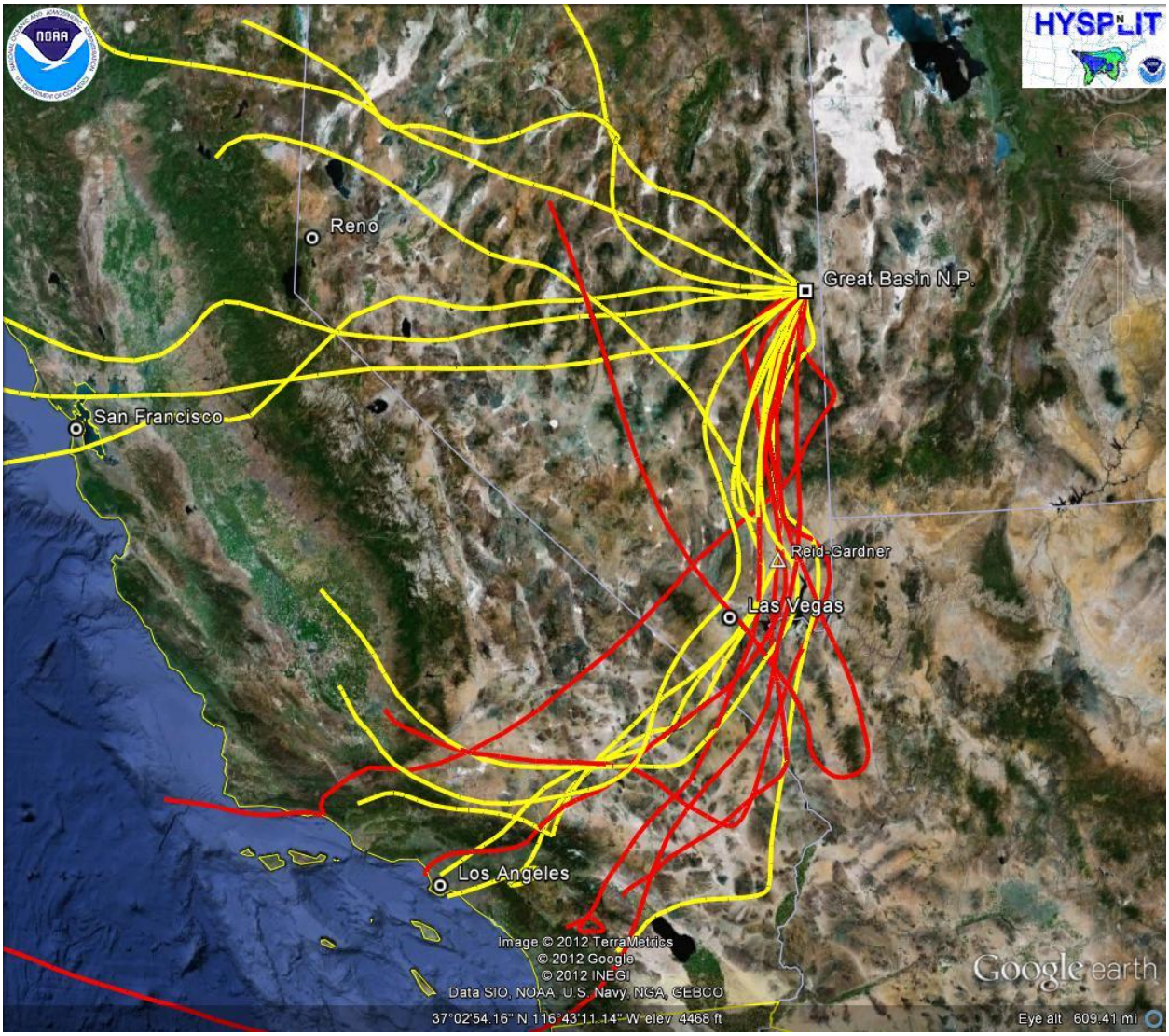

Figure 11. NOAA HYSPLIT back trajectories for Great Basin National Park. Trajectories with 8-hour average ozone >70 ppb are in red. Trajectories with 8-hour average ozone >65 ppb, but <70 ppb are in yellow.

Surface winds were also analyzed at Great Basin National Park. During the entire period of April-September winds were averaged over a 24-hour period. During the days that were greater than 65 ppb, 55% of the days had wind data missing. Of the remaining 45%, 78% of the time winds were from 170 – 270 degrees. During the April-September period 78% of the time winds were from 170-270 degrees.

The majority of high days for both rural locations occurred during May and June. Typically high ozone is seen in July and August when temperatures are warmer and conditions are favorable for ozone formation. Desert plants are typically more active (highest rates of photosynthesis and therefore VOC emission) early in the growing season when sufficient soil water is available. As soils dry later in the season, plants are forced into a dormant stage (little photosynthetic activity) and VOC emission is decreased. The drying of soils can have a secondary impact on ozone chemistry as

well. Bacterial respiration in desert soils, especially during periods of higher soil moisture in the spring, can result in NO_x emissions to the atmosphere. As soils dry, bacterial soil respiration decreases and therefore emission of NO_x from soils decrease as well.[8] In general, the magnitude of biogenic VOC emission from desert vegetation is much greater than soil emission of NO_x. Considering the lack of emissions at Lytle Ranch and Great Basin National Park, back trajectory analyses, and dominant surface wind patterns, it is likely that both transport of regional emissions and local generation of biogenic VOCs and NO_x contributed to high ozone observed in rural western Utah/rural central-eastern Nevada during 2011.

3. Forecasting Ozone for Washington County

The Utah Division of Air Quality provides a daily service to the public that announces an air quality index (green, yellow, and red days) of ozone concentrations for various areas around the State of Utah. Given that transport of ozone or ozone precursors into Washington County could be occurring it may be valuable to analyze ozone values upstream of Washington County. In an effort to more accurately predict air quality indexes in Washington County, ozone values were analyzed in St. George, Las Vegas (Joe Neal site, 6651 W. Azure Ave.), and Los Angeles (1630 N. Main St.). Daily hourly max ozone values were determined for all three sites and then compared to each other. Ozone values in St. George were compared to ozone values in Las Vegas one day prior and Los Angeles was analyzed two days prior to ozone values in St. George.

Higher ozone values typically occur when there are copious amounts of ultraviolet radiation, which normally happens when there are mostly clear skies. Given this fact, ozone values needed to be compared when skies were partly cloudy to clear for each area. For example, if it was sunny in St. George on a given day, in order to compare ozone values to the values in Las Vegas one day prior, the skies needed to be sunny in Las Vegas also. If skies were sunny in St. George, but one day earlier skies were mostly cloudy or rainy in Las Vegas then ozone was not compared. Also, ozone values in St. George only needed to be compared to Las Vegas and Los Angeles when surface winds were from those areas (blowing from 170-270 degrees). Wind direction was averaged each day over a 24 hour period. In summary, ozone values were only compared when the locations met both the clear skies and surface wind criteria. Wind speed, temperature, and relative humidity were neglected in this comparison. Table 8 displays the average difference between monthly average ozone values for St. George and Las Vegas. St. George is typically lower than Las Vegas.

[8] Yienger, J.JK. and H. Levy II (1995), "Empirical model of global soil-biogenic NOx emissions," *Journal of Geophysical Research*, **100**:11, 447-11,464.

Table 8. The average difference between monthly average ozone values for St. George and Las Vegas. St. George is typically lower than Las Vegas.

Month	***Average Difference***	***Standard Deviation***
April	+1	3
May	0	9
June	-5	10
July	-11	1
August	-3	8
September	-9	5
Full Season	-5	8

The average difference ranged from +1 to -11 during the entire season. Only during the month of April was St. George higher than Las Vegas. During the month of May the average difference was zero. The rest of the season St. George was always lower than Las Vegas. During the month of July, St. George was -11 ppb with only one standard deviation. This analysis shows that during the early spring, ozone values are fairly similar and in the summer months ozone values should be on average about seven ppb lower than Las Vegas. Little comparison could be done against Los Angeles due to the fact that rarely did the sky and wind direction meet the criteria.

V. RECOMENDATIONS:

1. Location of a Permanent Monitoring Site

The most suitable location for a permanent monitoring site is Hurricane.

Values:

Hurricane had the 2nd highest 8-hour concentration overall (only being shy of the 1st highest 8-hour concentration by 1 ppb) and the highest 4th highest 8-hour concentration. Hurricane had the 2nd highest number of days above 70 ppb (only shy of the highest locations by one or two days) and the 2nd highest number of days above 65 ppb (only behind Dalton Wash). Hurricane had the 2nd highest, mean daily 1-hour maximum, being tied with Washington, and only slightly behind Dalton Wash. Hurricane had the highest result from the scoring metric.

Logistics:

Hurricane is the most suitable site logistically for a permanent monitoring site. The temporary site was located at a small local airport which would provide plenty of space for a trailer and would meet EPA criteria for an ozone monitoring site. In close proximity to the airport, there are three public schools that may be good locations for a permanent site. Hurricane would also represent a population center and provide data applicable to those living in the Washington county area. Although Hurricane was not the location with the highest concentrations in Washington County, it proves to be a better location given that the Zion NP monitoring site in the Dalton Wash is very close to Zion NP and away from the populated areas. Despite relatively high ozone, Virgin would not be suitable for an ozone monitoring site due to a lack of locations meeting EPA monitoring site criteria and its proximity to the Dalton Wash monitor.

Although a trailer already exists in the city of St. George at 200 South 300 East, and showed some higher ozone concentrations, it does have some logistical problems. The trailer is pushed up against the fence of a baseball field that is used quite often by locals and for baseball tournaments and is located in a dirt parking lot that is used for overflow parking. There is a widely used park across the street to the southeast and rodeo grounds to the east of the station that also use the dirt parking lot for overflow when there is not sufficient parking elsewhere. The trailer's north side is also watered by the baseball field's sprinkler system in the evening hours and has caused some water damage in the floor of the trailer.

The monitor at Lytle Ranch also showed some high ozone concentrations, but scored lowest in the scoring metric. Lytle Ranch also does not have access to AC power and is very remote and away from the populations.

Hurricane proves to be the most suitable location for a permanent monitoring site, given its higher ozone concentrations and the good logistics of the area.

2. 2012 Plan to Monitor Potential Ozone/Ozone Precursor Transport

Lytle Ranch had higher than expected ozone values and could prove to be anomalous. Lytle Ranch is located in the Beaver Dam Wash in an area that has many cottonwood trees and other vegetation, unlike the areas surrounding it that is populated with only desert plants. The additional cottonwood trees and other vegetation may cause additional VOCs to be released into the air and therefore cause more ozone. To determine whether ozone at Lytle Ranch is representative of ozone concentrations in rural southwest Utah, a small saturation study will be conducted in the early spring of 2012. Sites will be established at Lytle Ranch, Badger Spring, and Gunlock State Park. The Lytle Ranch site will be in the same location as the previous year. A second site will be established at Badger Spring which is four miles NE of Lytle Ranch with an elevation increase of 300 meters. Badger Spring should be located high enough in elevation to be out of the Beaver Dam Wash. To assess the ozone values further east and on the east side of the Beaver Dam Mountains, a site will be located at Gunlock State Park. When the representative site has been established, that site will remain until the end of September 2012, while the other two sites will be removed.

ACKNOWLEDGMENTS

There were many UDAQ employees that contributed to the planning and execution of the 2011 Washington County summer ozone saturation study. Firstly, thank you to Bruce Allen and Roman Kuprov for help in writing the proposal for and creating the framework of the saturation study. A special thanks goes out to Ken Symons for assistance with fieldwork when an extra hand was needed. Thank you to Colleen Delaney and Kimberly Kreykes for help with the analysis and report writing. Finally, thanks to Bill Swensen of St. George city in helping locate suitable temporary monitoring sites and assistance with field work.