Attachment E

Information Submitted to the TCEQ for the San Miguel Electric Plant

Contents:

Part 1: ***San Miguel Electric Cooperative FGD Upgrade Program Update***

Part 2: ***San Miguel SO_2 Air Dispersion Modeling Report***

Attachment E

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Part 1: ***San Miguel Electric Cooperative FGD Upgrade Program Update***

San Miguel Electric Cooperative
FGD Upgrade Program Update

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1.0 Introduction

This report discusses the results of the program that AECOM undertook with San Miguel beginning in 2009 to study ways to upgrade the SO_2 removal performance of the FGD system and subsequently to implement those changes on all four modules. The first sections summarize the results of AECOM's engineering study to evaluate options to upgrade the SO_2 removal performance. The last section provides an interim update of the FGD system and how it has performed since the upgrades were implemented.

Prior to initiating this FGD upgrade study, AECOM reviewed a report provided by San Miguel on the SO_2 upgrade that was completed at the plant in 2006. The result of AECOM' review indicated that there were additional opportunities to possibly improve the scrubbers to boost removal and/or reduce the reliance on the additive DBA. The study confirmed that initial assessment. The first sections describe the scope of work and costs for two different upgrade alternatives – one a low-cost approach that could be completed in a relatively short period of time and a second, more comprehensive approach that involved more money and time, but which had the potential for greater benefits.

The rest of this report contains the following sections:

- Section 2 – Summary of Upgrade Options Considered;
- Section 3 – Process Analysis;
- Section 4 – Cost Estimate;
- Section 5 – Economic Analysis;
- Section 6 – Project Schedule; and
- Section 7 – Conclusions of the Study phase
- Section 8 - Interim Results of Implementation of Option 1 and 2 Improvements on FGD Performance

2.0 Summary of Upgrade Options Evaluated

The San Miguel FGD system consists of four modules that are typical of the first generation limestone FGD systems designed in the late 1970's and early 1980's. The modules have a venturi section for the first contact zone of flue gas and recycled slurry and an absorber section for the second contact zone where the majority of the SO_2 scrubbing is accomplished. The venturi section was originally intended to remove residual fly ash and some SO_2, and to saturate the flue gas prior to entering the tray section of the absorber. The absorber utilized two counter-current trays and a flooding spray header to distribute the recycle slurry to the trays. At the time of the study, both zones of the modules have been modified from their original designs – the venturi had been opened up to reduce its pressure drop and the recycle slurry fed to it was

introduced in a down-flow, co-current-with-the-flue-gas manner. The absorber had its spray nozzles modified (wider spray angle).

When AECOM examined the layout of the recycle spray headers, good opportunities for improvement were identified. AECOM has been redesigning the internals of older FGD systems in the U.S. for many years. More recently AECOM has been focusing on how to improve gas/liquid contacting so that absorber towers can maximize SO_2 removal – often targeting upper 90 percent SO_2 removal efficiencies for absorbers without having to rely on organic acids like DBA. AECOM has also been designing and installing trays in some of these same towers, combining the synergy of the upgraded spray headers/nozzles with our new sieve tray designs to achieve high SO_2 removals.

Two basic upgrade options were identified and examined in the study phase of the program:

- Option 1 – Modification of Existing Absorber Spray Section; and
- Option 2 – Option 1 plus Moving Quench Spray to Absorber Section.

Both options included upgrading slurry spray headers to use the Lechler TwinAbsorb® spray nozzles. This nozzle has two outlets that produce intersecting hollow cone sprays, known as double hollow cones (DHC), which improves SO_2 removal as compared with standard spray nozzles. Figure 2-1 shows the intersecting sprays, which break up the drops and regenerate droplet surface area.

Research has shown that most of the SO_2 removal in a spray tower absorber occAECOM within 18” of the spray nozzle exit. Improved scrubbing results when the spray is turbulent in that zone and the number of droplet-to-droplet collisions are high. Experience has shown that the DHC nozzles provide maximum scrubbing efficiency when designed with a wider spray angle. The two DHC outlets each have 120-degree spray angles, but the two are tilted about 15° apart, which creates an oval pattern overall. AECOM has installed DHC nozzles in a number of FGD systems and the results have consistently shown an improved ability to scrub SO_2 compared to conventional single cone nozzles.

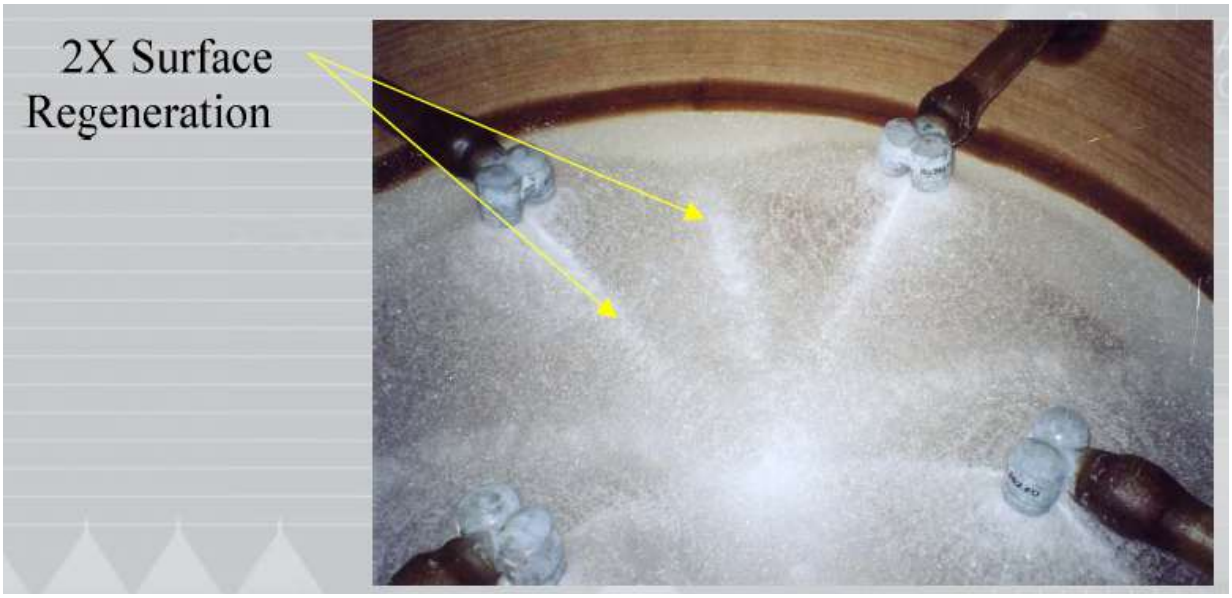

Figure 2-1. Spray Pattern from Proposed Double Hollow Cone Spray Nozzles

The summary of equipment modifications and construction scope of work associated with each of these basic options is presented below. The information presented below is for one absorber (four absorbers have been upgraded):

- Option 1 – Modification of Existing Absorber Spray Section (quantities are per absorber)
  - Remove the 28 existing six-inch spray nozzles
  - Install 28 2205 duplex stainless steel flow splitters or "spiders", one at each six-inch flange where the existing six-inch spray nozzles are currently located. The spiders are approximately two feet tall and split the flow from each six-inch connection (24,000 gpm / 28 = 857 gpm) so that it feeds three tangential four-inch nozzles at the bottom of the spider.
  - Install three new high-efficiency 4-inch silicon carbide DHC nozzles on each spider. Each DHC nozzle has 286 gpm of flow.
  - Install a spray impingement plate on the walls where the spray from the DHC nozzles hits the walls to protect the rubber lining from erosion.
  - Repair the existing rubber lining after the impingement plates were installed.

Figures 2-2 and 2-3 on the next page show the improvement in spray pattern with the spiders. The 28 original six-inch nozzles provided only 85% coverage of the cross-sectional area of the absorbers at a point 18 inches below the nozzles; the 84 four-inch nozzles on the spiders provide 265% coverage at the same distance. Figure 2-4 is a sketch of an individual spider arrangement.

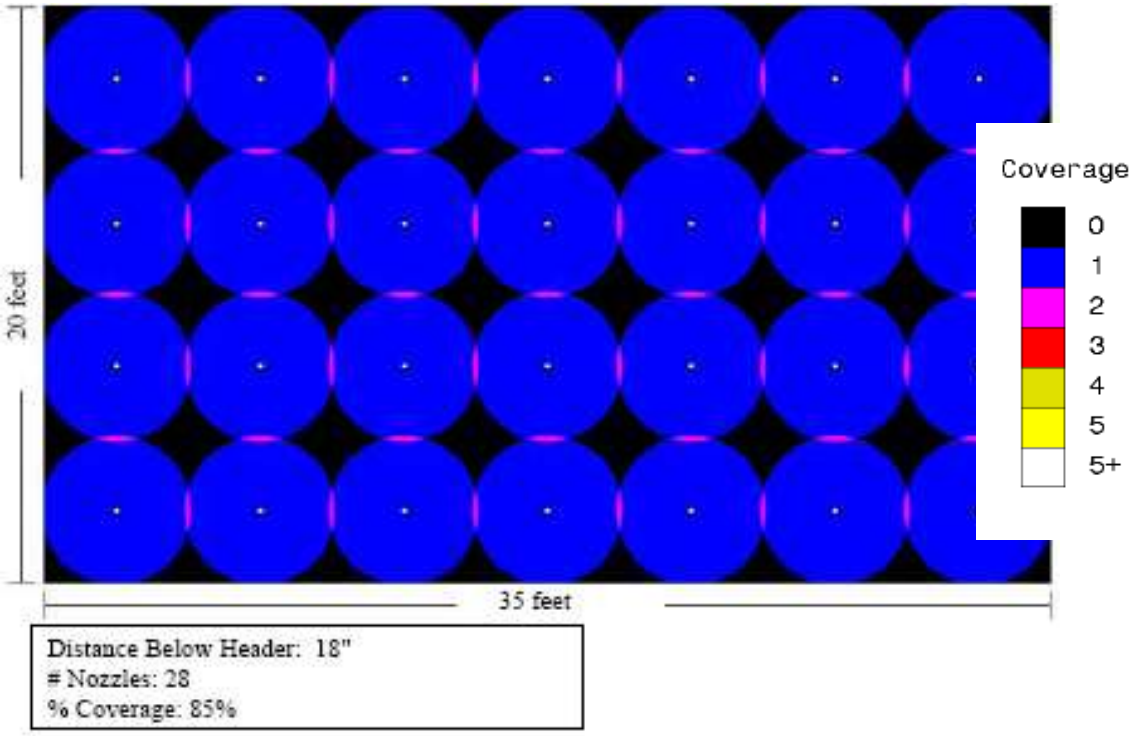

Figure 2-2. Spray Pattern from 28 Existing Six-Inch Nozzles in the Absorbers

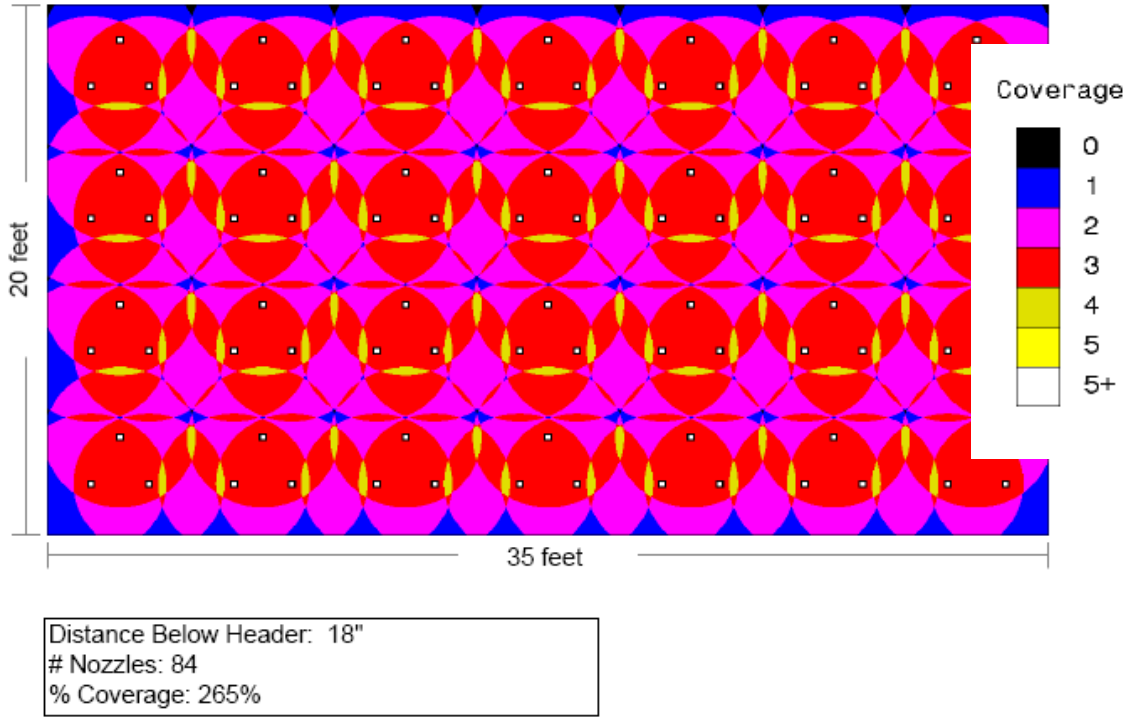

Figure 2-3. Spray Pattern from 28 Spiders, Each with Three Four-Inch DHC Nozzles

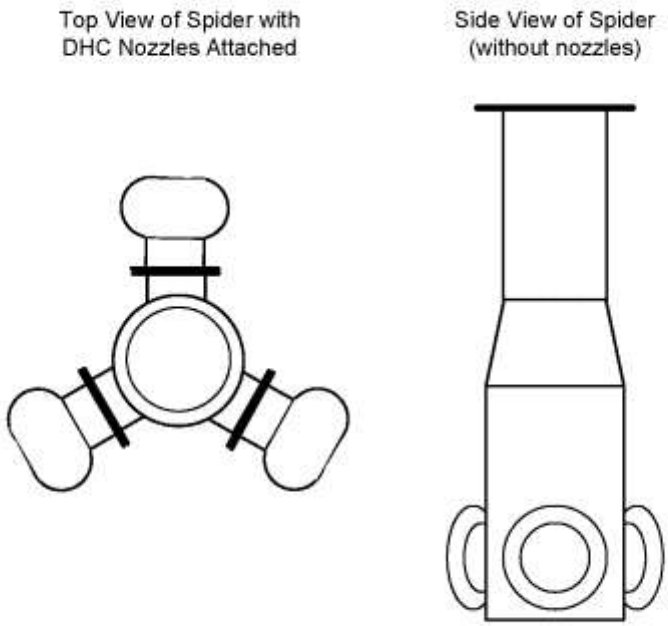

Figure 2-4. Sketch of the Spider

- Option 2 – Option 1 plus Move Quench Spray to Absorber Section.
  - Option 1 work scope
  - Remove the external FRP headers feeding the two existing quench spray levels and existing 20-inch FRP piping that fed those headers back to the 20-inch rubber-lined steel pipe flange.
  - Remove the existing internal headers, nozzles, and any non-structural internal beams or other items in the existing quench spray area. Repaired rubber lining at new wall penetrations.
  - Install new 20-inch abrasion-resistant FRP piping, supports, and expansion joints from the flange referred to above to the absorber section between the existing sprays and the top tray.
  - Relocate (raise by one foot) the existing absorber stiffener beams between the existing sprays and the top tray so they do not interfere with the new header/sprays described below.
  - Install six new 12-inch penetration spools (2205 duplex) and six new self-supporting internal headers and support brackets (2205 alloy) between the existing absorber spray and the top tray, approximately in the location of the existing internal absorber stiffener beams described above.

- Install 14 new high-efficiency 3-inch DHC nozzles on each of the six new internal headers for a total of 84 DHC nozzles. Each DHC nozzle has 133 gpm of flow for a total of 11,300 gpm for this new absorber spray section.
- Install 2205 duplex SS spray impingement plates on the walls just below the new spray headers/DHC nozzles.
- Repair the damage to the existing rubber lining incurred while relocating the beams and installing the new spray headers and the spray impingement plates.
- Remove the two existing trays. Reused the existing tray supports as much as possible.
- Install two new 2205 duplex high-efficiency trays with 37% net open area (versus 31.7% net open area for the existing trays).
- Conduct CFD modeling to evaluate gas and liquid flow patterns from the modified equipment to determine the extent of the wet-dry interface, alloy wall papering needed, and the design of an internal baffle to smooth the gas flow immediately upstream of the bottom tray.
- Install C-276 alloy wall papering in the new wet/dry interface areas and baffle as needed based on the CFD modeling.
- Remove existing rubber lining as needed to install the wall paper and the baffle.

Figure 2-5 on the next page shows the spray pattern from the 84 new three-inch DHC nozzles in the new lower spray header in the absorber section. The new spray coverage, measured 18 inches below the nozzles, is 254%.

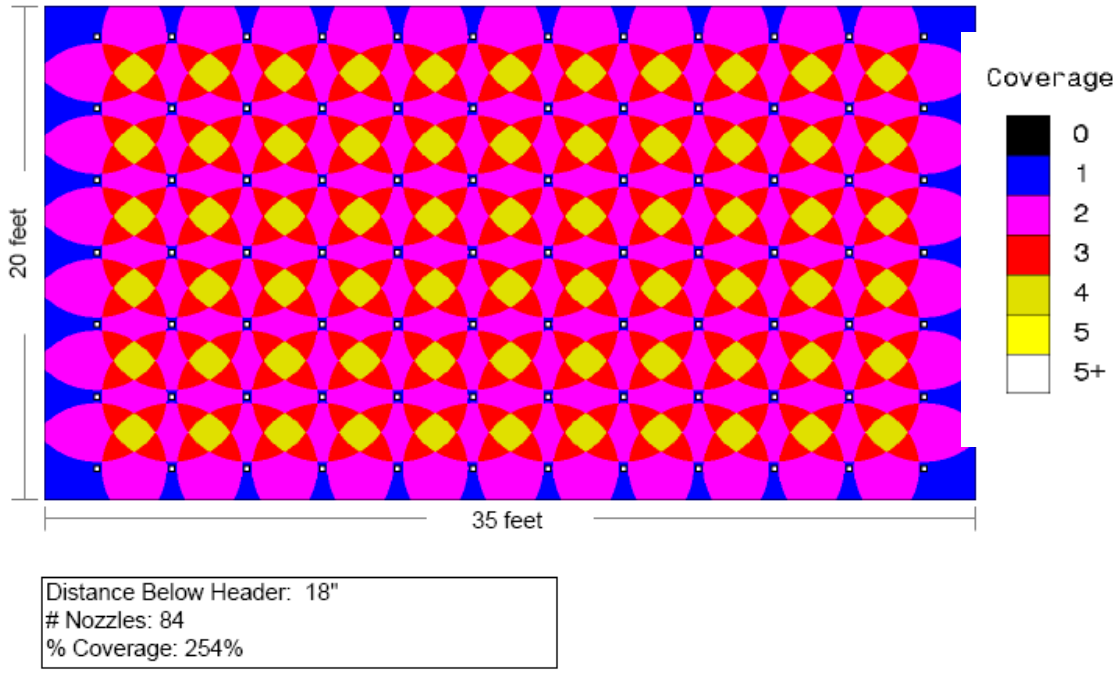

Figure 2-5. Spray Pattern from the 84 Three-Inch DHC Nozzles at the New Lower Absorber Spray

3.0 Process Analysis

To evaluate the potential benefits of improving the scrubbers at San Miguel by the options described in the previous section, we used the EPRI (Electric Power Research Institute) FGDPRISM computer model. This model was developed by AECOM for EPRI to simulate a variety of lime and limestone FGD systems based on numerous investigations of laboratory, pilot, and full-scale FGD systems. Based on the data supplied from San Miguel on the current system design and operation, we applied the FGDPRISM model to the existing layout and operating conditions and matched the currently observed SO_2 removal efficiency by adjusting the model's liquid and gas-side mass transfer coefficients.

The different options being considered were then examined for operation at a higher inlet SO_2 level of 10.5 lb SO_2 / MMBtu. As described earlier, Option 1 consists of modifications where the absorber spray header systems are upgraded to provide improved gas/liquid contacting as well as a change-out of the type of spray nozzles to the higher performing double hollow cone designs. The second option includes Option 1 modifications plus additional changes where the quencher sprays are redirected to the absorber side and a second spray header installed above the two sieve trays and the quencher is essentially converted into straight-through ductwork. The existing trays are replaced with new, high efficiency trays having more open area to accommodate the additional slurry flow without excessive pressure drop.

Figure 3-1 is a plot of the FGDPRISM predictions for Options 1 and 2 with respect to SO_2 removal as a function of DBA concentration in the scrubbing liquor.

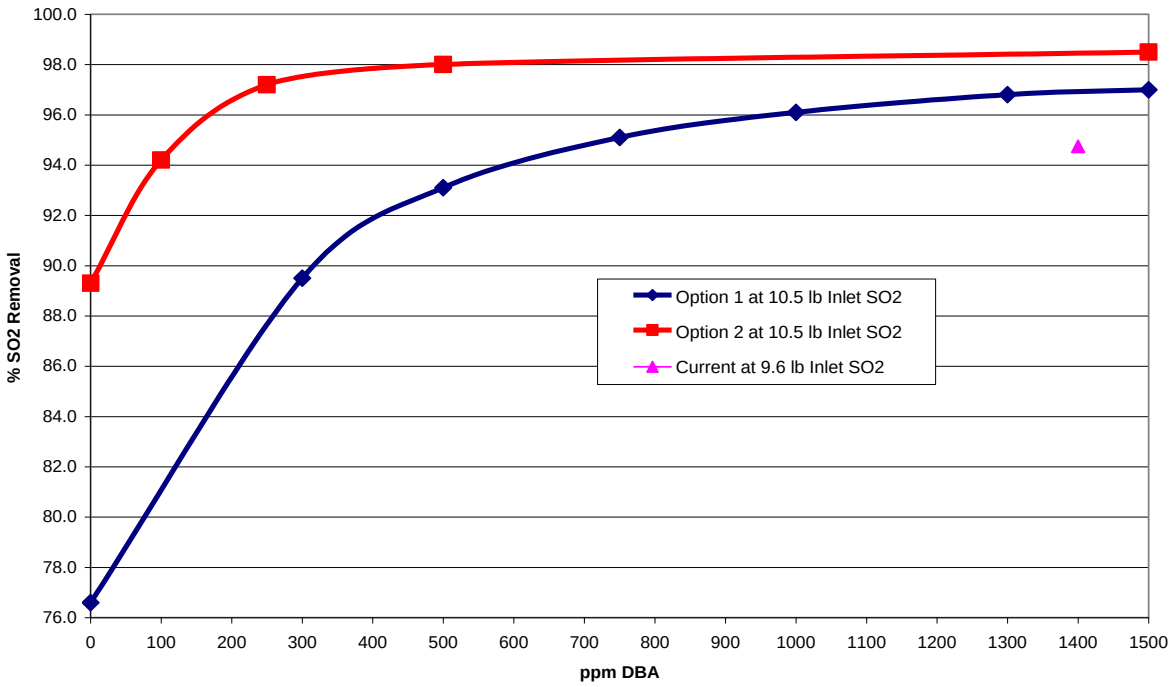

Figure 3-1. FGDPRISM Predictions for San Miguel FGD System Performance

Also shown in Figure 3-1 is the current operating point, 94.75% SO_2 removal using 1400 ppm DBA with an inlet SO_2 level of 9.6 lb SO_2 / MMBtu.

Results of the modeling indicated that the modifications associated with Option 1 would result in the SO_2 removal efficiency being maintained at the 94.75% level while allowing the DBA concentration to be dropped to about 725 ppm (about 50% of current operation level). The predicted DBA consumption rate for this concentration is about 1.62 million lbs/yr as compared to the current consumption rate of about 3 million lbs/yr.

The FGDPRISM modeling results for Option 2, which involves more extensive modifications to the absorbers, are also shown in Figure 3-1. The model predicted that the current removal level of 94.75% could be achieved with 10.5 lb inlet SO_2 using a DBA concentration of only 125 ppm. The predicted DBA consumption for this scenario is about 275,000 lbs/yr.

Table 3-1 presents a summary of the DBA concentrations and predicted consumptions rates for the cases modeled by FGDPRISM. The DBA losses are broken into the solution loss (the amount that is bled from the system with the product solids and liquid blowdown) and the

degradation loss (the amount that degrades into CO_2 and H_2O or is co-precipitated with the calcium sulfite solids) components.

Table 3-1. San Miguel DBA Consumption Predictions

Summary of DBA Consumption Predictions						
			DBA Consumption, lb/ton SO2		Total Consumption	
Option	DBA Conc, ppm	% SO2 Rem	Soln Loss	Deg. Loss	lb/ton SO2	lb/yr
Current	1400	94.75	12.8	6.7	19.5	3,000,000
1	725	94.75	6.6	3.2	9.8	1,620,000
1	1500	97	13.4	6.4	19.8	3,390,000
2	125	94.75	1.1	0.5	1.6	275,000
2	240	97	2.1	1.0	3.1	538,000
2	500	98	4.4	2.1	6.6	1,140,000

Note: Current case is based on 9.6 lb SO_2 lignite; Options 1 & 2 are based on 10.5 lb SO_2 lignite.

4.0 Cost Estimate

Section 2 described the scope of work for the two upgrade options. Table 4-1 summarizes the purchased equipment and materials that were included in the Option 1 and 2 cost estimates. Table 4-2 presents the estimate for the total installed costs for each. The estimated total project cost (engineering, procurement, and construction) for Option 1 is $1,600,000 and for Option 2 is $8,800,000.

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Table 4-1. Summary of Purchased Equipment and Materials

Description of Purchased Equipment and Materials	
OPTION 1	**OPTION 2 INCREMENT OVER OPTION 1 (Continued)**
Modification of Existing Recycle Slurry Spray Headers	*Trays*
Spiders, 1-6" inlet with 3-4" outlets, flanged, 2205 Duplex	37% Open Area Tray (2 per module; 4 modules total)
DHC nozzles, 4", NBSC, 286 gpm each (includes 5% spares)	Tray Level Supports (includes main beams, cross channels, and wall brackets)
Spray Impingement Plate, 2205 (includes wall attachment)	Rubber Liner Repair at Tray Level (1 ft high around perimeter per tray)
Rubber Liner Repair at spray impingement plates	
	External Recycle Pipe Supports
Fasteners & Gaskets	20" Supports
4" Nozzle Connections	16" Supports
Fasteners, 2205 (4 per nozzle, 5/8") (includes 5% spares)	12" Supports
Gaskets, EPDM (1 per conn., 1/8" thick) (includes 5% spares)	Spring Cans
6" Spider Connections	Structural Steel for Supports
Fasteners, 2205 (4 per nozzle, 3/4") (includes 5% spares)	
Gaskets, EPDM (1 per conn., 1/8" thick) (includes 5% spares)	*Fasteners & Gaskets*
	3" Nozzle Connections
Material Indirect Cost	Fasteners, 2205 (4 per nozzle, 5/8") (includes 5% spares)
Freight (3.5% of material cost)	Gaskets, EPDM (1 per conn., 1/8" thick) (includes 5% spares)
Vendor Field Services	12" Penetration Spool Connections (2 per spool)
	Fasteners, 2205 (12 per conn., 7/8") (includes 5% spares)
	Gaskets, EPDM (1 per conn., 1/8" thick) (includes 5% spares)
OPTION 2 INCREMENT OVER OPTION 1	20" External Recycle Pipe Connections (2 total)
	Fasteners, Galvanized CS (20 per conn., 1-1/8") (includes 5% spares)
Lower Level Recycle Slurry Spray (re-routed from current quench section)	Gaskets, EPDM (1 per conn., 1/4" thick) (includes 5% spares)
External Recycle Slurry Pipe (20"), flanged, AR-FRP	
External Recycle Slurry Manifold (20"x16"x12"), flanged, AR-FRP	*Relining of Absorber Internal Wall (wet/dry interface area only)*
Expansion Joints, 12", rubber, filled arch, (one at each absorber penetration)	Wall Paper, C276, 16 gauge, with 30% overlap
Absorber Wall Penetration Spools, 12", flanged, 2205	
Spray Headers, 12"x10"x8"x6" with 8-4" stubs for nozzles, flanged, 2205	*Modifications for Flow Distribution*
Spray Header Supports, wall bracket type, 2205	Bullnose at transition from quench tower to absorber tower, C276, 1/4" plate
DHC nozzles, 3", NBSC, 133 gpm each (includes 5% spares)	
Spray Impingement Plate, 2205	*Structural Modifications (Absorber Wall)*
Rubber Liner Repair at spray impingement plates	Wall Stiffeners Modifications
Rubber Liner Repair at Spray Level (wall brackets and penetration spool repads)	Wall Repads at new spray level penetrations, Internal, CS
Rubber Liner Repair for Relocated Internal Stiffners	
	Material Indirect Cost
	Freight (3.5% of material cost)
	Vendor Field Services

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Table 4-2. Cost Estimate

			Scope of Work and Estimated Costs			
			Option 1		**Option 2**	
					(Includes Option 1)	
			Scope of Work		**Scope of Work**	
			a. New spiders to split the flow to 28 existing nozzles in absorber.		a. New spiders to split the flow to 28 existing nozzles in absorber.	
			b. 84 new DHC nozzles, mounted on new spiders		b. 84 new DHC nozzles, mounted on new spiders	
			c. Add spray impingement plates		c. Add spray impingement plates	
					d. External FRP piping to relocate existing quench flow to absorber, above top tray	
					e. New external FRP maniford, above top tray	
					f. New internal headers, above top tray	
					g. 48 new DHC nozzles on new headers	
					h. Replace existing trays with two new high-efficiency trays	
					i. Wall papering and assoc rubber lining removal	
					j. New bull nose to distribute gas to bottom tray more evenly (if CFD modeling confirms need)	
	EP Contractor and Construction Contractor					
			Estimated Cost, $		**Estimated Cost, $**	
EP Contractor -- Engineering and Purchased Equipment						
	Total EP Contractor Costs*			1,100,000		4,700,000
Construction Contractor -- Construction Materials and Labor**						
	Wall papering and bull nose materials***		0		1,100,000	
	Other construction materials		50,000		150,000	
	Construction labor and fees		450,000		2,850,000	
	Total Construction Contractor Costs			500,000		4,100,000
Total Project Cost (Engineering, Procurement, Construction, Guarantees)				1,600,000		8,800,000
Notes:	* Includes 5% spares for nozzles, bolting and other small parts plus 15% contingency on purchased equipment. There is no markup on purchased equipment.					
	** The extent of wall papering and the materials need for the "bull nose" to more evenly distribute the gas to the first tray will not be known until a CFD study is completed as part of the detailed engineering design by the EP Contractor. This estimate assumes that the materials for wall papering and the bull nose will be purchased by the construction contractor (or by San Miguel) and will not be part of the equipment purchased by the EP Contractor.					
	*** Estimated cost for the wall papering materials, the bull nose, and associated construction labor is an approximation at this point.					

5.0 Economic Analysis

Prior to the start of the upgrade program, the San Miguel FGD system required a DBA level of approximately 1400 ppm to achieve 94.75% SO_2 removal while firing lignite with an average sulfur content of 9.6 lb SO_2 per million Btu. This DBA level resulted in an annual consumption of around three million pounds of DBA (dry basis). At the then current DBA price of $0.90 per pound (dry basis), the annual cost of DBA was about $2.7 million dollars.

By installing the Option 1 upgrade described earlier, the required DBA level to achieve 94.75% SO_2 removal with a 10.5 lb SO_2 per million Btu fuel was predicted by the FGDPRISM process model to be about 725 ppm. Based on AECOM's experience that the DBA feed rate would decrease directly proportional to the concentration in the scrubbing slurry, the annual consumption would drop to about 1.62 million lb per year. At a DBA cost at $0.90 per lb. this would be about $1.46 million per year. An Option 1 upgrade was projected to reduce San Miguel's annual DBA cost by nearly $1.3 million even with nearly 10% more sulfur in the lignite. With the Option 2 upgrade described earlier, the required DBA level to achieve 94.75% SO_2 removal with 10.5 lb SO_2 per million Btu lignite was projected to be about 125 ppm, the DBA use would be about 0.28 million lb per year, and the annual DBA cost at $0.90 / lb. would be about $0.25 million. The Option 2 upgrade was projected to reduce San Miguel's DBA cost by nearly $2.5 million, again, at the higher sulfur level in the lignite.

Table 5-1 on the next page summarizes the cost savings for these two options, the associated costs of the upgrades, and the simple payback period of each for the current 94.75% SO_2 removal situation. This analysis does not consider potential benefits from the sale of SO_2 allowances should a trading program be established in Texas. The payout for Option 1 is around 1.3 years and for Option 2 it is around 3.6 years.

Table 5-1. Comparative Economics for Original (pre-2010) FGD Operations versus Upgrade Options 1 and 2

SO2 Removal	94.75%					97.0%					98.0%				
DBA Price, $/lb dry			0.90					0.90					0.90		
	DBA Use Million Lb/yr	DBA Cost $Million	Cost Savings $Million/yr	Upgrade Cost $Million	Upgrade Payback Period Years	DBA Use Million Lb/yr	DBA Cost $Million	Cost Savings $Million/yr	Upgrade Cost $Million	Upgrade Payback Period Years	DBA Use Million Lb/yr	DBA Cost $Million	Cost Savings $Million/yr	Upgrade Cost $Million	Upgrade Payback Period Years
Case															
Current equipment	3.00	2.70		0		NA	NA		NA		NA	NA		NA	
Option 1	1.62	1.46		1.60		3.39	3.05		1.60		NA	NA		NA	
Option 2	0.28	0.25		8.80		0.54	0.48		8.80		1.14	1.03		8.80	
Option 1 vs Current	-1.38	-1.24	1.24	1.60	1.29	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Option 2 vs Current	-2.73	-2.45	2.45	8.80	3.59	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Option 2 vs Option 1	-1.35	-1.21	1.21	7.20	5.93	-2.85	-2.57	2.57	7.20	2.80	NA	NA	NA	NA	NA
DBA Price, $/lb dry			1.20					1.20					1.20		
	DBA Use Million Lb/yr	DBA Cost $Million	Cost Savings $Million/yr	Upgrade Cost $Million	Upgrade Payback Period Years	DBA Use Million Lb/yr	DBA Cost $Million	Cost Savings $Million/yr	Upgrade Cost $Million	Upgrade Payback Period Years	DBA Use Million Lb/yr	DBA Cost $Million	Cost Savings $Million/yr	Upgrade Cost $Million	Upgrade Payback Period Years
Case															
Current equipment	3.00	3.60		0		NA	NA		NA		NA	NA		NA	
Option 1	1.62	1.95		1.60		3.39	4.07		1.60		NA	NA		NA	
Option 2	0.28	0.33		8.80		0.54	0.65		8.80		1.14	1.37		8.80	
Option 1 vs Current	-1.38	-1.65	1.65	1.60	0.97	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Option 2 vs Current	-2.73	-3.27	3.27	8.80	2.69	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Option 2 vs Option 1	-1.35	-1.62	1.62	7.20	4.45	-2.85	-3.42	3.42	7.20	2.10	NA	NA	NA	NA	NA

6.0 Project Schedule

Based on vendor inquiries AECOM had made at the time of the study, all of the material needed for both options could be delivered by the March 2010. However, there was not enough time for AECOM to complete enough detailed design work to be able to order all the equipment needed for Option 2. The schedule did allow time to implement Option 1 during the March 23 - April 30, 2010 outage.

7.0 Study Conclusions

Based on the process model results the two options evaluated offered San Miguel the ability to substantially reduce absorber DBA concentration and therefore consumption with the current lignite sulfur content of 9.6 lb SO_2 / MMBtu coal and the current SO_2 removal level of 94.75%. Option 1 was the lowest cost and was recommended for implementation first. Option 2 being higher in cost was not implemented until 2012 and as described below was aimed primarily at achieving compliance with the original version of the Cross State Air Pollution Rule promulgated in 2011.

8.0 Addendum – Interim Results of Implementation of Option 1 and 2 FGD Improvements

This section presents and discusses the results of upgrading the San Miguel FGD system with both Options 1 and 2 since the improvements were implemented up to the current date of June 27, 2014. While successful in achieving the desired reduction in DBA concentration, the process has taken much longer and proven more challenging than expected. AECOM has had to expend significant costs and resources to achieve the performance improvements. San Miguel has supported the AECOM initiatives by providing the labor to install equipment modifications that have been necessary and assisting in additional testing of the absorbers. The work has been a joint and cooperative with both parties participating in a collaborative fashion.

San Miguel contracted with AECOM to install the Option 1 improvements in all four modules during the spring 2010 scheduled unit outage. The system was tested shortly after startup and the performance met or exceeded guarantees. To achieve an average SO_2 removal efficiency of about 95% removal prior to the Option 1 improvements required the absorbers to operate at a DBA concentration of about 1,400 ppm. The absorbers were able to operate at a DBA concentration of around 700 ppm and achieve 95% SO_2 removal, effectively cutting in half the required levels of DBA.

Not long after the Option 1 improvements were installed, the Clean Air Interstate Rule (CAIR) was replaced by the Cross State Air Pollution Rule (CSAPR) in the summer of 2011. This rule required significant reductions in the annual SO_2 emissions from San Miguel unit. AECOM was contracted in September 2011 to begin work on the detailed engineering of the Option 2

improvements described above in Table 4.1 so that the unit could be kept in compliance with the new CSAPR requirements.

At the time, San Miguel conducted with AECOM's assistance a test of the FGD system to quantify the performance of the absorbers after 1.5 years of operation and in a "seasoned" condition, meaning partially scaled and plugged components in the absorber internals (nozzles, spray headers, trays, mist eliminators, etc.). This test which was done in August 2011 revealed that the SO_2 removal performance of the absorbers had degraded measurably relative to the performance test done shortly after the Option 1 improvements were installed in April 2010. Given the very high inlet sulfur dioxide concentrations in the flue gas entering the San Miguel FGD system, this result is not surprising. Any shortfall in the gas/liquid contact area is magnified to a much greater extent than in the typical FGD system in the U.S.

The test results from August 2011 showed that the absorbers required over 50% more DBA in solution to maintain a nominal SO_2 removal efficiency of 95% as compared to the testing conducted shortly after the Option 1 improvements were made in the spring of 2010.

The Option 2 improvements were installed in the spring outage of 2012.

Table 8-1 presents results of a number of tests which were conducted over the coAECOMe of time from when both the upgrades had been completed until present day. The first line in the Table shows the baseline SO_2 removal efficiency and required DBA concentration for the FGD system prior to the absorbers being upgraded. As mentioned earlier, under typical conditions, the absorbers needed about 1,400 ppm of DBA to achieve nominally 95% SO_2 removal.

Results from the first test conducted shortly after the spring outage of 2012 and after the Option 2 improvements were installed indicated that the absorbers were not performing anywhere near expectations. At that time, AECOM initiated a significant corrective action program to identify the reason for the performance shortfall and to come up with the best solutions.

This work identified a number of possible causes for the performance shortfall including:

1. Low tray pressure drop
2. Trays coming detached from their supports allowing flue gas bypass and/or uplifting in the center area
3. The new wall ring obstructing flow of recycle slurry to the top tray
4. Low recycle pump flow due to eroded impellors
5. Poor quencher and absorber tank agitation
6. Short circuiting of slurry in the recycle tanks
7. Mal-distribution of slurry to the upper tray
8. Mal-distribution of flue gas from absorber to absorber

Table 8-1. Results of FGD testing from April 2012 through June 2014

Date	Load, MW	Average Absorber DBA, mg/L	Stack CEMS SO_2, lbs/MMBtu	Average Module pH	Measured FGD Removal Efficiency, %	Guaranteed FGD Removal Efficiency, %	Measured vs Guaranteed Performance
Pre Upgrade	430	1400	0.50	5.9	94.8%	-	-
4/26/2012	430	1670	0.71	5.9	93.2%	98.5%	-5.3%
1/16/2013	430	710	0.63	5.9	93.0%	97.5%	-4.5%
4/15/2013	430	230	0.61	6.15	93.5%	91.5%	2.0%
10/31/2013	435	838	0.31	6.1	96.9%	97.9%	-1.0%
10/31/2013	431	841	0.25	6.1	97.5%	97.9%	-0.4%
11/1/2013	430	782	0.29	6.15	97.1%	97.8%	-0.7%
11/1/2013	430	663	0.62	5.96	93.8%	97.5%	-3.7%
5/15/2014	415	504	0.39	5.96	96.1%	96.0%	0.1%
5/25/2014	431	250	0.56	5.95	93.8%	91.8%	2.0%
6/20/2014	432	275	0.69	5.94	91.9%	92.5%	-0.6%
6/21/2014	431	530	0.56	5.95	93.4%	96.0%	-2.6%
6/25/2014	435	430	0.45	6.02	94.7%	95.4%	-0.7%

The first problem that was solved was the lower than expected pressure drop. This required the reduction in the open area of the trays using thin pieces of stainless steel to block off holes. The result was some improvement in the system SO_2 performance but not as much as expected.

Inspections of the internals of the absorbers revealed that some of the trays had come loose from their supports allowing them to lift and therefore bypass flue gas around this critical scrubbing zone. An improved method of attaching the trays to their supports solved this problem around the perimeter of the tower and also clamps were installed in the center of the tower to make sure the trays remained flat. These improvements were added in the fall of 2012. Significant performance improvements were not seen after these were added.

AECOM conducted CFD modeling of both the absorber and quencher tanks to investigate if there was any short-circuiting of slurry from the down-comers directly to the recycle pump suctions. Short-circuiting can be very detrimental to SO_2 removal and can lead to rapid scaling inside the absorbers and in downstream equipment. The CFD results did not identify any problems and showed that the agitators were providing very good mixing in each tank. San Miguel replaced all the original tank agitators in the 2011 to 2012 time frame with newer models that give better tank agitation. AECOM modeled the power inputs and prop speed of these new agitators. Figure
8-1 is an example output from this tank modeling.

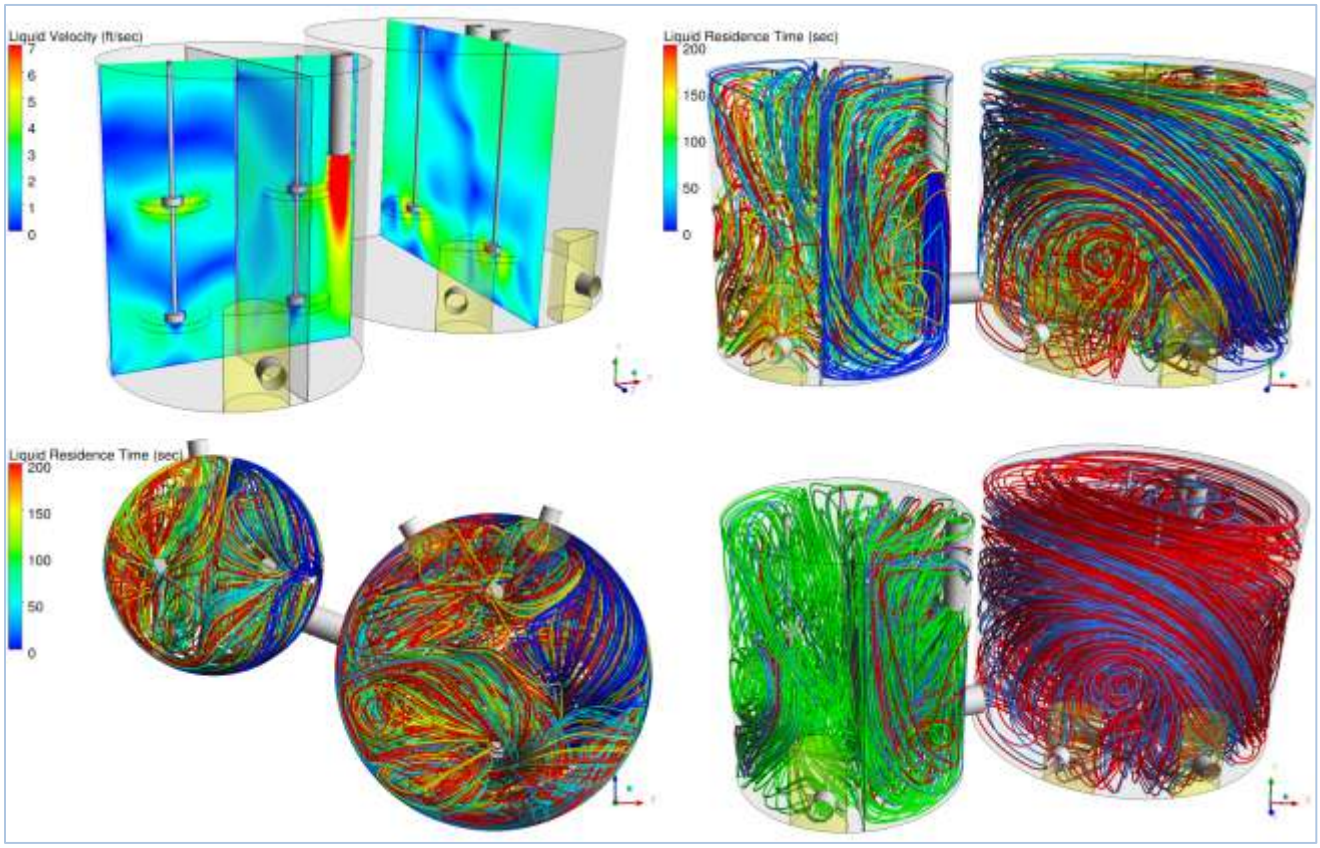


Figure 8-1. Graphics from CFD Modeling Study of San Miguel FGD Reaction Tanks

To determine if there were any problems with gas/liquid distribution inside the absorber in the key scrubbing zones around the spray headers and counter-flow trays, AECOM conducted a CFD study in that area of the system. This modeling did turn up a potential problem in that the new high efficiency double hollow cone spray nozzles could be impacting the walls of the towers and channeling slurry down to the tray in an irregular fashion. The new spray nozzles are designed for a 120 degree cone angle, which is wider than the old nozzles. The wider angle nozzles are important to maximize SO_2 scrubbing from the spray headers. AECOM has used these exact nozzles and a very specific nozzle-to-nozzle spacing to achieve maximum SO_2 removal efficiency from absorbers with limited recycle pump capacity as at San Miguel. There were no detrimental effects in these other absorbers, but then again they do not operate anywhere near the fuel sulfur levels at San Miguel.

The consequence of using the wider cone angle nozzle can be seen in Figure 8-2.

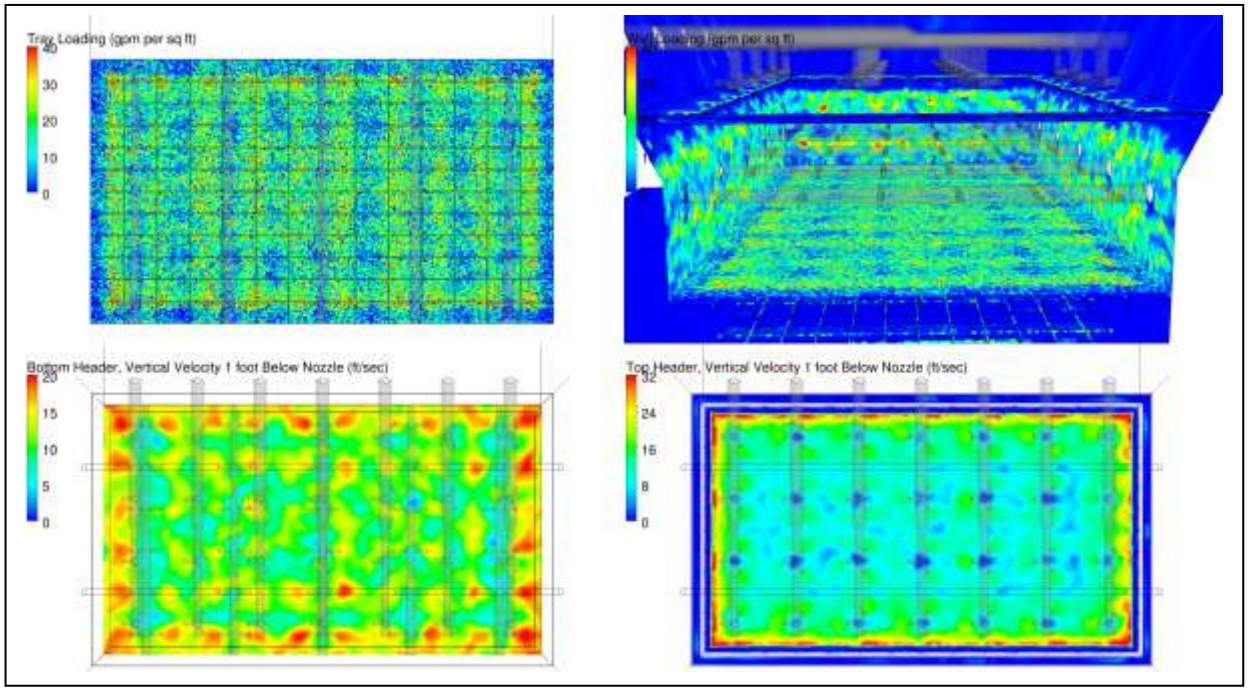


Figure 8-2. Results of CFD Study of San Miguel Absorber Internals

The upper right CFD image shows that there is a fairly significant amount of slurry from the two spray headers that impacts the walls of the towers. While this is a normal occurrence in many other spray/tray FGD systems, the conditions at San Miguel with the much higher incoming SO_2 means that highly efficient gas/liquid mixing must occur in all areas of the tower with no margin. So AECOM redesigned the upper tray to minimize the number and height of the partition walls on the outer areas of the tray. Modeling showed that the new trays would even out the recycle slurry distribution on the tray, allowing slurry coming down the walls to spread out horizontally and evenly flood the tray. Figures 8-3 and 8-4 show the before and after slurry distribution to the upper tray, respectively. Given the flow improvement that could be achieved by redesigning about half of the upper tray compartments, AECOM procured new sets in late 2013 for installation in the spring 2014 outage.

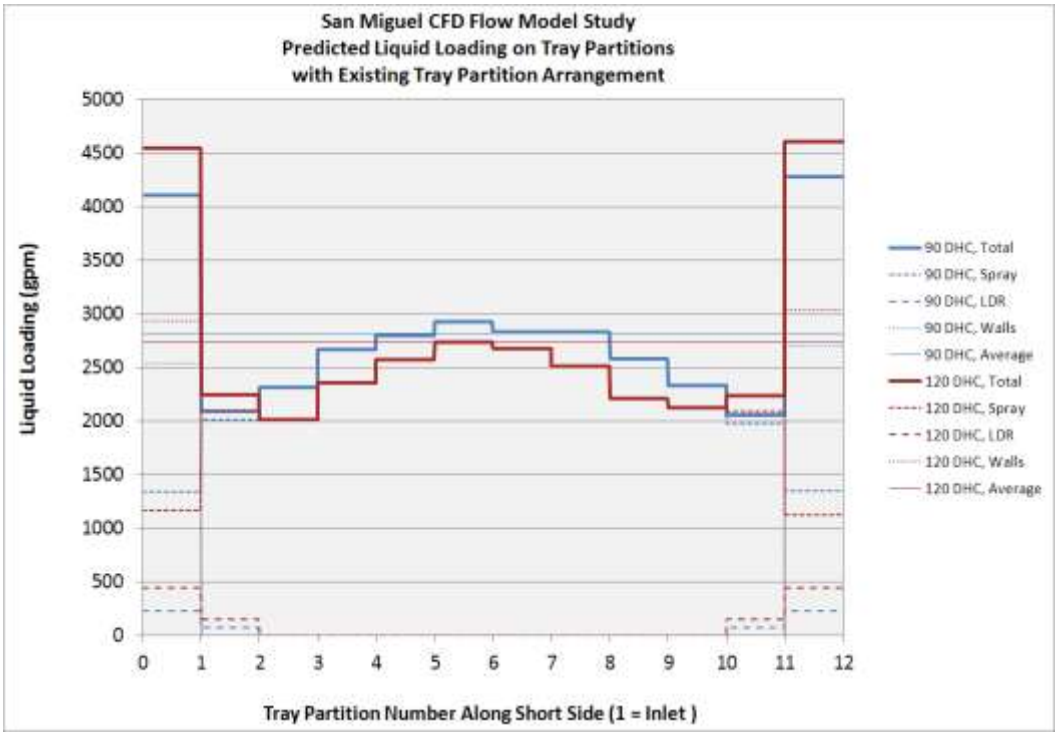


Figure 8-3. Results of CFD Evaluation Showing Uneven Distribution of Slurry to the Upper Tray

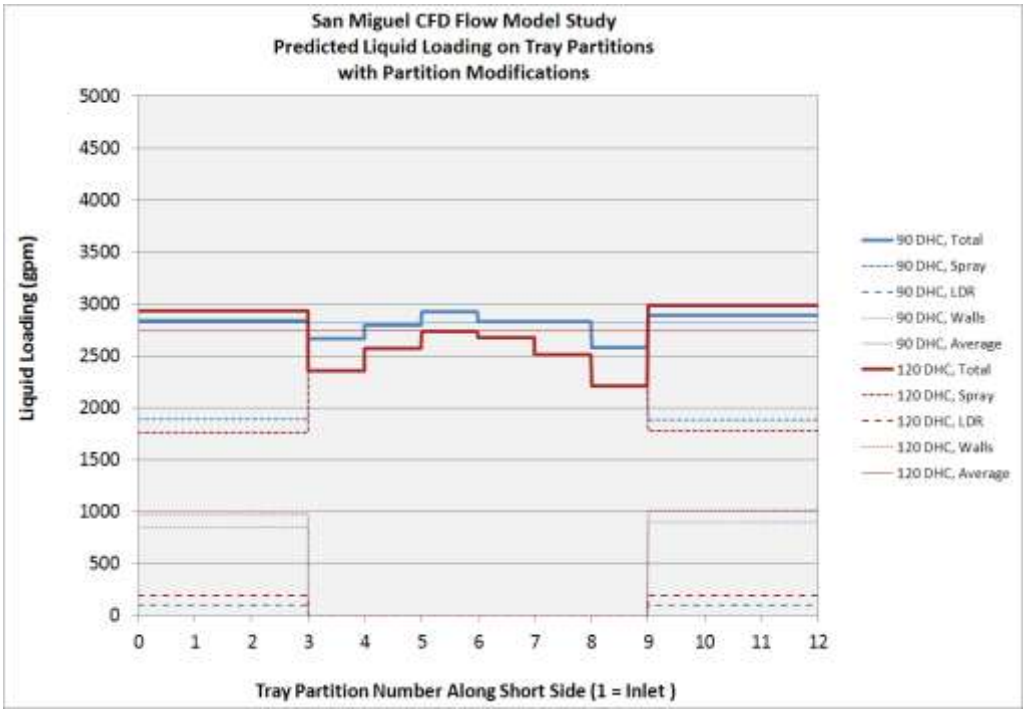


Figure 8-4. Results of CFD Evaluation Showing Improved Distribution of Slurry to Modifed Upper Tray

Numerous times during the last two years AECOM has conducted traverses of each of the four absorber outlet ducts in an effort to determine if one or more of the absorbers was having a problem causing the stack SO_2 to be elevated. There were no problems that were clearly identified from this work. It did show that in general the gas flowing near the outer areas of the absorber walls had very low SO_2 concentrations as compared to the inner area where the SO_2 was highest. Figure 8-5 is an example of the SO_2 profile that was typically seen during these traverses.

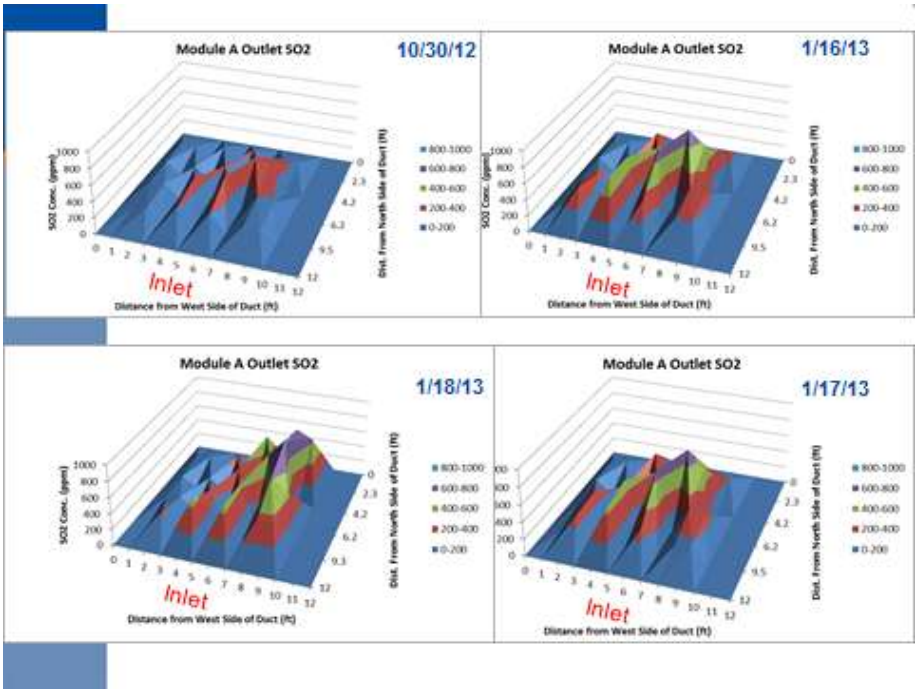


Figure 8-5. Example of SO_2 gas traverses of the outlet duct of the A module

The results in the figure graphically show how the flue gas in the center part of the duct just above the absorber mist eliminators has much more SO_2 in the middle area as compared to the perimeter. This supported the CFD modeling results of the absorber internals discussed earlier. Those results showed a significant portion of the recycle slurry was trapped around the outer areas of the trays. This heavy slurry loading on the outer regions of the tray would provide better SO_2 scrubbing in that area. However, the heavy loading will force flue gas into the middle areas of the tray where there is less resistance due to a lower slurry loading. The combination of more flue gas passing through the center of the tray and proportionally less slurry there would have an overall detrimental effect on SO_2 removal. These observations supported AECOM's decision to pay for new trays in an effort to solve this problem and help boost overall SO_2 removal by improving gas/slurry contact. These trays were installed by plant personnel during the recent spring 2014 outage.

Another area that could cause lower SO_2 removal of the upgraded system was the physical condition of the absorber recycle pumps. These large capacity pumps need to be running at or near their rated outputs to allow the upgraded system to perform as designed. A common problem with older recycle pumps is worn impellors. Figure 8.6 shows a photo of one of the pump impellors taken during the fall 2012 outage. This impellor has significant wear and would not be expected to be able to pump at design capacity. Plant maintenance staff keep track of the conditions of the pumps and this particular pump impellor was in line for replacement. San Miguel made a concerted effort to inspect and replace all excessively worn pump impellors to return the pumps to good operation condition. Subsequently, new pressure gauges were installed on the recycle pump discharge piping to confirm that the pumps are operationg satisfactorily. These have been tracked over the past year and for all pumps, the pressures indicate that the pumps are flowing at design levels.

Figure 8.6. Inspection of San Miguel FGD Recycle Pump Showing Worn Impellor

9.0 Summary

Significant troubleshooting efforts have been completed by AECOM and San Miguel since the Option 2 improvements were installed in the spring outage of 2012. From all available information (flue gas and pump flows, absorber chemistry, absorber internals, CFD and process modeling, etc.), it appears the FGD system is currently operating as intended both from a

chemical and physical design standpoint. Referring back to Table 8.1, the most recent performance data collected with the unit at full load during May and June, shows that the FGD system is achieving 94 to 95% SO_2 removal efficiency at absorber DBA concentrations of about 400 ppm. As mentioned earlier, prior to the Option 1 and 2 upgrades, to achieve 94 to 95% removal typically required an absorber DBA concentration of 1,400 ppm.
The current required DBA concentration of about 400 ppm is what was expected from the absorber upgrades for a target SO_2 removal in the range of 94 to 95%. The various re-work items described above completed in the past two years each contributed to achieving the goal. The redesigned trays were the latest improvement and resulted in the final incremental boost in performance.

It should also be noted that improvements made in the FGD area, specifically in the rake upgrade in the T1 tank and conveyor improvements in the filter building, have allowed the absorbers to be controlled at higher thiosulfate concentrations and therefore lower sulfite oxidation levels. This is very important since it has proven very challenging to maintain consistent control of the absorber chemistry – in particular sufficient concentrations of thiosulfate in the absorber slurry – to keep the sulfite oxidation levels in the desired range which is 5 to 10%, to minimize chemical scaling inside the absorbers. This scaling would occur whenever the thickeners or T1 had to be bypassed for cleaning due to pluggage of the equipment, or failure of the drum filters/conveyors/pug mill in FGD. The root cause of the problem was that the desirable, low oxidation conditions also brought with them the production of more pure calcium sulfite crystals, which settled much more rapidly causing problems with the dewatering systems that were not originally designed to handle them.

Since the upgrades to the dewatering system, the feed rate of emulsified sulfur has been much more regular and there have been fewer cases of absorber blowdown slurry being sent directly to the pond which increases chemical consumption rates. Consistent operation of higher thiosulfate residuals in the quencher and absorber tanks has been the result. This will maintain cleaner conditions within the absorber towers and help the overall system to operate more efficiently for longer periods of time.

AECOM and San Miguel recently conducted a final performance test in association with the FGD upgrade program. The tests were completed on 6/27/14. Test results are discussed in Section 9.1 below.

9.1 2014 Test Results

In May of 2014, not long after the spring outage where the FGD was cleaned and the new perimeter trays were installed, the overall SO_2 removal showed marked improvement. The SO_2 removal, as calculated using data provided by the plant, was at or above the guarantee point; however, this period of high SO_2 removal proved to be transient. SO_2 removal dropped by the end of the month when AECOM was first able to perform a detailed analysis of the process chemistry. Scrubber slurry samples analyzed from May and June of 2014 showed strikingly

different ion concentrations compared to the many sets of chemistry samples AECOM had collected over the past several years (more in Section 9.2).

AECOM set up another performance test for June 25, 26, 27, 2014. The goal of this test was to measure SO_2 removal while operating the scrubbers at pH = 6.0 and high thiosulfate concentrations. AECOM performed testing over three days in order to gather data at a range of DBA concentrations. The performance of the FGD system failed to meet the guaranteed removal rate for each DBA concentration evaluated during the testing.

Table 9-1 presents the results of all the FGD performance tests conducted by SMEC and AECOM from April 2012, after the Phase 2 upgrade, through June 2014. The most recent performance test in November 2014 was invalid and was not included in this data set (this test is discussed later). The removal calculations in this table were adjusted whenever possible to use lignite samples for the inlet SO_2 concentration and the stack CEMS (in lbs SO2/MMBtu) for the composite outlet SO_2 concentration. This alternate calculation methodology helps to remove any bias in ealier calculations that may have been caused by flow imbalances between the FGD modules.

Prior to the June performance testing, AECOM instructed the San Miguel lab to adjust the sulfur pumps to achieve a target thiosulfate of 1000 pm in the absorbers and quenchers. This change in operations succeeded in keeping the oxidation very low but the removal was still below the guarantee point. A closer analysis of the scrubber chemistry showed that the liquid phase alkalinity, which helps boost SO_2 removal, was much lower than it has been historically. Thus it appears that recent changes to the FGD system, scrubber chemistry and other changes, have taken the FGD system further away from the goal of optimizing the process chemistry to help increase the SO_2 removal.

Table 9-1. Updated Summary of FGD Testing Results

Date	Average Absorber DBA, mg/L	Stack CEMS SO_2, lbs/MMBtu	Average Module pH	Measured FGD Removal Efficiency, %	Guaranteed FGD Removal Efficiency, %	Measured vs. Guaranteed Performance
Pre Upgrade	1400	0.5	5.9	94.8%	98.5%	-3.7%
4/26/2012	1670	0.71	5.9	93.2%	98.6%	-5.4%
1/16/2013	674	0.69	5.8	92.8%	97.4%	-4.6%
1/17/2013	683	0.54	5.9	94.4%	97.4%	-3.0%
1/18/2013	786	0.40	6.05	95.1%	97.8%	-2.7%
4/15/2013	230	0.61	6.15	93.5%	91.0%	**2.5%**
9/2/2013	471	0.79	5.9	90.8%	95.8%	-5.0%
9/3/2013	982	0.42	5.93	94.8%	98.3%	-3.5%
9/3/2013	995	0.42	5.91	94.9%	98.3%	-3.4%
9/4/2013	716	0.46	5.95	94.0%	97.6%	-3.5%
9/4/2013	708	0.50	5.98	93.4%	97.5%	-4.1%
9/5/2013	961	0.41	5.91	94.6%	98.2%	-3.6%
9/5/2013	1046	0.38	5.85	95.0%	98.4%	-3.4%
9/6/2013	1439	0.29	5.93	96.2%	98.5%	-2.3%
9/6/2013	1368	0.27	5.91	96.5%	98.5%	-2.0%
9/9/2013	368	0.55	6.12	93.4%	94.3%	-0.9%
9/9/2013	374	0.57	6.1	93.1%	94.4%	-1.3%
10/31/2013	846	0.36	6.12	96.4%	98.0%	-1.6%
10/31/2013	854	0.32	6.13	96.5%	98.0%	-1.4%
11/1/2013	754	0.32	6.10	96.5%	97.7%	-1.2%
11/1/2013	658	0.42	6.085	95.7%	97.3%	-1.6%
5/15/2014	504	0.39	5.96	96.1%	96.0%	**0.1%**
5/25/2014	250	0.56	5.95	93.8%	91.8%	**2.0%**
6/20/2014	275	0.69	5.94	91.9%	92.5%	-0.6%
6/21/2014	530	0.56	5.95	93.4%	96.0%	-2.6%
6/25/2014	575	0.46	6.01	94.0%	96.8%	-2.8%
6/26/2014	711	0.37	6.00	95.5%	97.5%	-2.1%
6/27/2014	939	0.37	6.00	95.7%	98.2%	-2.5%

9.2 Final Results and Further Analysis of Process Chemistry

AECOM set up a final FGD performance test for November 20, 2014. This test was supposed to be run at an average pH of 5.9 and an average DBA concentration of 400-600 ppm. The test was

started at approximately 2:00 PM with the average pH = 5.89 and the DBA = 500 ppm, but not long into the test the outlet SO_2 value began increasing above the target emissions level necessary to meet San Miguel's air permit. In response to this SO_2 excursion, the feed rate of DBA to the absorbers was increased substantially. This action helped to bring down the SO_2 emissions which was positive for the plant, but the downside is that the DBA concentration during the test period was not stable nor was the incoming SO_2. This much variation in two of the more important FGD performance variables invalidated the SO_2 removal results collected during the test period.

The increasing stack SO_2 concentration at the beginning of the test was mainly due to the sudden spike in the lignite sulfur content. On the morning of 11/20/14 the lignite sample contained 9.3 lbs SO_2/MMBtu and the following morning the sample contained 10.0 lbs SO_2/MMBtu; however, the sharp and sudden decrease in scrubber performance without any significant changes to the process indicate that the system was likely seeing a substantially increased SO_2 loading. AECOM guaranteed the performance of the system up to an inlet sulfur concentration of 10.5 lbs SO_2/MMBtu, and it is likely this threshold was exceeded during the testing. Short term spikes in lignite sulfur do not occur regularly at San Miguel, but it is not unheard of either. Unfortunately a lignite sample was not collected during the performance test which would have helped to confirm this suspicion. A lignite sample is necessary to accurately calculate the SO_2 removal during the test period, especially if the sulfur level is changing rapidly.

Between the suspected spike in lignite sulfur, the lack of a representative lignite sample for the test period, and the rapid increase in DBA concentration during the test, the 11/20/14 performance test prevented a valid performance test. However, we were still able to extract some very useful information from the performance test, just not valid removal efficiency. The chemistry samples gathered on 11/20/14 are of particular interest and will be discussed later. Figure 9-1, below, shows results of the outlet duct SO_2 sampling that was performed on each module during the 11/20/14 test. The measured SO_2 concentration (in ppm) for each point on the test grid (4 ports for Modules A, C, and D; 2 ports for Module B; and 6-7 depths for each port) is shown as a surface plot for each outlet duct. The data show that the SO_2 concentration varies significantly across the cross section of the ducts for all but the D module. Ideally the surface plots below would be relatively flat as are seen in the D module plot, indicating that the SO_2 has been evenly treated across the entire usable area in the scrubber. Note that the sampling is done at a location just above where the duct constricts after the mist eliminator so there is some side to side mixing of the flue gas from the point where it exited the scrubbing zone of the absorber. Combining this mixing with a well performing tower, we would expect to measure a fairly uniform SO_2 concentration in the outlet duct.

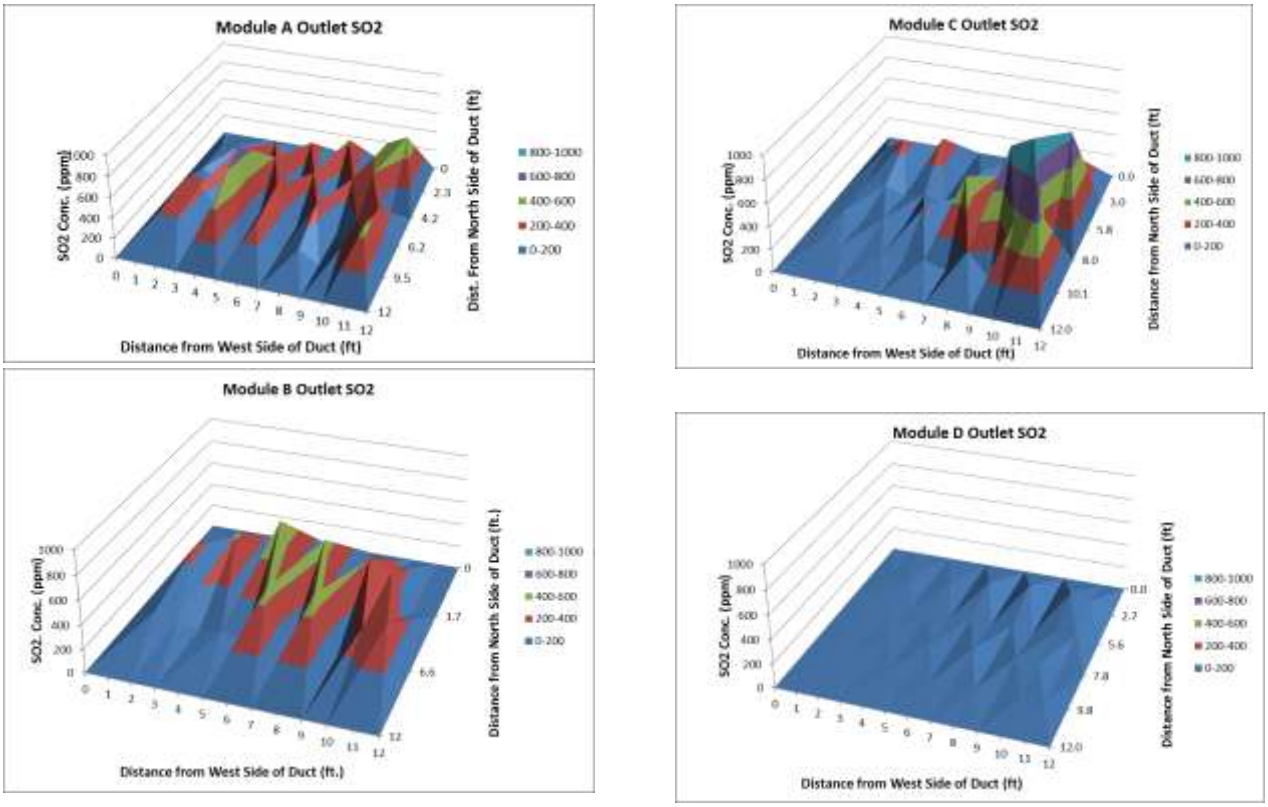


Figure 9-1. 11/20/14 SO_2 Gas Traverses of Outlet Ducts

These results indicate both that the SO_2 concentration is not uniform across the individual outlet ducts and that the overall SO_2 removal is uneven from module to module. Experiencing different levels of SO_2 removal between the four different modules would seem to imply that there is either a mechanical failure in one, or more, modules or that the modules are treating different different amounts of gas.

One of the key design factors for a FGD system is the liquid-to-gas ratio (L/G), or the amount of liquid scrubber slurry sprayed in the absorber tower (in gpm) divided by the gas flowing through the absorber (in 1000 acfm). All other process conditions being equal, the SO_2 removal will be higher with a higher L/G, and vice versa. Since the liquid rate should be roughly equal in all four modules, unequal gas flow between the modules will lead to varying L/G's for the modules. This could signficantly impact the SO_2 removal.

During the November 2014 testing, AECOM used an S Type pitot tube to collect differential pressure data at each measurement point in order to calculate the gas velocity at each sample point. From this data, an average gas velocity was calculated. Table 9-2 shows the average gas velocity at the outlet duct location where the measurements were made as well as the total gas volume being treated in each module.

Table 9-2 Gas Flow and SO_2 Removal Results from 11/20/14 Testing

Module	Flue Gas Duct Velocity, ft/sec	Fraction of Total Gas Treated, %	Flue Gas Flow Rate, 1000's acfm	Avg Outlet Duct SO2 concentration, ppm	SO2 Removal per Module, % (1)	Module Liquid to Gas Ratio, gpm/1000 acf	Total Limestone Feed, gpm
A	57	27	492	323	89.2	73	101
B	49	23	422	331	89.0	85	105
C	62	29	536	279	90.7	67	91
D	44	21	380	34	98.9	95	70
Average	53	25	458	242	91.9	79	92

(1) Assuming 3,000 ppm inlet SO2 to modules
(2) Assumes an average recycle pump flow of 12,000 gpm

The data in the table shows that the total volume of flue gas treated in each of the modules varied from a low of 380 kacfm (1000's of actual cubic feet per minute – absorber outlet conditions) to a high of 536 kacfm. The average flow rate per module was 458 kacfm and this corresponds to a an L/G ratio of 79. Note that module D was performing much better than the other three from an SO_2 removal perspective. It was removing almost 99% of the incoming SO_2 while the other three modules averaged about 90% removal.

As discussed earlier, reasons why Module D was performing so much better than the others likely include:

1. The other modules had highly variable SO_2 concentrations in the outlet duct indicating uneven gas/liquid contacting in the scrubbing section of the towers
2. The D module had a very even SO_2 profile in its outlet duct, indicating good gas/liquid contacting and therefore efficient removal of SO_2 in its scrubbing section.
3. Due to it treating a little less than the target 25% share of the flue gas, D module had the highest L/G ratio of the four modules – at 95 gpm/1000 acf. This was about 27% greater than the average of the other three. L/G is one of the most important variables controlling SO_2 removal with higher being better.
4. And finally, the DBA concentration was a little higher in Module D than in the other three modules – 620 ppm vs an average of 460 ppm for the others.

Samples were also collected from each absorber to characterize the chemistry of the modules during the test. Samples were collected by both AECOM and SMEC and analyzed for important constituents. Table 9-3 and 9-4 present the results of this analytical work.

Table 9-3. Summary of AECOM and SMEC FGD Analytical Results for 11/20/14 Test

Module	Absorber pH	Slurry Density, wt. %		DBA, mg/L		Limestone Stoichiometry		Sulfite Oxidation, %		Thiosulfate, mg/L	
		URS	SMEC Lab	URS	SMEC Lab	URS	SMEC Lab	URS	SMEC Lab	URS	SMEC Lab
A	6.0	14.1	14.3	450	540	1.08	1.15	1.2	17.6	610	200
B	5.9	15.2	14.4	450	450	1.05	1.18	2.1	5.5	690	300
C	5.8	14.3	14.6	490	490	1.03	1.24	1.2	2.4	970	720
D	5.8	14.8	15.0	620	630	1.03	1.21	1.9	5.6	720	490

Table 9-4. Summary of AECOM Analysis of Absorber Liquid Phase for 11/20/14 Test

Module	Ca, mg/L	Mg, mg/L	Na, mg/L	SO3, mg/L	SO4, mg/L	Cl, mg/L
A	720	710	2,420	340	580	5,230
B	710	710	2,320	470	530	5,090
C	690	760	2,470	470	390	5,410
D	610	690	2,150	450	560	4,420

Examining Table 9.3, there are a couple of results regarding the scrubber chemistry that are notable. First, the relative agreement between the AECOM and SMEC lab on DBA concentration in the absorber slurry was the closest it has ever been. The most likely reason for the agreement between the two labs is that the dissolved sulfite concentrations in the absorbers were fairly low (averaging about 430 ppm) on 11/20/14. High dissolved sulfites in the slurry can result in artificially elevated DBA measurements when using the common buffer capacity titration laboratory method that is used by the SMEC lab. For this reason it may be necessary to add additional peroxide to the sample to remove excess sulfite before performing the buffer capacity titration. The SMEC lab does account for some background sulfite in their buffer capacity calculation; however,when the buffer capacity vs DBA concentration curve was first developed by Radian many years ago (1982?) the dissolved sulfite concentration was probably fairly close to where it was during the test on 11/20/14 and much lower than it was in 2012 through early 2014.

The AECOM lab uses a different laboratory technique called ion chromatography that is capable of accurately measuring each individual chemical component of DBA. Since sulfite does not interfere with this method, variations in sulfite have not influenced those results.

Another notable observation is the significant difference between the AECOM and SMEC limestone stoichiometry numbers. In the past, AECOM stoichiometries have always been lower than the SMEC numbers (typically the offset is about 0.05), but not by the large deviation seen this time – which was on average 0.15. The reason for the differences between the two labs is not known, but considering that very different analytical methods are used it is not that surprising.

The best way to monitor accuracy when doing analytical work is to have a quality control/assessment routine. This usually involves running duplicates, standards and standard additions on the samples being analyzed. Then if there is a problem identified by the QA/QC work, a sample or samples can be rerun. One recommendation for the SMEC lab would be to include a QA/QC sample of known composition each time a batch of new FGD samples are run which would serve as the FGD absorber solids “standard”. For example, a sample that had a calcium sulfite, sulfate and carbonate blend that was similar to the current levels that the absorbers operate at would be best. This would correspond to a sulfite oxidation level of 10% and a limestone stoichiometry of 1.10. This sample, or standard, could be created by thoroughly

mixing the proper quantities of reagent grade calcium sulfite, calcium sulfate and calcium carbonate together.

Similar to the limestone stoichiometry numbers, examining the sulfite oxidation results shows significant differences between the AECOM and SMEC labs. AECOM' results showed the oxidation numbers to be very low on 11/20/14 – averaging about 2%. These are the lowest oxidation rates AECOM has measured at SMEC over the past five years, but not surprising given the low dissolved sulfite levels and relatively high thiosulfate concentrations in the absorber slurry. In inhibited oxidized limestone scrubbers, the sulfite oxidation rate correlates well with the ratio of thiosulfate-to-sulfite. The higher this ratio, the greater the inhibiting effect of thiosulfate on the oxidation of dissolved sulfite, all other variables being constant (flue gas O_2, reaction tank pH, and absorber L/G in particular). So it is not surprising to see such low oxidation numbers when the sulfite levels are low.

Changes in the Natural Alkalinity of the San Miguel FGD Scrubbing Slurry

Analyzing the last five years of slurry chemistry at San Miguel raises the important question of why are the dissolved sulfites so low now as compared to the past. Initially AECOM thought that the reduction in sulfites was associated with generally higher levels of thiosulfate and trithionate (trithionate is the resulting compound from thiosulfate inhibiting sulfite oxidation reactions). Higher thiosulfate levels were thought to be desirable since they would decrease oxidation reactions and increase the dissolved sulfite levels. Higher dissolved sulfites are effective at increasing the liquid phase alkalinity of the scrubbing slurry in a limestone FGD system, particularly if the slurry pH is 6.0 or higher. As the pH rises, more of the dissolved sulfite exists as $SO3^{=}$ and less as $HSO3^{-}$. Bisulfite ($HSO3^{-}$) is not beneficial at increasing the alkalinity of the scrubbing solution, only the sulfite ion ($SO3^{=}$) contributes to the alkalinity.

In May 2014 AECOM requested that SMEC increase the feed rate of sulfur to limestone slurry tank in order to generate higher concentrations of thiosulfate in the absorber slurry. This request was made in preparation for the scrubber performance test that was to be conducted after the tray improvements were made. The sulfur feed rates were increased substantially and the target thiosulfate concentration was 1,000 ppm. Past chemistry data had shown that this concentration of thiosulfate was effective at achieving low oxidation rates and along with this, high sulfite levels.

The desired result was not achieved, and instead relatively low levels of sulfite were measured. In fact, they were the lowest levels AECOM had measured in the past five years of testing. It should be pointed out that the sulfite oxidation rates dropped to some of the lowest levels measured at SMEC which if for no other benefit should help protect the absorbers from gypsum scaling. Table 9-5 presents a summary of this historical information, up to and including the 11/20/14 test results.

Table 9-5. Summary of Analytical Results from Absorber Sampling 2011 through 2014

	Averages from Absorber Sampling by URS from 8/23/11 through 4/30/15						
	Aug. 23-24, 2011	Dec. 5, 2012	Jan. 16-17-18, 2013	May 30 & June 6, 2014	June 25-27, 2014	Nov. 20, 2014	Apr. 30, 2015
Absorber pH	5.8	5.8	6.0	6.1	6.0	5.8	5.9
Sulfite Oxidation, %	8.2	8.4	8.0	4.7	7	1.6	3.6
Limestone Stoichiometry	1.05	1.01	1.07	1.35	1.14	1.05	1.06
Dissolved Species, mg/L							
Ca	300	392	378	1,482	1,357	696	
Mg	1,134	1,082	1,479	939	1,167	714	1,120
Na	4,540	4,061	4,749	2,694	4,113	2,336	3,289
K	-	69	81	-	-	-	
Br	-	-	561	-	-	-	
Cl	6,431	6,548	8,755	7,573	9,780	5,037	7,259
CO3	258	356	285	265	301	246	
SO3	1,719	1,493	964	202	116	432	
SO4	2,124	1,721	1,933	861	714	516	
S2O3	552	979	714	915	1,230	748	
DBA	1,440	880	660	420	740	500	
Mg + Na, meq/L	291	266	328	194	275	160	235
LGF, (Mg + Na)-Cl, meq/L	109	81	81	-19	-1	18	30

Examining the data in this table reveals that there are other factors controlling the dissolved sulfite concentration in the absorbers than the three that were originally thought – dissolved magnesium, sodium, and sulfite oxidation rate (controlled by thiosulfate concentration). The two charts immediately (Figures 9-2 and 9-3) below show that there is little effect of thiosulfate, magnesium and sodium on dissolved sulfite. Also of importance to optimum performance of the FGD system is the dissolved calcium concentration since the lower the calcium the better the system will perform – by increasing limestone dissolution rate and lowering DBA losses.

Limestone dissolution rates increase as the dissolved calcium decreases in limestone FGD systems. Also, studies over the years have demonstrated that DBA consumption is essentially directly proportional to the dissolved calcium concentration at a given DBA level. In other words, if the DBA is being controlled at a target value of 500 ppm, then the addition rate of fresh DBA will rise or fall proportional to the dissolved calcium concentration in the absorber liquor. If the calcium is 500 ppm, and the feed rate to maintain that level is 0.10 gpm per absorber, then at a dissolved calcium level of 1,500 ppm, the feed rate of fresh DBA will need to be 3 times higher (1,500 ppm ÷ 500 ppm = 3) or 0.30 gpm per absorber. **Over the course of one year, this difference in feed rate (0.2 gpm) amounts to around $1 million in DBA costs (exact cost difference depends on unit capacity factor) and therefore is a variable that has a very large impact on FGD operating costs.**

Figure 9-4 shows that there is little relationship between sodium and magnesium and the dissolved calcium level, either.

However, factoring in the chloride concentration in the scrubbing slurry along with the magnesium and sodium reveals a *strong relationship* between these three species and the

concentration of sulfite. Since all three of these species (Mg, Na, and Cl) are highly soluble in the scrubber slurry aqueous phase, they would be expected to influence the dissolved sulfite concentration.

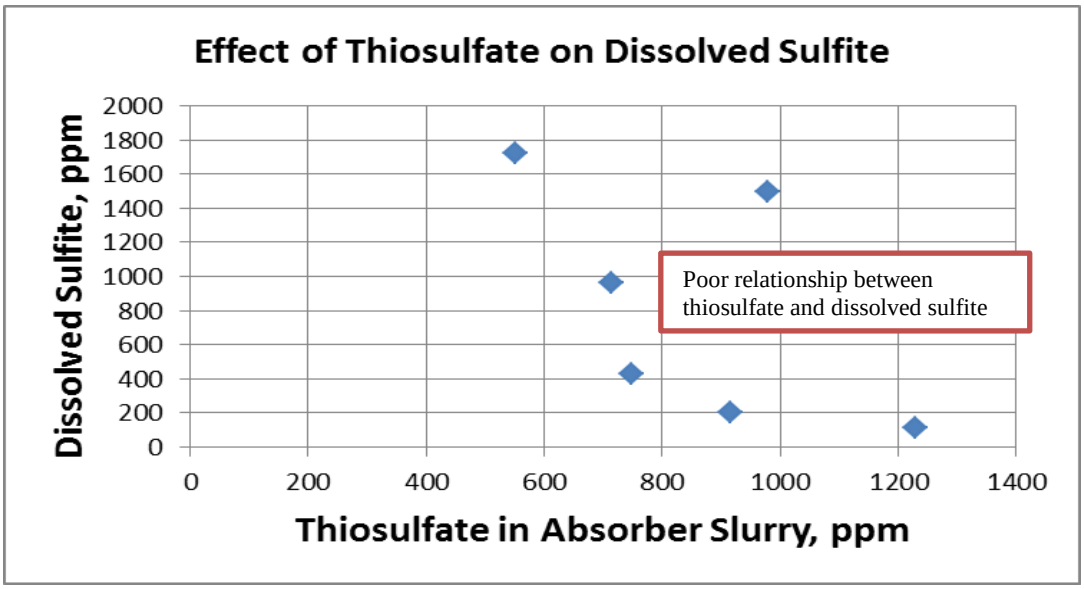


Figure 9-2. Effect of Thiosulfate on Dissolved Sulfite

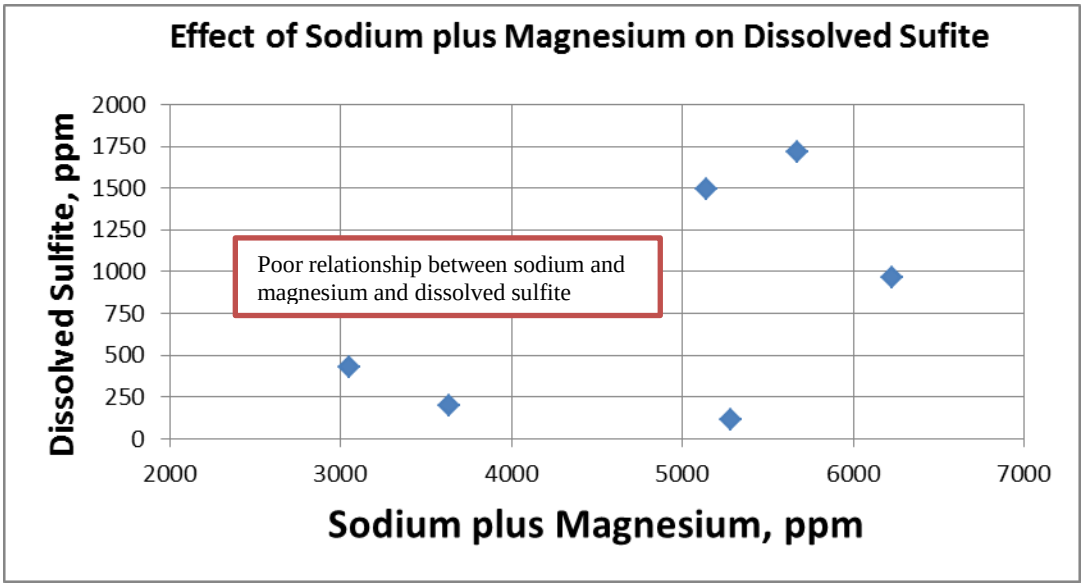


Figure 9-3. Effect of Sodium plus Magnesium on Dissolved Sulfite

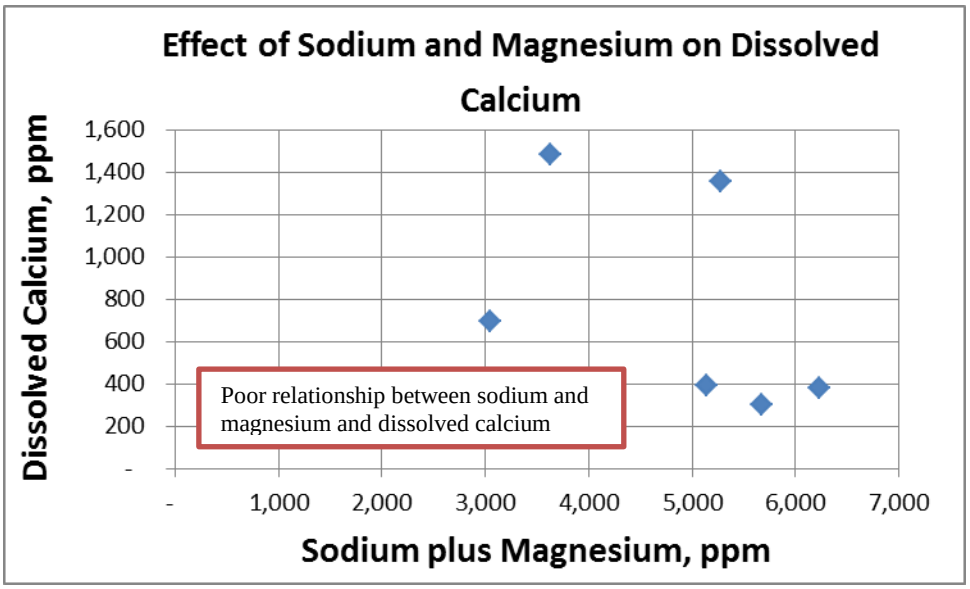


Figure 9-4. Effect of Sodium and Magnesium on Dissolved Calcium

Factors Affecting the Natural Alkalinity of Scrubbing Slurry

Early in the history of FGD application to the coal fired industry in the U.S., the special relationship between these four species (Na, Mg, Cl and SO_3) was documented as they were found to influence SO_2 removal. The term that was given to this relationship was "liquid goodness factor" (LGF) and it was defined as the number of equivalents of magnesium and sodium minus the equivalents of chloride in the scrubbing liquor. The higher the number the better in terms of increasing the liquid phase alkalinity (primarily dissolved SO_3) which translated to improved SO_2 removal. Also, the higher the LGF, the lower the dissolved calcium which improves the limestone dissolution rate at a given absorber pH, freeing up the "solid-phase" alkalinity provided by limestone inside the absorbers – particularly on the trays.

The following equation is used to calculate LGF from an analysis of the major cations and anions in an FGD absorber reaction tank liquor:

LGF = (Mg/24.3 x 2 meq/mm + Na/23) – Cl/35.45
(Note: The units of measurement are mg/L for the Mg, Na and Cl)

Therefore, understanding what is controlling the dissolved sulfite is helpful in investigating what factors are affecting the SO_2 removal efficiency (and probably sulfite oxidation rates) of FGD absorbers.

Figure 9-5 shows the excellent relationship between LGF and dissolved sulfite from all the data AECOM has collected on the San Miguel absorbers over the past four years. The LGF has spanned a very wide range over the years, being fairly high in 2011, 2012 and early 2013 (80 to

110), and trailing off in the recent past (-20 to +20) in 2014. Figure 9-6 shows the effect LGF has on the dissolved calcium. The relationship demonstrated by Figure 9-6 indicates that the calcium concentration decreases as the LGF increases, and a lower calcium concentration is beneficial for scrubber chemistry.. The reasons for the changes in LGF at San Miguel are discussed later, but next we will examine what effect changes in this factor can have on the SO_2 removal efficiency of the absorbers.

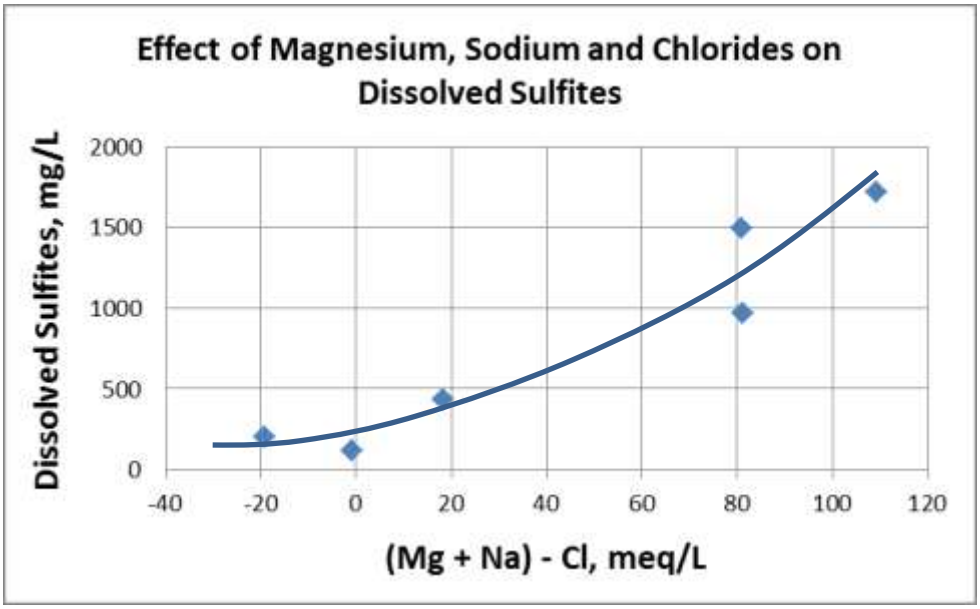


Figure 9-5. Effect of Sodium, Magnesium, and Chlorides on Dissolved Sulfite

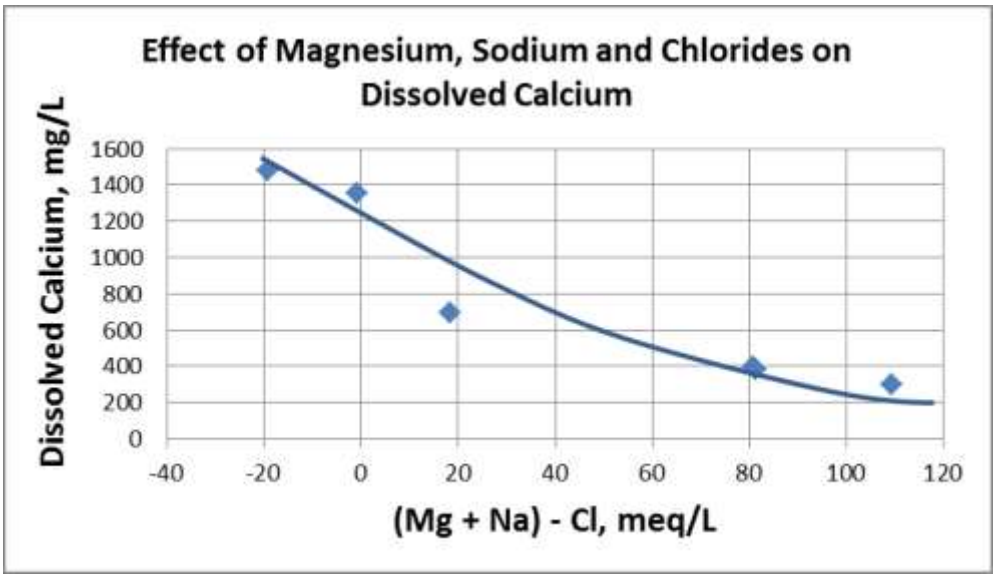


Figure 9-6. Effect of Sodium, Magnesium, and Chlorides on Dissolved Calcium

How Much Does the Natural Alkalinity of the Scrubbing Slurry Effect SO_2 Removal

To examine the effect this degree of variation in the LGF has had on the San Miguel scrubber performance, AECOM ran several simulations of the scrubbers using the FGDPRISM process model. The model was developed as a tool which predicts the effect of various changes in scrubber operation – whether it be chemistry or mechanical changes – on the SO_2 removal efficiency of the system.

The results of the model runs shown below in Table 9-6 predict that moving the LGF from a positive 123 to a negative 15 will decrease the SO_2 removal efficiency of the San Miguel FGD system by about 2.0% - from 97.3% down to 95.3%. The model runs were made with the DBA concentration in the absorber slurry set at 500 ppm and a limestone stoichiometry of 1.06. The absorber L/G was held constant for both runs (about 75 gpm/1,000 acf) and the inlet SO_2 for the simulations was 9 lbs/MMBtu.

Table 9-6. Effect of LGF on SMEC Absorber SO_2 Removal Efficiency

	Case 1 - High LGF	Case 2 - Low LGF
FGD Operating Conditions		
Absorber Flue Gas Flow Rate, acfm	490,000	490,000
Slurry Recycle Rate per Absorber, gpm	35,200	35,200
Inlet SO2, lbs/MMBtu	9.0	9.0
Absorber Chemistry		
pH	5.99	5.83
Ca, ppm	355	876
Mg, ppm	1,413	1,145
Na, ppm	4,557	3,156
Cl, ppm	6,800	8,746
CO3, ppm	78	110
SO3, ppm	1,440	191
SO4, ppm	693	93
Thiosulfate, ppm	550	916
DBA, ppm	500	500
Limestone Stoichiometry	1.06	1.06
LGF, (Mg+Na-Cl), meq/L	+123	-15
FGDPRISM Predicted SO2 Removal, %	***97.3***	***95.3***

This difference of 2% in SO_2 removal is significant and may explain why the absorbers have not been performing as well as predicted at a given DBA concentration. The loss in background or "native" alkalinity in the scrubbing slurry over the last year has decreased SO_2 removal despite the physical improvements made to the absorber trays.

Unfortunately, it is difficult to control the LGF since it moves up and down as the magnesium, sodium and chloride levels in the absorber liquor change. The challenge with managing the LGF

can be seen by examining the different pathways these species take as they enter the FGD system.

Magnesium enters the system primarily with the limestone – all limestones contain at least a small percentage of magnesium and typically anywhere from 20 to 50% of the magnesium in the stone is soluble in the scrubber and the remainder (in the form of dolomite) is not. The San Miguel limestone has been measured in the past by AECOM and the magnesium fraction was around 1.0% as $MgCO_3$.

Sodium comes from the makeup water - there is little sodium in the limestone and virtually none in the flue gas. The sodium concentration in the slurry is relatively high at San Miguel because cooling tower blowdown is the primary source of makeup to the FGD system. The cooling towers cycle up the concentration of sodium in the makeup well water by about a factor of 7 – from 150 ppm in the wells to almost 1,000 ppm in the circ water according to results of AECOM analyses done in December 2012.

And finally, the chlorides enter the system primarily from the flue gas, although a small amount feeds in via the circ water. The lignite contains chlorine and that is volatilized in the furnace and enters the FGD system as vapor phase HCl (hydrochloric acid) where it is removed very efficiently owing to it being highly soluble in water. Once in the slurry, it is quickly neutralized by limestone to form the soluble anion, chloride.

Changing LGF in SMEC Absorbers

Based on the varied paths for these three components the ability to control the LGF components is limited. It might be possible to find a local limestone which has a higher soluble magnesium fraction in it. That would increase the dissolved magnesium in the slurry and since magnesium is a divalent cation, increasing its concentration has more of an effect on LGF than sodium. There are a number of high quality limestone quarries in the San Antonio area but there is no database on the differing levels of soluble magnesium in the various quarries. AECOM has experience with an FGD system in San Antonio and the soluble magnesium in the limestone it uses is similar to that measured in the San Miguel limestone.

Regarding sodium, if the the cooling tower could be cycled up more then that would help increase the sodium in the FGD system. However, cooling tower chemistry has probably been optimized at San Miguel based on costs for treatment chemicals and the need to keep below scaling thresholds for calcium sulfate and calcium carbonate so this approach has limited practicality.

There are a couple of other ways that sodium could be increased in the FGD system. One is to switch from DBA to the use of sodium formate as the FGD SO_2 removal enhancement additive. San Miguel has tested the use of sodium formate in the past and the results were positive from an

SO_2 removal standpoint, but there were problems in dewatering the scrubber solids and the savings compared to using DBA just were not there.

Review of the results from the 2009 testing indicated that the dewatering problems occurred shortly after stopping the feed of sulfur to the absorbers. AECOM suspects that this resulted in a quick rise in oxidation rates in the absorbers which is known to cause problems with the size and shape of the sulfite crystals, increasing the unit area and making them difficult to dewater. Had sulfur addition and thiosulfate levels been maintained constant through the testing, this likely would not have happened.

Sodium formate continues to be used successfully by other utilities in the U.S. to enhance SO_2 removal in inhibited oxidized scrubbers. AECOM has made a recommendation in the past to conduct a test to see what the benefits might be from a switch in FGD additives. At the sodium formate addition rates that would be needed to deliver roughly equivalent buffer capacity as the DBA provides (20 lbs formate/ton of SO_2 removed vs. historically about 12 lbs DBA/ton SO_2 removed)) the sodium levels would increase by approximately 2,300 ppm. This alone would raise the LGF from 18 (level measured in late November, 2014) up to 67 which is closer to what was last seen in 2013 when the boiler operated at a higher capacity factor.

And sodium levels could be further increased by switching from the use of sulfur to using sodium thiosulfate to provide inhibited sulfite oxidation conditions in the absorbers. The effect is not as significant as substituting sodium formate for DBA because much less sodium thiosulfate is needed. Still, analysis indicates that the LGF would increase from 67 up to 77, if used in conjuction with sodium formate, which would still benefit SO_2 removal. While sodium thiosulfate is slightly more expensive than using sulfur to hit similar thiosulfate concentrations in the absorber, there are a few other benefits besides the increase in sodium and that is the ability to quickly increase the thiosulfate concentration when necessary. When using sodium thiosulfate for oxidation control there is no lag time in increasing thiosulfate as there is when sulfur is used (it has to react with sulfite to form thioulfate in the absorbers and this is not a fast reaction). Also, there is no unreacted sulfur left in the calcium sulfite solids when using sodium thiosulfate (only about 50% of emulsified sulfur is utilized in generating thiosulfate based on historical data). This means that the sulfite crystals will settle a little faster in the thickeners and dewater more easily on the filters (sulfur crystals are small and tend to be very sticky). AECOM estimates at the current sulfur feed rates that switching to sodium thiosulfate would increase annual costs by about $80,000 over the cost of sulfur. However, the benefits in improved SO_2 removal could likely offset most if not all this cost increase by lowering DBA addition rates and keeping absorbers cleaner.

Effect of Cycling Unit Load on FGD Water Balance and Chemistry

Another important question that is raised by the significant drop in the alkalinity of the scrubbing slurry is what effect the current load cycling of the unit had on the FGD chemistry. Prior to

2014, the San Miguel boiler was baseloaded the vast majority of the time at 430 MW's. Since the spring of 2014, the unit has been cycling from a minimum load of about 250 MW's to a max load of 430 MW's although some days the unit never reaches full load. This mode of operation creates a set of circumstances that the FGD has never been exposed to and is fairly detrimental to its process chemistry as well as to its overall water balance – meaning the ability to match the inflow of makeup water with the outflow of water from the system.

To investigate the impact of load cycling on process chemistry, AECOM, with assistance from the plant, conducted a review of the FGD water balance and how it changes with differing unit load conditions. Below in Table 9-7 is a summary of the results. The main water streams entering the FGD system are identified and flow rates listed as a function of unit load. Along with those flow rates, the amount of water leaving the system is estimated. The difference between the two flow rates is the NET amount of water that is moving through the system and there is one of three basic conditions that can exist – either the system has:

1. A negative water balance, which means it is consuming more water than is being fed to it;
2. A positive water balance, which means there is more water entering than being consumed; or
3. An even balance between the inflows and outflows of the water streams.

Given that San Miguel runs as a zero water discharge plant, the FGD water balance cannot be positive for very long periods of time or significant amounts of water will accumulate in the EQ and ash ponds.

Table 9-7. Results of San Miguel FGD Water Balance Evaluation

SAN MIGUEL FGD WATER BALANCE	Case 1	Case 2	Case 3
	Typical load profile pre-2014	Current load profile - cycling	Current load profile - cycling; low flow pump seals
Unit Capacity Factor, %	90	70	70
Water Exiting FGD, gpm			
Water Evaporated in Absorbers	387	301	301
Water in Filter Cake @ 65% solids	79	61	61
Total Water Out, gpm	466	362	362
Water Entering FGD, gpm			
ME Wash, circ water	200	200	232
FGD recycle pumps seal water, circ water	160	160	24
Miscellaneous pumps seal water, circ water	26	26	26
Wash down & housekeeping - ash pond water	80	80	80
Total Water In, gpm	466	466	362
Net FGD Water Balance, gpm	0	*104*	0

The primary water consumer in the FGD system are the absorbers as a portion of the water in the slurry being recirculated through the towers is continously evaporated to cool the hot, incoming flue gas from nominally 300F to 140F. Typically about 1 gpm of water is evaporated in the FGD for every 1 MW of unit load for a solid fuel fired utility boiler. Thus with the unit operating at

full load, the four absorbers are evaporating 430 gpm of water. And with the unit operating at half load, 215 MW's, the evaporation rate will be roughly 215 gpm.

The other significant water stream leaving the FGD system is the water associated with the calcium sulfite/sulfate solids that make up the filter cake. The exact amount of water leaving is a function of the moisture content of the filter cake and this can vary significantly depending on the condition of the filters and how they are being operated as well as by the size and shape of the sulfite/sulfate crystals which can vary significantly depending primarily on the fraction of sulfate in the solids. The lower the oxidation, the smaller the amount of sulfate in the calcium sulfite crystal lattice and thus the larger and more regular its shape. These larger crystals will dewater much easier, and at times create problems in the thickeners and T1 because of their rapid settling rates (low unit areas or UAT's).

For the water balance in Table 9.7 the moisture fraction in the filter cake was assumed to be 35%. This number is based on our experience with typical inhibited oxidized scrubbers and we have not made any measurements of the San Miguel filter cake moisture levels. It is recommended that SMEC make a few measurements of the filter cake moisture to improve the accuracy of this water balance. Another variable that can affect the magnitude of this flow rate is the average sulfur level in the lignite being burned. The higher the sulfur level, the more solids produced by the absorbers and the more water that is removed with the solids. Also the higher the average unit load over a given period of time the greater the amount of solids produced, and vice versa. Thus there are a number of variables affecting the size of this stream. Based on the assumptions used for this particular water balance comparison shown in Table 9.7, which assumes an inlet SO_2 of about 9 lbs/MMBtu, the filter cake will contain about 79 gpm of discharge water for a 90% unit capacity factor and 61 gpm for a 70% unit capacity factor.

This results in a total quantity of water leaving the FGD system of about 466 gpm with the unit running at 90% capacity factor with minimal cycling versus about 372 gpm with the unit at 70% capacity factor and significant cycling.

The other aspect of the water balance is the supply side – it is important to understand where the incoming makeup water streams enter into the FGD system. When evaluating an FGD water balance, do not consider the internal process water entering and leaving the thickeners, T1, the filters, the ball mills, or clarifier tank. These streams originate and terminate within the boundaries of the FGD system itself. When constructing a water balance it is only important to include the influents to the system and the effluents. The influent streams are primarily comprised of: 1) circ water used for ME wash, 2) circ water used for seal water for the big recycle pumps as well as other smaller pumps including the vacuum pumps in the filter building and 3) ash pond water used to supply hoses used for housekeeping in the FGD area.

The largest influent to the FGD systems is the ME wash supply, which uses a time average flow of 200 gpm of circ water. The next largest stream is pump seal water which is also supplied

from the circ water system. The large absorber/quencher recycle pumps take roughly 160 gpm of water combined through their seals. This flow rate is not measured and was estimated assuming each pump seal is using about 13 gpm. There are a number of other smaller pumps throughout the FGD system that take seal water, including the vacuum pumps and they are estimated to total a little under 30 gpm, again this being a best guess. This water also comes from the circ water system. Also, there is a moderate volume source of incoming water to the FGD system from the ash pond and it supplies the various hoses used for washdown and cleanup in the FGD area. The estimated rate for this water is 80 gpm.

These various incoming streams amount to about 466 gpm which roughly equals the total amount of water leaving the FGD system via evaporation and in the filter cake during high load operation. Note that this analysis does not include the times when T1 has to be dumped because the rake trips. This was a common occurrence prior to the upgrade of the rake in the spring of 2014 and resulted in significant volumes of FGD liquid and slurry being discharged to the FGD pond because there is no other place to store such large volumes of water and slurry. As a result, the FGD pond, and to a lesser extent, the ash pond have significant amounts of chemicals (DBA and thiosulfate) in their waters that originated from FGD. Some of that water is returned to the FGD system via the ash pond water used for housekeeping and cleanup so not all the chemicals are lost. The possibility of increasing the return of this water to FGD is discussed later. Unfortunately, the quality of this water is not good – it is saturated in calcium sulfate (gypsum) - and so should not be used for ME wash and would be best to direct it to the clarifier tank and returned to the absorbers for density control or better still, to the pug mill for blending with fly ash and filter cake so it would not impact FGD chemistry..

Thus from a water balance standpoint, the FGD system does a good job of balancing the incoming and outgoing streams *for the high capacity factor case* examined. The only time water leaves the system other than in the filter cake is during an upset condition. When AECOM analyzed the critical balance of the sodium, magnesium, and chloride salts, the result was that the absorber slurry had a positive LGF of about 120 which closely matches measured conditions back in August, 2011.

The second water balance case examines a lower unit capacity factor of 70%, reflecting more typical conditions for the boiler with it cycling from low load to high load throughout the day. This case reveals that the FGD water balance goes positive under these conditions by approximately 100 gpm. A positive water balance means that water is accumulating in the system. The reason the water balance goes positive is that there is no way to adjust the amount of water entering the FGD system to balance the lower quantities of water that are leaving. At lower loads less flue gas is treated in the absorbers and so less water is evaporated by cooling the flue gas. Also, with less flue gas, there is less SO_2 removed and so the amount of filter cake declines so the water in the cake is proportionally lower.

When the FGD water balance goes positive, the excess water leaves the boundaries of the FGD system and ultimately ends up in the FGD pond. Over a period of one day, being 100 gpm positive on the FGD water balance amounts to about 140,000 gallons of excess water. And over a period of 100 days, 100 gpm will amount to around 14 million gallons of excess water. This condition cannot go on indefinitely if the plant hopes to maintain an overall zero liquid discharge.

AECOM has investigated the application of low flow seals to the San Miguel recycle pumps and found that a switch to this type of seal could reduce the seal water flow rate from 160 gpm to about 24 gpm (2 gpm per pump). For example, a Chesterton 442 split mechanical seal was installed several years ago by a Western utility on their six large recycle pumps and reduced their per pump seal water flow from 15 to 20 gpm down to 2 gpm. There are several good mechanical seal suppliers in the U.S. with experience with large FGD recycle pumps. Most utilities now employ this style seal to allow them to better manage their water balance as cycling load operation has become much more the norm for coal fired power plants.

This change alone would bring the FGD water balance back to where it needs to be. The third case in Table 9.7 evaluates an operational scenario where there is load cycling and low flow pump seals and shows the impact on the overall water and salt balance. As the results show, the water balance is now where it needs to be, at least for this 70% unit capacity factor condition. In fact the balance is somewhat negative and to balance it, more circ water was applied to washing the ME's in an effort to keep them cleaner.

Should the unit run at much less than this capacity factor, then it could go positive once again. For example, should the unit operate at half load for extended periods of time, then the amount of excess water would be roughly 50 gpm. This is because of the further reduction in water evaporated in cooling the flue gas and water leaving with the filter cake as compared to Cases 2 or 3. This mode of operation would require either operating the FGD with only three modules in service to reduce ME wash volumes and recycle pump seal water or a moderate reduction in the wash frequency and/or duration for the ME wash.

Effect of Low Load Operation on FGD Chemistry

To study the effect of heavy load cycling on the FGD system, AECOM evaluated not only the water balance impacts, but also the effect on the soluble salts such as magnesium, sodium, and chlorides. If the FGD system operates with a positive water balance, then there will be lower concentrations of these soluble species in the scrubber slurry. The water balance spreadsheet was created to evaluate the differing load conditions and was organized to also include salt balances for the magnesium, sodium and chlorides as they enter and leave the FGD system through their various routes.

Table 9.8 presents the results of this analysis and is organized into the same three cases as was the water balance in Table 9.7 – a base case which reflected the historical high load operation of the unit, current cycling load with no changes to water balance, and current cycling load with changes to bring the FGD system back a neutral water balance.

The results in Table 9-8 show that with the current load cycling conditions the main soluble species (magnesium, sodium, and chlorides) all drop as a result of the positive water balance. This reduction in concentration happens because the cycles of concentration in the FGD are not as high when the amount of water leaving the FGD system is increased. There is a similar effect with cooling towers. When their blowdown rates are reduced, then they cycle up the incoming salts in the makeup water and produce a saltier circulating water composition. When the blowdown rates are increased, then they operate under less salty conditions. For example, the design conditions for the San Miguel cooling tower system was for the incoming well water to be cycled up by about a factor of 6. In other words, with 4,000 gpm of well water being fed to the cooling towers as makeup and 720 gpm being sent to blowdown – most of which was the FGD system – the cycles of concentration (COC) = 4,000/720 = **5.6**.

Table 9-8. Results of Salt Balance Around SMEC FGD System

FGD Salt Balance for Mg, Na and Cl	Case 1	Case 2	Case 3
	Typical load profile pre-2014	Current load profile - cycling	Current load profile - cycling; low flow pump seals
Magnesium in FGD liquor, ppm	1,704	662	1,792
Sodium in FGD liquor, ppm	4,927	1,889	5,016
Chlorides in FGD liquor, ppm	8,333	4,123	10,499
Effect of Salt Concentrations on LGF			
LGF if using DBA (current conditions)	***119***	***20***	***69***
LGF if using NaF @ 20 lbs/ton SO2	272	93	267
LGF if using NaF @ 10 lbs/ton SO2 and Sodium Thiosulfate	206	67	178

Similarly a COC can be calculated for the FGD system. For the base case there is 466 gpm being fed into the system and 79 leaving as liquid water (evaporated water does not contain any salts and for this reason is not included in calculating the COC). Thus the FGD COC is equal to:
466 gpm/79 gpm = 5.9
which is a fairly similar number that the cooling towers operate at. Taking sodium as an example, it's concentration is about 150 ppm in the well water, so the cooling towers cycle it from 150 up to: 150 x 5.6 = 840 ppm and the FGD system further cycles up the sodium to: 840 x 5.9 = 4,900 ppm.

It is important to point out that at lower unit loads the FGD system can be taking so much circ water that the cooling tower COC drops at the same time as the FGD COC drops. This results in a greater than expected decrease in salt levels with sodium, magnesium, as well as chlorides all dropping by a relatively large amount in the absorber slurry. As can be seen comparing Case 1 to Case 2 the salt levels are cut by more than 50%.

When the LGF is calculated, its value drops by more than a factor of 5 which as was shown earlier can have a significant impact on the SO_2 removal efficiency of the absorbers. In addition, DBA feed rates will increase since more water is being lost from the FGD system which carries this valuable additive out of the system and into the FGD pond. Once in the pond, DBA can be consumed by bacteria when it sits for significant amounts of time since the conditions are generally ideal for bacteria to grow and feed on this carbon-rich nutrient.

The water and salt balance analysis reveals that operating the FGD system in a positive water balance condition results in several significant problems. These include exceeding the water storage capability of the onsite pond systems, decreasing the SO_2 removal performance of the absorbers, increasing the costs for DBA by purging excessive water from the FGD system, and potentially increasing the cost of anti-scale and corrosion additives for the cooling towers.

Installation of low flow seals for the absorber/quencher recycle pumps can resolve these issues as long as the unit capacity factor does not drop below 70%. If it does, then reduction in the number of operating absorbers is needed to reduce the influx of seal water and ME wash water or adjustments need to be made to the ME wash frequency and/or duration.

Table 9.8 also quantifies the effect of using sodium formate instead of DBA on the LGF in the absorbers. Adding sodium formate results in a significant increase in the sodium levels in the absorbers. At a formate consumption rate of 20 lbs/ton SO_2 removed, which is the amount roughly needed to replace DBA and maintain similar levels of buffer capacity, the LGF increases significantly for Cases 2 and 3 which should be a benefit to the absorber SO_2 performance.

For Case 2, which is not a long term operating condition that the plant should operate under, the LGF increases from 20 up to 93 which is close to levels the system was operating at in 2011. Case 3, however, which is the recommended long term operating condition for the unit with significant load cycling reveals what a powerful effect the sodium formate would have on the LGF. At a dosage rate of 20 lbs/ton SO_2 removed, the LGF will hit 267 once the system hits steady state. Under these conditions, the boost in SO_2 removal beyond just the buffer capacity of the formate should be very beneficial. Since the combination of formate plus a very high LGF might allow for a sizable reduction on sodium formate feed rate, a case where the addition rate was decreased by 50% to 10 lbs/ton SO_2 removed was examined. In this case, the LGF drops to 165 which is still a very large value and should provide much improved chemistry needed for high SO_2 removal in the absorbers. This case includes adding thiosulfate to the system as sodium thiosulfate, which is the original anti-oxidant reagent used by utilities to help slow gypsum scaling. The idea is to take advantage of the sodium in the sodium thiosulfate molecule to further boost the LGF of the scrubbing slurry.

A brief cost analysis indicates that this method of adding thiosulfate to the absorbers would cost about $80,000 per year more than the current approach of adding emulsified sulfur, however, the

instantaneous effect of using the chemical on maintaining proper thio levels in the absorbers combined with the SO_2 enhancement capability will probably make the extra costs a wash.

Recommendations for ME Wash System to Reduce Scaling

AECOM has reviewed the quality and quantity of water used for washing the mist eliminators to help reduce chemical scaling. One of the most important variables affecting the cleanliness of a mist eliminator operating in a wet limestone FGD system is the quality of the water used for washing. In particular, the concentration of calcium sulfate, or gypsum is one of the most important criteria when evaluating the quality of ME wash water. Table 9-9 below presents measurements that AECOM made back in 2012 for the absorbers, thickener overflow, clarified water and ME wash. Also measurements made in March 2015 of the FGD pond and ash pond are included which allows some insight into the quality of water in those ponds.

Table 9-9. Results of Gypsum Saturation Measurements Around the FGD System and Plant

Sample Description	A Absorber	B Absorber	C Absorber	D Absorber	A Thickener Overflow	B Thickener Overflow	Clarifier	ME Wash	Circ Water	Ash Pond	Eq Basin
Sample Date	12/6/2012	12/6/2012	12/6/2012	12/6/2012	12/6/2012	12/6/2012	12/6/2012	12/6/2012	11/1/2012	3/17/2015	3/17/2015
pH	5.80	5.80	5.80	5.80					7.80	6.80	6.70
Sulfite Oxidation	6.3	8.0	10.4	8.8							
Limestone Stoichiometry	1.01	1.01	1.01	1.02							
Ca, mg/L	302	531	362	375	549	592	643	344	20	606	824
Mg, mg/L	1,075	1,211	1,020	1,023	1,124	985	869	508	4	257	465
Na, mg/L	4,165	4,406	3,808	3,864	4,107	3,686	3,437	2,385	990	1,000	1,800
K, mg/L	69	73	69	65	69	61	57	36	12		
Br, mg/L	0	0	0	0	0	0	0	0		20	38
Cl, mg/L	6,461	6,949	6,280	6,504	6,737	5,822	4,965	3,194	160	2,410	3,870
CO3, mg/L	209	342	266	605	347	296	328	154			
SO3, mg/L	1,795	1,698	1,339	1,138	756	562	407	277		7	0
SO4, mg/L	1,435	1,985	1,431	2,034	2,455	2,717	3,011	2,729	1,800	3,080	4,050
Thiosulfate, mg/L	1,032	1,030	955	899	1,250	977	782	526			
Total hydrlizble S, as mg/L SO4	7,121	7,704	7,163	7,283	6,889	6,616	5,832	4,296			
Slf.-Nitrgn. species, as mg/L SO4	1,766	1,919	2,491	2,345	1,386	1,553	994	335			
Succinic, mg/L	<50	<69	<35	<33	<35	<29	<21	<28			
Glutaric, mg/L	317	412	488	479	357	401	273	<56			
Adipic, mg/L	370	418	407	447	386	382	95	28			
LGF	87	95	72	69	81	77	81	55	39	-40	-52
Gypsum Saturation, %	**12**	**26**	**15**	**22**	**36**	**46**	**59**	**41**	**4**	**94**	**117**

There are a number of important observations that can be made from the data in Table 9.9. First, it is helpful to understand what the gypsum saturation number at the bottom of the table has to do with the scaling potential in and around a limestone FGD system. Monitoring and understanding how gypsum saturation changes and what controls the variation in saturation is important in minimizing the sometimes severe scaling that can occur inside the FGD absorbers. From a general standpoint, scaling inside absorbers has been controlled by taking one of two approaches. The most popular is to force oxidize the absorber by sparging air into the slurry to convert virtually all sulfite to sulfate – in both the liquid and solid phases. The other approach, which is the one used at San Miguel, is to operate the system at low sulfite oxidation levels such that little sulfate is produced in the absorbers. This is done by running the absorbers with thiosulfate in the slurry which inhibites the oxidation reactions that convert sulfite to sulfate. If the sulfite oxidation fraction, as measured by analysis of the absorber slurry solids, is 10 percent or below, then scaling conditions are typically lessened.

Unfortunately, inhibited systems seldom can operate scale free as is often the case with forced oxidized systems. The reason for this is that sulfite – mainly in the liquid phase – can react with oxygen in the flue gas and form sulfate. This happens more in the regions of an absorber where there is not a lot of slurry irrigation such as on the mist eliminator, along walls or areas under beams or tray supports. The pH will drop to fairly low levels in these areas and low pH degrades thiosulfate quickly, defeating its inhibiting effects. This condition is worsened if the flue gas contains a high fraction of oxygen typical of lower load operation, for example. With ample O_2 in the flue gas, low pH conditions, and plenty of sulfite in the both the liquid and solid phase, calcium sulfate scale will slowly but steadily grow.

Inspections of the interior of the San Miguel absorbers over the years has revealed that within six months (from a fall to a spring outage for example), gypsum can coat a significant portion of the absorber from below the trays to the upper mist eliminator bank despite relatively consistent operation of the absorbers with enough thiosulfate in the slurry to keep oxidation rates at or below 10 percent.

As the data in Table 9.9 shows, the sulfite oxidation fraction in the solids was between 6 and 10 percent in the absorbers and the thiosulfate levels in the slurry were fairly high at 900 to 1000 ppm. (Note that AECOM typically measures higher thiosulfate in the slurry than the plant lab measures by several hundred ppm, probably because thiosulfate regenerates over time and AECOM measurements would be biased high in that event). The calculated gypsum saturation level is presented in the last line in the table. The saturation levels are relatively low, between 12 and 26 percent, which is well below the 100% or saturated gypsum condition. This would imply that the conditions do not favor gypsum precipitation within the absorber. Unfortunately, the reality is that the only place gypsum is not precipitating is in the reaction tank slurry. And inspections reveal that almost every solid surface inside the tank – and a fair amount of the absorber internals themselves – have evidence of gypsum scale growth after six months of operation.

The unfortunate circumstance is that the conditions inside the San Miguel absorbers are such that even consistent use of thiosulfate and operation at sulfite oxidation and gypsum saturation levels that typically keep most other inhibited oxidized scrubbers fairly free of scale have proven time and time again that gypsum scaling cannot be avoided. A conversion to forced oxidized operation would probably resolve most of the gypsum scaling, however, this is an expensive conversion and over time reductions in the costs of scale removal would likely not provide a good return on investment.

AECOM feels, however, that scaling in the mist eliminators could be reduced significantly with a few key changes made to the wash system. Scaling of the mist eliminators is probably more detrimental to the overall SO_2 removal performance of the system than scaling in other areas of the absorber towers. That is because as the mist eliminators scale and plug up, the flue gas

pressure drop through them increases significantly. Historically, the ME scale accumulation is not uniform from absorber to absorber at San Miguel. This causes one absorber to have greater or lesser resistance to flow than another. The result is that flue gas flow rates are no longer an even 25% split between the four modules. Generally two problems occur when gas flow is skewed.

First, the SO_2 removal performance of the overall system declines as the degree of ME pluggage increases. For example, prior to the Spring 2015 outage the absorbers were struggling to keep stack SO_2 below 0.8 lbs/MMBtu with the unit at full load. When the absorbers were opened up, C was severely scaled in the mist eliminator area, D totally clean, with A and B being partially plugged. Note that C tower ME's were also almost totally plugged when the unit came down for the fall 2014 outage. The reason for C's scaling problem is unknown but could be due to that tower receiving more than its share of flue gas. High gas velocities would increase the amount of carryover to the ME's and create conditions for more rapid scaling. Recall the gas flow results from the 11/20/14 testing showed C to have the highest flow of the four towers and D had the lowest (Figure 9.1). The test was not long after the short fall outage when the ME's were cleaned. So this high velocity condition would not have been due to plugged ME's. But the reason for higher gas velocities in C are not obvious. They could be due to partially shut dampers on one or more of the other towers forcing more gas to C. Alternatively, the pressure drop through C is lower than through the adjacent D tower which could be caused by tray sections lifting or blowing out, although there was no evidence of this when the tower was inspected. Also, D's pressure drop could be higher if its inlet or outlet dampers were not opening completely.

Considering that C tower appears to be treating more than an equal share of the flue gas when the towers are all clean and the FGD systems have a less than optimum ME wash water quality explains why its ME elements are the most plugged up after extended operation.

Having online gas flow instrumentation installed in the quencher section would be the best way to provide continuous monitoring of the flow distribution between the towers. The capital cost for this improvement would have to be weighed against the downside of long term operation of the C and D towers with skewed gas flow – those being decreased SO_2 removal efficiency of the system (which would require increased DBA concentrations) and severe pluggage of the C tower ME's which increases cleaning costs and time.

The second problem with skewed gas flow between the absorbers is that it increases the chances for slurry carryover into the outlet duct and stack. Carryover occAECOM when the gas flow through the cleaner absorbers exceeds the maximum velocity that the mist eliminators can handle. This can lead to solids and scale buildup in the outlet duct and on turning vanes that have to be removed by cleaning crews at some expense. In more extreme cases, carryover can result in slurry being discharged from the top of the stack and raining over the plant site. Also,

solids can accumulate on the walls of the stack eventually requiring a difficult and potentially expensive cleaning.

Improving the ME wash could help offset the scaling in A, B and C. The changes have to do mainly with the quality of the ME wash water. Currently it is a blend of clarified water (thickener overflow) and circ water. The quantity of circ water has historically been limited to about 200 gpm, for water balance reasons. The amount of clarified water added to the ME wash tank is determined by the amount of water needed over and above the circ water to supply the total demand of the wash system. This demand is established ultimately by the frequency and duration of the ME wash water controls. AECOM was told that the amount of clarified water entering the ME wash tank is typically around 270 gpm. This results in a total water consumption for ME washing of 470 gpm.

As AECOM understands, the ME's are being washed continuously with the valves cycling through one absorber and then moving the adjacent absorber until all four have been washed. An individual wash valve stays open for 90 seconds and there are four valves per absorber for the upper and lower ME wash. Then the cycle repeats with no dwell time between absorbers giving a total of 2.5 washes per absorber per hour. The lower wash was designed for an intensity of 1.5 gpm per ft^2 of crossectional area and the middle wash for 0.75 gpm per ft^2 to each ME face. Note that if the wash water pressure increases above the original design point (which typically is 30 psig), then the flow rate will increase at the square root of the ratio of the two pressures. So if the pressure increased to 60 psig, the wash intensities would increase by a factor of $(60/30)^{0.5}$ - which would raise the flow rates by a significant amount - 41%.

The crossectional area of the ME's is 1,000 ft2. So with the above wash intensity rates, durations and frequencies, the total water used for washing the ME's is estimated to be 750 gpm. This average flow rate is not consistent with the stated wash water consumption of 470 gpm. Thus the wash frequency or valving is different than AECOM's understanding stated above.

Based on the analytical results in Table 9.9, AECOM feels that the cleanliness of the ME's would be substantially improved if they were washed with 100% circ water. The reason is that the circ water does not contain any dissolved sulfite and much less sulfate than clarified water. The concentrations of sulfite and sulfate are significant in the clarified water and since this makes up the majority of the ME wash (about 60%) these species are present at relatively high levels in the wash water. It is interesting to note how the sulfite levels drop from the absorbers to the thickeners to the clarifier tank. Apparently they are continuing to oxidize and form sulfate as the water picks up oxygen from the ambient air. This results in the gypsum saturation levels rising fairly significantly from the absorber to the clarifier (an average of about 20% saturation in the absorbers versus about 60% in the clarified water).

The better quality water of the circ water makes it a more desirable source for washing the ME's. This stream has no sulfite and over 1,000 ppm less of sulfate than the clarified water. Also there

is very little calcium in the circ water versus what is in the clarified water. The gypsum saturation level in the circ water is only 4% but up to 60% in the clarified water. The result of using 100% circ water would be that the ME's would not be sprayed with water that contains significant levels of sulfate and sulfite, both of which contribute to the formation of solid calcium sulfate – gypsum – on the ME elements.

The current convention for new FGD systems is to wash with all fresh water, no recycle or process or clarified water. The reason is that the reclaimed process water is 100% saturated with calcium sulfate for these forced oxidized scrubbers and spraying this quality of water on the ME's has proven to cause scaling a pluggage of the ME elements. Given that ME's operating in forced oxidized limestone scrubbers maintain fairly clean mist eliminators over extended periods of time, AECOM recommends that the San Miguel ME's be operated using 100% circ water rather than the current blend of clarified water and circ water.

By switching to a better quality water, the wash frequency and duration can be reduced and thus still maintain the FGD system water balance at net zero. For current load cycling conditions, this assumes that the recycle pumps have been retrofitted with low flow seals so that the amount of circ water that was going to the seals can be redirected to the ME wash tank. The wash frequency can be set so that each absorber's ME's are washed twice per hour as long as the duration of the wash is limited to 45 seconds. This will give a time averaged wash water consumption of 300 gpm which is okay if the unit is running at full load. However, at lower loads, a dwell time will need to be programmed into the ME controls so that at lower loads the ME's are washed at less than 2 cycles per hour. Even though the total quantity of wash water is less than the current 470 gpm rate, the much improved quality will more than make up for the reduced volume and the result should be cleaner mist eliminators in each module.

The data in Table 9.9 also show that both the EQ basin and ash pond contain high levels of dissolved gypsum and the EQ is actually supersaturated in calcium sulfate. These waters are not good for use in the FGD system, especially for ME washing, and considering they have negative LGF's they would only decrease the SO_2 removal performance of the absorbers if any more is used than the current 80 gpm used to cleanup in the dewatering area. In fact if all or even a portion of this 80 gpm could instead be sent to wetting the ash in the pug mills the FGD chemistry would be expected to improve. Circ water would be the best water to use for hoses and cleanup.

Effect of Dissolved Calcium in the Absorber Slurry on Limestone Stoichiometry

Another important relationship seen in the AECOM analytical data collected since 2011 is how varations in the dissolved calcium in the absorber slurry influences the limestone stoichiometry measured in the absorber/quencher slurry. Figure 9-9 below shows how the dissolved calcium in the absorber slurry liquor relates to the measured limestone stoichiometry for samples that have been analyzed from 2011 through 2014. The results are for samples which were collected when

the absorber pH was within the range of 5.8 to 6.1. The data shows that as the dissolved calcium levels increase above about 1,000 ppm the amount of excess calcium carbonate in the slurry begins to rise to maintain pH's in the desired operating range. This relationship is commonly seen in other FGD systems and can explain why at times at SMEC the excess limestone can be quite high at a pH of 5.8 to 6.1.

The higher calcium levels shown in the chart were collected in 2014 when the FGD system was operating under positive water balance and discharging water to the ponds. Should high calcium levels (1,300 ppm or greater) be seen again, then the pH setpoint has to be decreased below 5.8 to keep from wasting limestone and scaling the mist eliminators.

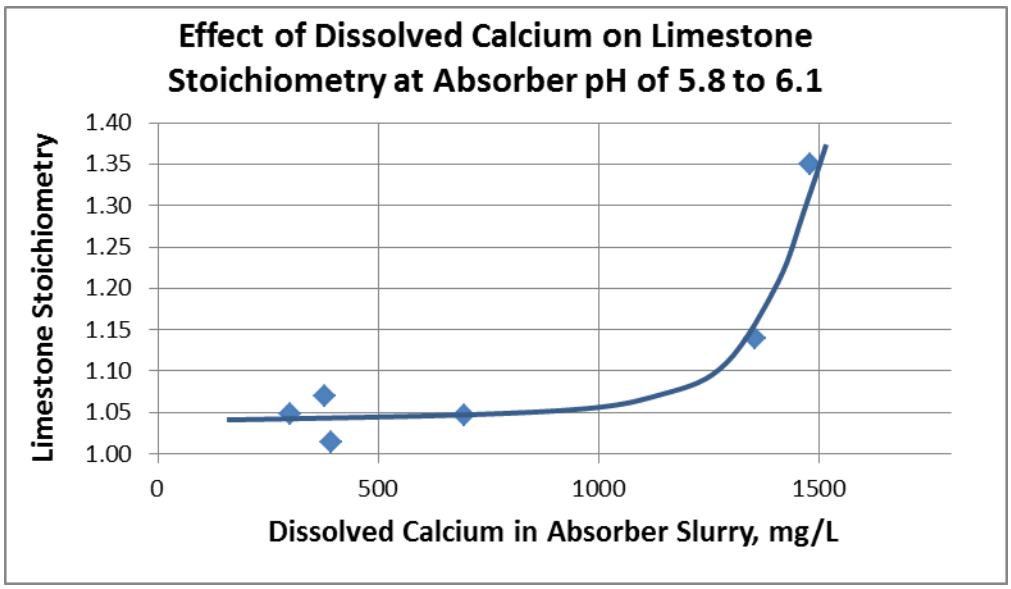


Figure 9-9. Effect of Dissolved Calcium on Absorber Limestone Stoichiometry

Over the past year or so, AECOM has noticed a consistent difference between the AECOM limestone stoichiometry values and those reported by the San Miguel lab. Closer analysis has led AECOM to believe that the discrepancy between the two labs is due to AECOM correcting for the unreactive magnesium carbonate ($MgCO_3$) fraction in the total carbonate (CO_3) value measured when performing the limestone stoichiometry calculation. A portion of the $MgCO_3$ fraction of the raw limestone will not dissolve at typical pH values in limestone FGD systems and as a result does not provide any solid phase alkalinity. Some of the $MgCO_3$ in the limestone is soluble and provides valuable liquid phase magnesium to the absorber slurry. The form of $MgCO_3$ known as dolomite does not dissolve however and so to get a good picture of the utilization of limestone in the absorbers, the dolomitic fraction of the limestone needs to be taken out of the stoichiometry equation. It is important to know precisely what fraction of the available limestone is reactive because otherwise it could lead to controlling the absorbers at an unnecessarily low pH. Typically SO_2 removal will increase with higher pH, so it is best to run at higher pH's as long as the stoichiometry can be kept within a range of 1.05 to 1.10. This will

ensure enough available limestone to maximize SO_2 removal while not unnecessarily wasting limestone. Figure 9-10 shows two scatter plots of limestone stoichiometry versus reaction tank pH. One data set show the stoichiometry calculated by San Miguel's lab and the other show the AECOM stoichiometry adjusted for the Mg concentration.

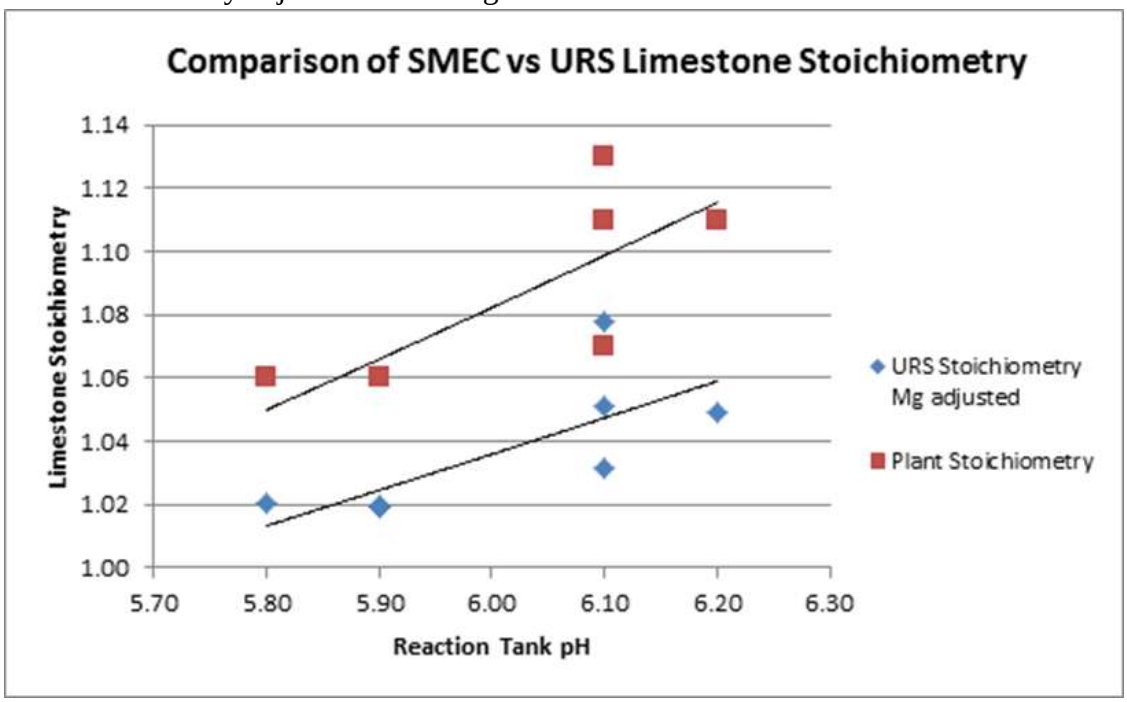


Figure 9-10. Comparison of Limestone Stoichiometry Calculation Methods

9.3 Conclusions and Recommendations

The testing done on November 20, 2014 did not result in a valid test because of what appeared to be a significant spike in lignite sulfur in the middle of the day. However, AECOM has taken data collected on that day and along with the past information dating back to August 2011 to study the various changes that the system has gone through, and how these changes have affected the present day performance of the FGD system. As a result of this in depth analysis, important relationships of key variables affecting the absorber chemistry and SO_2 performance have been revealed.

Based on this analysis of the system, the following conclusions and recommendations are made:

Conclusions:

- Changes in the dispatch of the unit resulting in significant load swings has resulted in the FGD system water balance going positive, with substantial amounts of water leaving the system and ending up in the EQ basin or ash pond.
- The dilution of the FGD system chemistry due to a positive water balance can have a negative effect on absorber SO_2 removal efficiency. If the water balance goes too

positive as it does currently during extended low load operation, the system can take so much circ water in that it decreases the cooling tower cycles of concentration. When this happens, the sodium levels in the circ water drop and this causes a further drop off in the quality of the FGD system chemistry (i.e., the slurry chemistry is less conducive to high SO_2 removal efficiencies).

- Taking into account the magnesium, sodium and chloride salt levels in the absorber slurry liquor can explain the changes in dissolved sulfite and calcium in the slurry. A relationship between the milliequivalents of sodium plus magnesium minus the milliequivelents of chloride (known as the liquid goodness factor or LGF) relate very well to the dissolved levels of sulfite and calcium. Since higher sulfite and lower calcium benefit absorber SO_2 removal, limestone stoichiometry and DBA additive costs, understanding how LGF affects these key variables provides much better insight into how best to operate the San Miguel absorbers.
- The AECOM FGD process model was used to predict the effect of varying absorber chemistry on SO_2 removal efficiency. Under the more dilute chemistry conditions seen in 2014 associated with the positive water balance, the estimated SO_2 removal with the unit running at full load and 500 ppm DBA was 95.3% removal. With the absorbers operating under conditions typical of 2011 through 2013, with the unit base loaded, the better chemistry resulted in an estimated removal of 97.3%.
- It is likely that the improvements made to the upper tray in the absorbers during the spring 2014 outage have been offset by the decline in absorber chemistry due to cycling load such that there has been little to no change in absorber performance.
- The positive FGD water balance can be resolved by decreasing the large quantity of seal water used by the absorber and quencher recycle pumps. Low flow pump seals are capable of reducing the per pump seal water flow to about 2 gpm each. Overall this would drop the seal water demand by about 140 gpm.
- Currently the magnesium, sodium and chloride levels in the FGD system are relatively low and this is hurting SO_2 removal. Installation of low flow pump seals alone would solve most of the water balance problems and increase these salts measurably giving improved SO_2 removal efficiency at the same time.
- If the unit runs for extended periods of time at minimum load, then even with low flow pump seals the water balance could go positive. During these times, either the ME wash sequencing would have to be adjusted, or a tower taken out of service (along with its pumps) to save on water.
- Using the alternative FGD performance additive sodium formate along with low flow pump seals would allow the FGD chemistry to be boosted significantly helping increase absorber SO_2 removal. SO_2 removal efficiencies of over 97% are expected if dosing in sodium formate at a rate of 20 lbs of additive per ton of SO_2 removed in the absorbers which should provide similar buffer capacity as the DBA does now.
- Use of sodium thiosulfate in the place of sulfur would help provide a smaller boost in the chemistry of the absorbers and could be more beneficial than emulsified sulfur in controlling the thiosulfate concentration at a specific level while improving SO_2 removal

at the same time. The extra costs for this solution compared to emulsified sulfur could be offset by the SO_2 removal benefits and reduced chances for gypsum scaling.

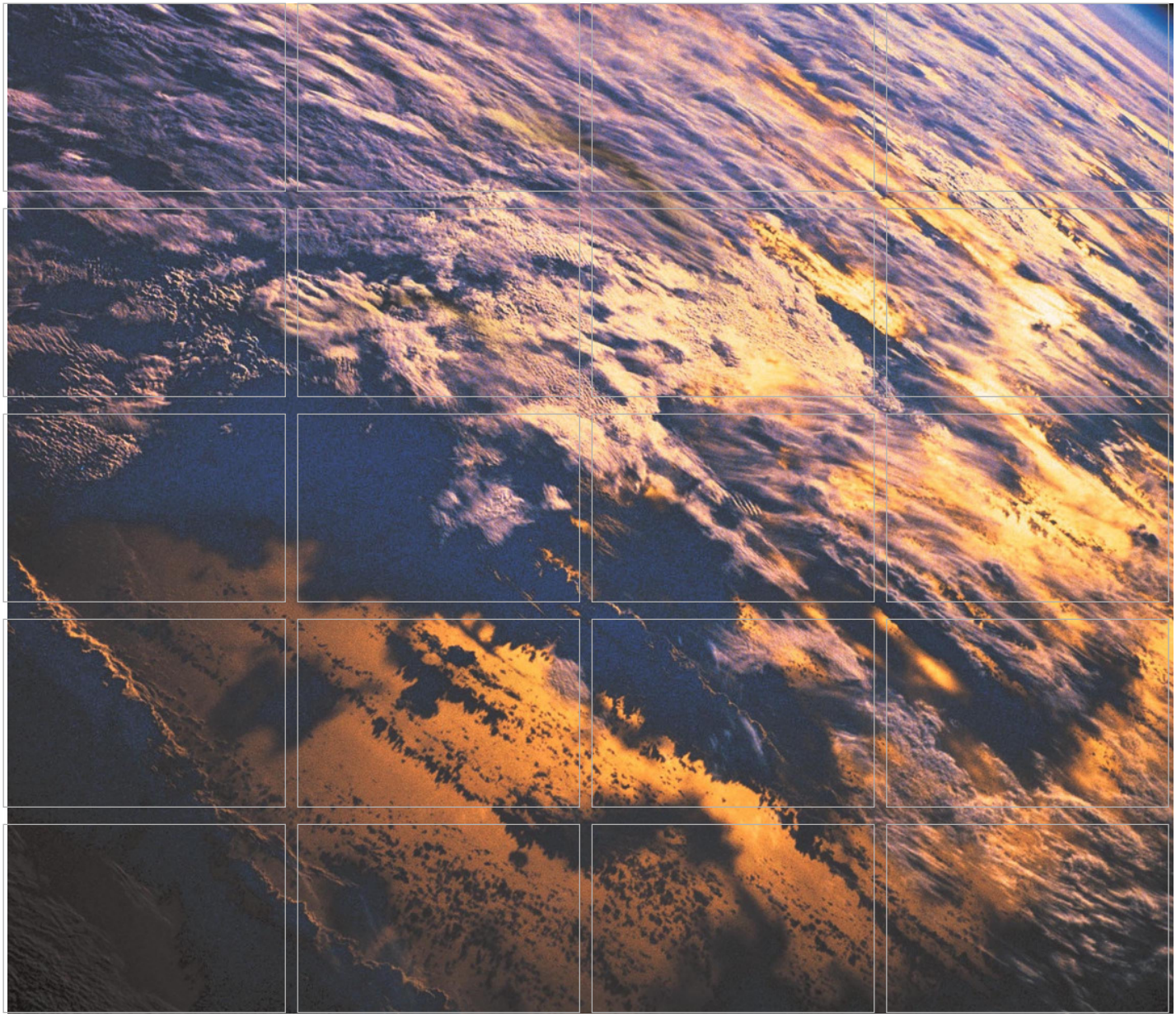
Recommendations:

- Low flow recycle pump seals should be installed on each of the 12 absorber and quencher pumps so that the FGD water balance can be better managed and kept from going positive.
- Use of circ water alone rather than a blend of circ water and clarified water would be expected to keep the mist eliminators cleaner. Pluggage in the mist eliminators is likely decreasing the overall SO_2 removal efficiency of the absorbers since the varying amounts of pluggage in the absorber ME's causes a maldistribution of the flue gas..
- During times of extended minimum load operation one absorber should be taken out of service and pumps and ME wash turned off to keep the FGD system water balance under control.
- Ash pond water use in FGD operations should be kept to a minimum since it contains undesirable levels of chlorides which adversely affect absorber chemistry. A small amount of ash pond water can be tolerated for supplying hoses for housekeeping, but keeping the total ash pond water usage in FGD to below 80 gpm is recommended. A better use for ash pond water is to use it for wetting the ash in the pug mills.
- If the sodium and/or magnesium levels in the absorber slurry can be increased enough to provide a LGF of 150 or greater then it is likely that the absorber/quencher pH setpoints can be increased to 6.2 and still maintain good limestone stoichiometry. For good long term economics and mist eliminator cleanliness, the limestone stoichiometry should be kept in the range of 1.05 to 1.10.

Attachment E

Information Submitted to the TCEQ for the San Miguel Electric Plant

Part 2: ***San Miguel SO_2 Air Dispersion Modeling Report***



SO_2 Air Dispersion Modeling Report for San Miguel Electric Cooperative Inc.

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SO_2 Air Dispersion Modeling Report for San Miguel Electric Cooperative Inc.

August 2015

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1.0 INTRODUCTION

Unlike previous National Ambient Air Quality Standard (NAAQS) attainment demonstrations, EPA has decided to make 1-hour SO_2 NAAQS attainment determinations using ambient air monitoring data and/or air dispersion modeling. The final 1-hour SO_2 Data Requirements Rule (DRR) allows the use of modeling in situations where representative monitoring data are not available. EPA also issued guidance in its draft "Modeling Technical Assistance Document" (TAD)[1] on how modeling for the purpose of determining the compliance status of an area should be performed. The Modeling TAD sets forth a significantly different technical approach compared to conventional regulatory modeling prescribed by 40 CFR Part 51, Appendix W (EPA's *Guideline on Air Quality Models*). The approach laid out in the SO_2 Modeling TAD is designed to meet the requirements of EPA's 1-Hour SO_2 DRR.

Environmental Resources Management (ERM) performed air dispersion modeling to estimate the ambient impact of Sulfur Dioxide (SO_2) emissions from San Miguel Electric Cooperative Inc.'s (San Miguel) electric generating unit following the guidance in the Modeling TAD. The cumulative modeling analysis evaluated the impacts on ambient air quality from SO_2 emissions at San Miguel when added to existing background represented by ambient monitoring values. In addition, although the approach for considering cumulative ambient impacts with other major sources in the region is not specifically covered in the rule, ERM considered all other major sources of SO_2 within 50 kilometers to determine the need for source specific inclusion in the modeling.

The model results demonstrate that maximum model-predicted SO_2 impacts are in attainment with the 1-hour SO_2 NAAQS. This analysis, designed to fulfill the requirements of the DRR, shows that the ambient air quality in the vicinity of San Miguel which is currently undesignated for the 1-hour SO_2 NAAQS is within the NAAQS and should be identified as "attainment" in the next cycle of designations.

This modeling report describes the methodology that was used to evaluate potential impacts of SO_2 emissions from San Miguel on ambient air quality. Section 2 of this report provides a description of the facility and the emissions included in the modeling. Model selection and the methodology used in the modeling are described in Section 3. The modeling results are presented in Section 4. References are provided in Section 5. Copies of the modeling files are provided in Appendix A, the Electronic Modeling Archive.

[1] http://epa.gov/oaqps001/sulfurdioxide/pdfs/SO2ModelingTAD.pdf

2.0 FACILITY DESCRIPTION AND REGULATORY SETTING

2.1 FACILITY LOCATION

The San Miguel electric generating unit is located in the town of Christine, Texas. The station is located about 6 miles south-southeast of downtown Christine. The site is accessed by FM 3387 south of Christine, TX. The station is approximately 50 miles south of San Antonio, Texas and 90 miles northwest of Corpus Christi, Texas. Approximate site coordinates are 28.704˚ North Latitude, 98.477˚ West Longitude. The Universal Transverse Mercator ("UTM") coordinates of the facility are 551,040 Easting and 3,175,345 Northing (using North American Datum of 1983 - NAD83) in UTM Zone 14. The base elevation of the facility is 325′ (99.06m) above sea level. Figure 2-1 shows the site location marked on a United States Geological Survey ("USGS") 7.5-minute topographic map.

2.2 SO_2 ATTAINMENT STATUS

In July 2013, EPA designated 29 counties or partial counties as non-attainment for 1-hour SO_2 NAAQS. However, the vast majority of the country was not designated by EPA at that time due to the lack of monitors, or poor siting of existing monitors, for the purpose of capturing source based maximum ambient SO_2 concentrations. None of the counties surrounding San Miguel, including Atascosa, the county in which San Miguel is located, have been designated as attainment or non-attainment for the 1-hour SO_2 NAAQS.

2.3 SOURCE PARAMETERS AND ACTUAL EMISSION RATES

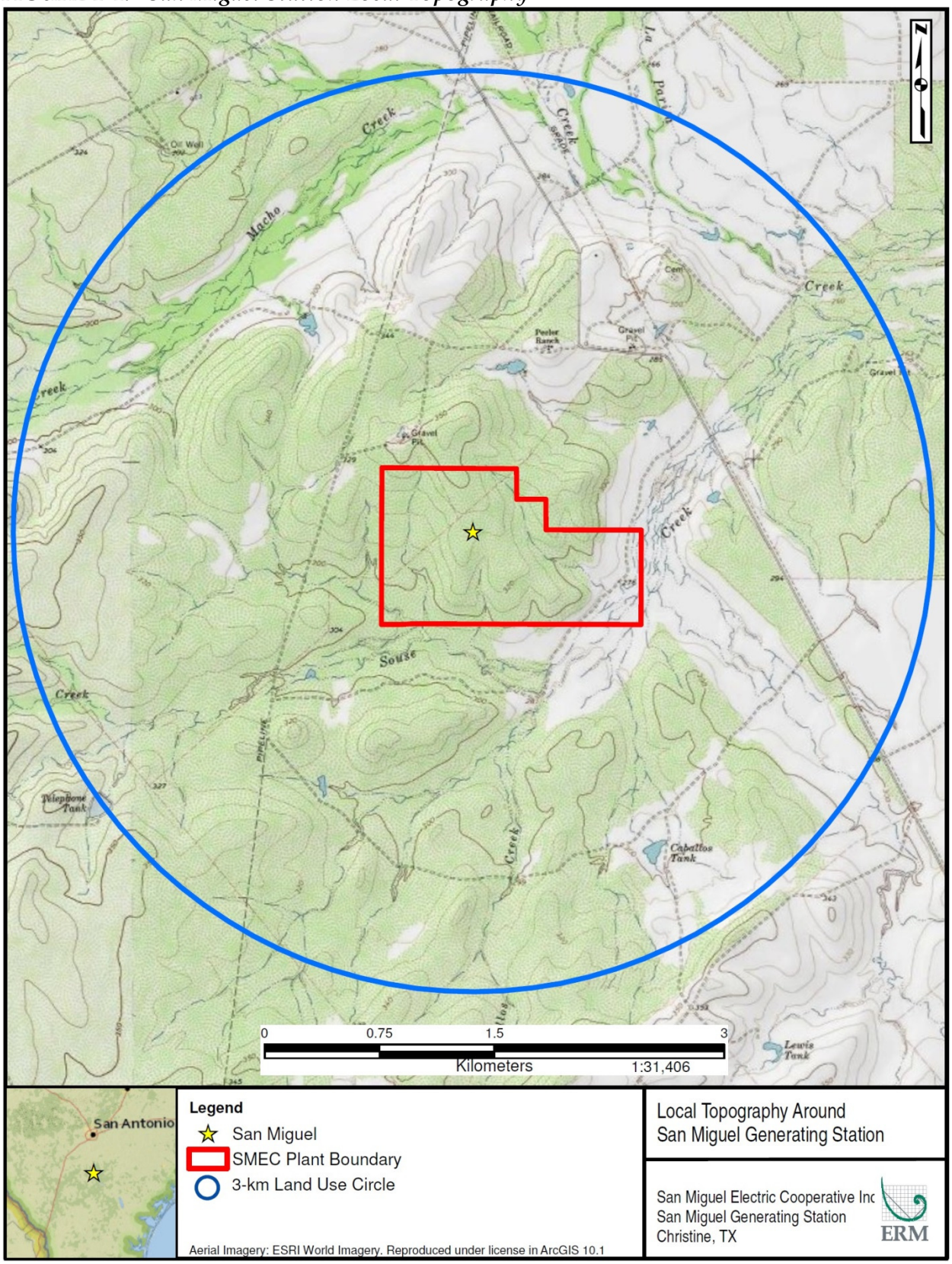
For this 1-hour SO_2 NAAQS modeling demonstration, the only significant source of SO_2 emissions at the facility was Boiler Stack (EPN 6). Per the 1-hour SO_2 Data Requirements Rule and SO_2 Modeling TAD, the most recent 3 years of actual emissions data, along with the actual stack height of the Boiler Stack, were used in the modeling. The following provides a description of all San Miguel SO_2 emission sources. Table 2-1 summarizes the characteristics of San Miguel Boiler Stack.

TABLE 2-1: San Miguel Boiler Stack – Stack Parameters

Description	*Model Source*	*Stack Height*		*Exit Temperature*		*Exit Velocity*		*Stack Diameter*	
		(ft)	*(m)*	*(F)*	*(K)*	*(ft/sec)*	*(m/s)*	*(ft.)*	*(m)*
Boiler Stack[1]	STACK	450	137.16	---	---	---	---	20.0	6.10

1. Exit temperature and exit velocity varied on an hourly basis based on actual emissions data.

FIGURE 2-1: San Miguel Station Local Topography



The actual emissions data used in the modeling are described below:

- Boiler Stack (Source ID: STACK). This unit is a coal fired utility boiler that produces steam for the generation of electricity. For this unit, three years (2012-2014) of actual hourly emissions, stack temperature, and exhaust flow rate data were input into the model. These data were provided by San Miguel based on CEMS data collected at the site. As per the 1-hour SO2 Data Requirements Rule, the actual height of the stack was represented in the model.
- Other sources at the site include emergency engines and fire pumps. These sources are used exclusively in emergency situations except for approximately one hour/week testing. Therefore, in accordance with USEPA guidance for intermittent sources[2], the emergency generator and fire pump engine were not included in the modeling demonstration for the 1-hour SO_2 NAAQS.

2.4 *SOURCE PARAMETERS AND MSS EMISSION RATES*

To supplement the actual emission rate model results, the maintenance, startup, and shutdown (MSS) emission rate of 5,967.7 lb/hr was modeled to demonstrate compliance with the 1-hour SO_2 NAAQS under facility maximum emission rates. The modeled MSS stack parameters are shown in Table 2-2 below.

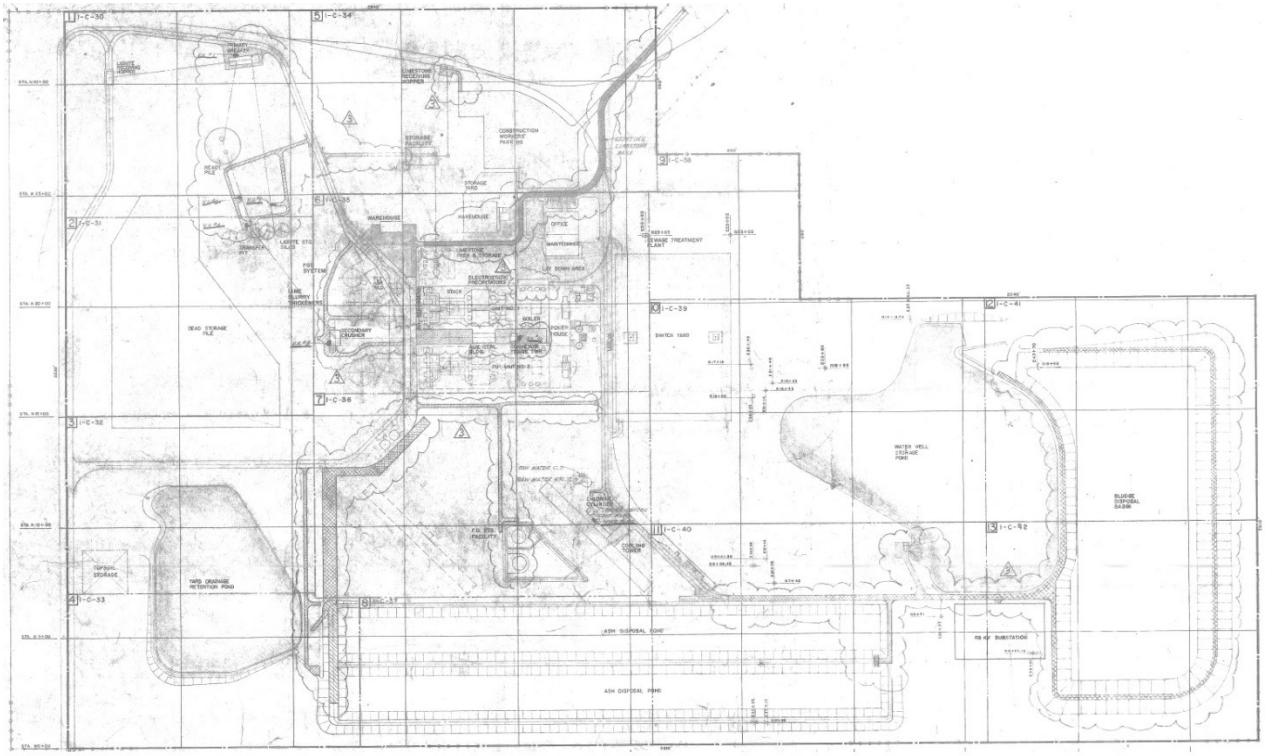
TABLE 2-2: San Miguel Boiler Stack – MSS Stack Parameters

Description	*Model Source*	*Stack Height*		*Exit Temperature*		*Exit Velocity*		*Stack Diameter*	
		(ft)	*(m)*	*(F)*	*(K)*	*(ft/sec)*	*(m/s)*	*(ft.)*	*(m)*
Boiler Stack	STACK	450	137.16	165	347	119.1	36.3	20.0	6.10

Figure 2-2 presents a site plan of the San Miguel facility.

[2] http://www.epa.gov/scram001/guidance/clarification/Additional_Clarifications_AppendixW_Hourly-NO2-NAAQS_FINAL_03-01-2011.pdf

FIGURE 2-2: San Miguel Station Site Plan



3.0 AIR DISPERSION MODELING ANALYSIS

EPA specifies that the approaches described in the SO_2 Modeling TAD are designed to "reflect a view that designations are intended to address current actual air quality (i.e., modeling simulates a monitor), and thus are unlike attainment planning modeling, which must provide assurances that attainment will occur." EPA's modeling guidance for the DRR utilizes several important differences from the modeling for permitting and/or attainment planning purposes including but not limited to the following:

- Simulating actual emissions and exhaust conditions (e.g., temperature and flowrate) on an hourly basis reflecting actual operations for a specified historical time period;
- Representing actual stack heights, irrespective of the GEP heights;
- Limiting modeled ambient air receptors to locations where monitoring could actually take place by excluding waterways, roadways, railways, restricted access property, and other locations that would conventionally be considered "ambient air" for regulatory and permitting purposes; and
- Simulating a three-year period of meteorological and background monitoring data, concurrent with the actual operating conditions and emissions, to meet EPA's objective that "modeling simulates monitoring" in this context.

Some of the above methodologies are specifically discussed in the DRR, while the less commonly used modeling approaches are not.

ERM conducted the modeling analysis for San Miguel to estimate maximum ambient 1-hour SO_2 concentrations for comparison with the NAAQS following the proposed approach described in the SO_2 Modeling TAD. ERM's assessments were conducted in a manner consistent with United States Environmental Protection Agency (EPA) and Texas Commission on Environmental Quality (TCEQ) air quality regulations and modeling guidelines, including the following EPA documents:

- *Guideline on Air Quality Models* – 40 CFR Part 51, Appendix W, Revised November 9, 2005.
- AERMOD Implementation Guide, Revised March 19, 2009;
- "SO_2 NAAQS Designations Modeling Technical Assistance Document (Draft)," December 2013;
- "SO_2 NAAQS Designations Monitoring Technical Assistance Document (Draft)," December 2013; and
- "Data Requirements Rule for the 1-Hour Sulfur Dioxide (SO_2) Primary National Ambient Air Quality Standard (NAAQS)," Pre-publication Final rule, August 11, 2015).

As well as:

- "Air Quality Modeling Guidelines, APDG 6232", TCEQ, April, 2015.

The steps that were undertaken by ERM to conduct the air dispersion modeling analyses are summarized below:

- Compiled information on the parameters and characteristics for the main boiler stack emissions at San Miguel;
- Developed a comprehensive receptor grid to capture the maximum off-site impacts from San Miguel sources using AERMAP (v.11103);
- Reviewed regional ambient background monitors to determine the most appropriate ambient background concentration data for SO_2 to represent sources not explicitly included in the modeling runs;
- Developed 3 years (2012-2014) of meteorological data using surface observations from South Texas Regional Airport in Hondo, TX with upper air data from Corpus Christi International Airport in Corpus Christi, TX using the most recent version (v.15181) of AERMET, the meteorological data processor for AERMOD, and its two preprocessors: AERSURFACE (v.13016) and AERMINUTE (v.14237);
- Reviewed all major sources of SO_2 within 50 kilometers of San Miguel for possible inclusion in the cumulative modeling analysis using the 2011 National Emission Inventory Database[3], based on guidance included in the SO_2 Modeling TAD.
- Conducted an air dispersion modeling analysis using the most recent version of EPA's regulatory dispersion model, AERMOD (v.15181) and 3 years (2012-2014) of actual emissions data from San Miguel, consistent with the methodology described in the SO_2 Data Requirements Rule and SO_2 Modeling TAD.
- Summarized the results and compared them with the 1-hour SO2 NAAQS to determine a recommended attainment designation for the vicinity of San Miguel.

3.1 *MODEL SELECTION AND APPLICATION*

The latest version of USEPA's AERMOD model (v.15181) was used for predicting ambient impacts for 1-hour SO_2. Regulatory default options were used in the analysis. Model predicted impacts were combined with an ambient background concentration and compared to the 1-hour SO_2 NAAQS to determine the recommended attainment status of the area in the vicinity of the facility.

3.2 *THE 1-HOUR SO_2 NAAQS*

This study focuses on the maximum model-predicted 1-hour SO_2 impacts associated with emissions from San Miguel and compares them to the 1-hour SO_2 NAAQS. The new standard came into effect in August, 2010. The form of the

[3] http://www.epa.gov/ttnchie1/net/2011inventory.html

standard is the 99th percentile of the 3-year average 1-hour daily maximum concentration, and the standard was set to 75 ppb (196.5 μg/m^3).

3.3 *METEOROLOGICAL DATA*

Guidance for regulatory air quality modeling recommends the use of one year of on-site meteorological data or five years of representative off-site meteorological data. The SO_2 Modeling TAD however, specifies that three years of meteorological data concurrent to the actual emissions data being input into the model be used. Since on-site data are not available for the San Miguel site, meteorological data available from the National Weather Service (NWS) were used in this analysis.

Three years (2012-2014) of surface observations from the NWS tower at South Texas Regional Airport in Hondo, TX (WBAN No. 12962) and concurrent upper air data from Corpus Christi, TX (WBAN No. 12924) were processed with AERMET (v.15181), the meteorological preprocessor for AERMOD, along with the two pre-processors to AERMET: AERSURFACE (v.13016) and AERMINUTE (v.14237). AERMET was applied to create the two meteorological data files required for input to AERMOD.

AERMET requires specification of site characteristics including surface roughness (z_o), albedo (r), and Bowen ratio (B_o). These parameters were developed according to the guidance provided by TCEQ using AERSURFACE. The area within 1 km of the facility was analyzed to determine the surface characteristics around the main stack. AERMET uses the surface characteristics in the sector from which the wind approaches the stack as part of the meteorological data processing for each hour.

In AERSURFACE, the various land cover categories are linked to a set of seasonal surface characteristics. As such, AERSURFACE requires specification of the seasonal category for each month of the year. The following five seasonal categories are offered by AERSURFACE:

1. Midsummer with lush vegetation;
2. Autumn with unharvested cropland;
3. Late autumn after frost and harvest, or winter with no snow;
4. Winter with continuous snow on ground; and
5. Transitional spring with partial green coverage or short annuals.

The AERSURFACE run was performed using the annual temporal resolution option. The seasonal default values were broken down as follows:

- January, December, February: Winter with no snow.
- March, April, May: Transitional spring.
- June, July, August: Midsummer

- September, October, November: Autumn

The precipitation was assigned to "Average" for the purpose of Bowen Ratio calculations during each month.

Additionally, 1-minute ASOS wind data, collected at the South Texas Regional Airport meteorological tower, were processed using the AERMINUTE pre-processor for AERMET. The data characteristics of South Texas Regional Airport are shown in Table 3-1. Figure 3-1 shows the relative location of South Texas Regional Airport and San Miguel, and Figure 3-2 shows the 3-year wind rose for South Texas Regional Airport.

TABLE 3-1: Characteristics of the South Texas Regional Airport Meteorological Data

Distance from San Miguel Station	61.8 miles
Average Wind Speed	4.14 m/s
Percent Calm Hours	1.72%
Data Completeness	98.75%

All files associated with the meteorological data processing are included in Appendix A: The Electronic Modeling Archive.

FIGURE 3-1: Relative Location of San Miguel and South Texas Regional Airport

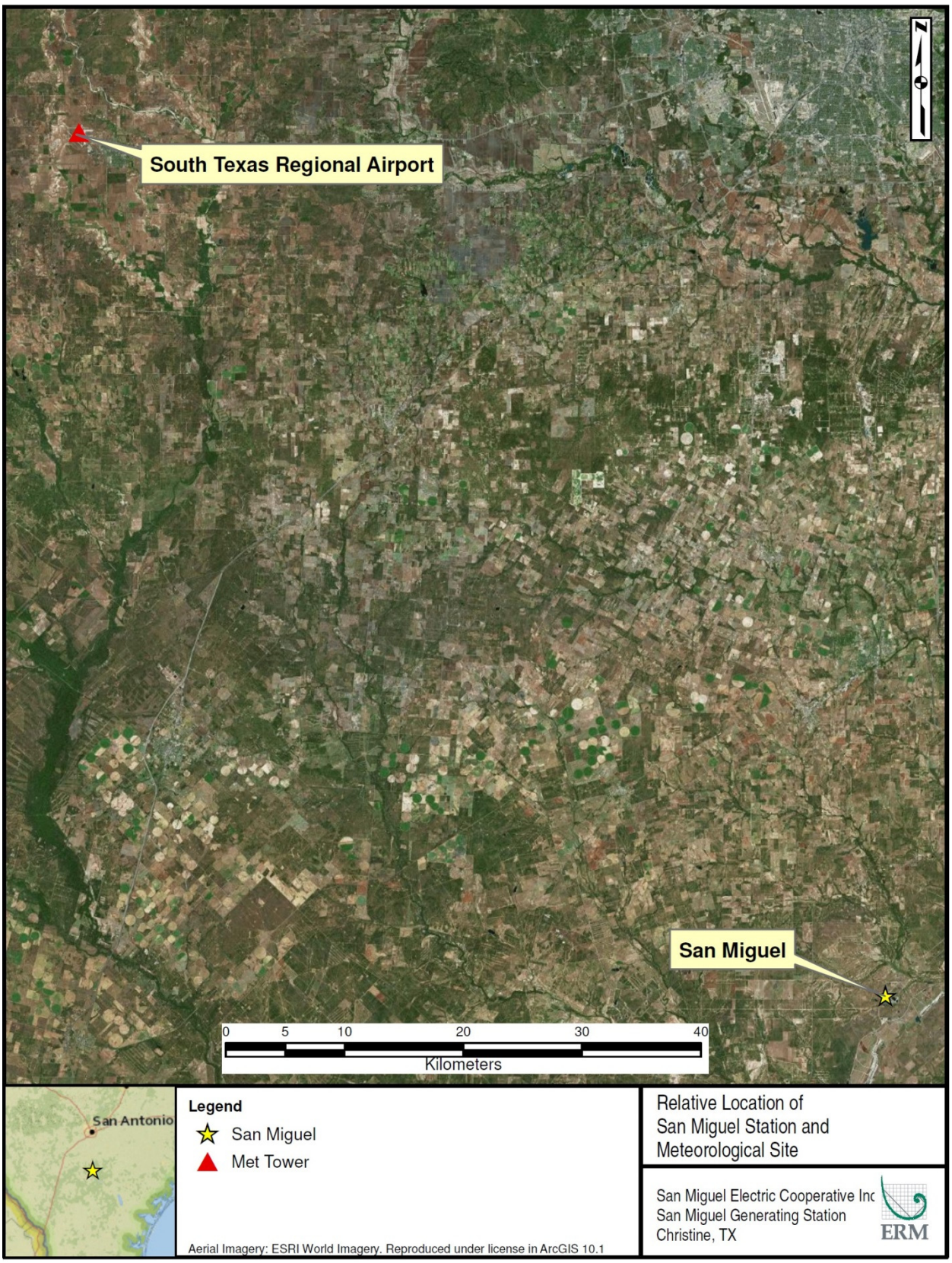
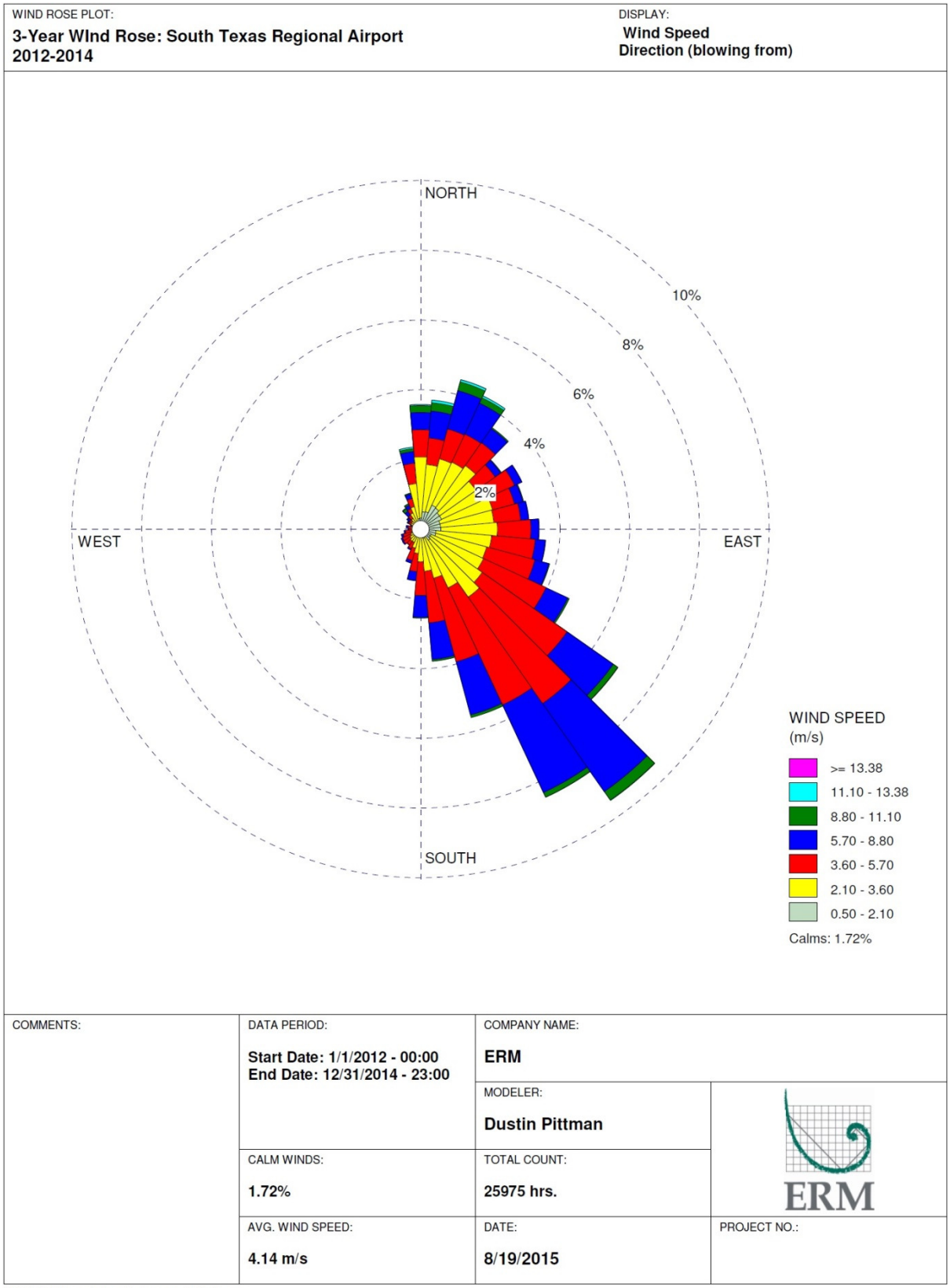


FIGURE 3-2: Three-year Wind Rose (2012-2014): South Texas Regional Airport



3.4 *RECEPTOR GRID*

A comprehensive Cartesian receptor grid extending out to approximately 50 kilometers (km) from San Miguel was used in the AERMOD modeling analysis to assess maximum ground-level 1-hour SO_2 concentrations. The SO_2 Modeling TAD states that the receptor grid must be sufficient to determine ambient air quality in the vicinity of the source being studied. The 50-kilometer receptor grid is more than sufficient to resolve the maximum 1-hour SO_2 impacts, and it clearly illustrates decreasing SO_2 concentration gradients in relation to the plant in all directions out to the edge of the grid.

The Cartesian receptor grid consisted of the following receptor spacing:

- 25-meter spacing along the facility fence line;
- 25-meter spacing extending from the fence line to 300 meters;
- 100-meter spacing extending from 300 meters to 1 kilometers;
- 500-meter spacing extending from 1 to 5 kilometers; and
- 1,000-meter spacing extending from 5 to 50 kilometers.

The above receptor data was used without modification in the modeling. Per the SO_2 Modeling TAD, a number of receptors located over the Choke Canyon Reservoir could have been excluded from the modeling domain because ambient monitors could not reasonably be placed at these locations, but these receptors were retained in this analysis as a measure of conservatism.

Terrain elevations from National Elevation Data ("NED") from USGS were processed using the most recent version of AERMAP (v.11103) to develop the receptor terrain elevations required by AERMOD. NED data files contain profiles of terrain elevations, which in conjunction with receptor locations are used to generate receptor height scales. The height scale is the terrain elevation in the vicinity of a receptor that has the greatest influence on dispersion at that location and is used for model computations in complex terrain areas. The near-field (within 5 kilometers) and far-field (full 50 km grid) receptor grids are shown in Figures 3-3 and 3-4, respectively.

3.5 GOOD ENGINEERING PRACTICE STACK HEIGHT ANALYSIS

Good engineering practice ("GEP") stack height is defined as the stack height necessary to ensure that emissions from the stack do not result in excessive concentrations of any air pollutant as a result of atmospheric downwash, wakes, or eddy effects created by the source, nearby structures, or terrain features.

A GEP stack height analysis was performed for the Boiler Stack using the Building Profile Input Program (BPIP) in accordance with USEPA's guidelines (USEPA 1985). Per the guidelines, the physical GEP height, (H_{GEP}), is determined from the dimensions of all buildings which are within the region of influence using the following equations, depending on the construction data of the stack:

For stacks in existence on January 12, 1979 and for which the owner or operator had obtained all applicable permits or approvals required,

$H_{GEP} = 2.5H$,

provided the owner or operator produces evidence that this equation was actually relied on in establishing an emission limitation;

For all other stacks:

$$HGEP = H + 1.5L$$

where:

H = height of the structure within 5L of the stack which maximizes H_{GEP}; and

L = lesser dimension (height or projected width) of the structure.

For a squat structure, i.e., height less than projected width, the formula reduces to:

$$H_{GEP} = 2.5H$$

In the absence of influencing structures, a "default" GEP stack height is creditable up to 65 meters (213 feet).

A summary of the GEP stack height analyses is presented in Table 3-2. As described in the SO_2 Modeling TAD, when modeling actual emissions in order to determine the attainment status of the facility when compared to the 1-hour SO_2 NAAQS, the full height of all stacks is allowed in the modeling regardless of their GEP Formula Heights. Since the San Miguel stack does not exceed GEP, the SO_2 Modeling TAD guidance did not alter the allowable modeled height of the stack; the stack was modeled with its actual stack height in the analysis. The heights and locations of all structures included in the GEP analysis, as well as the main stack, are shown in Figure 3-5.

FIGURE 3-3: Near-Field Model Receptors

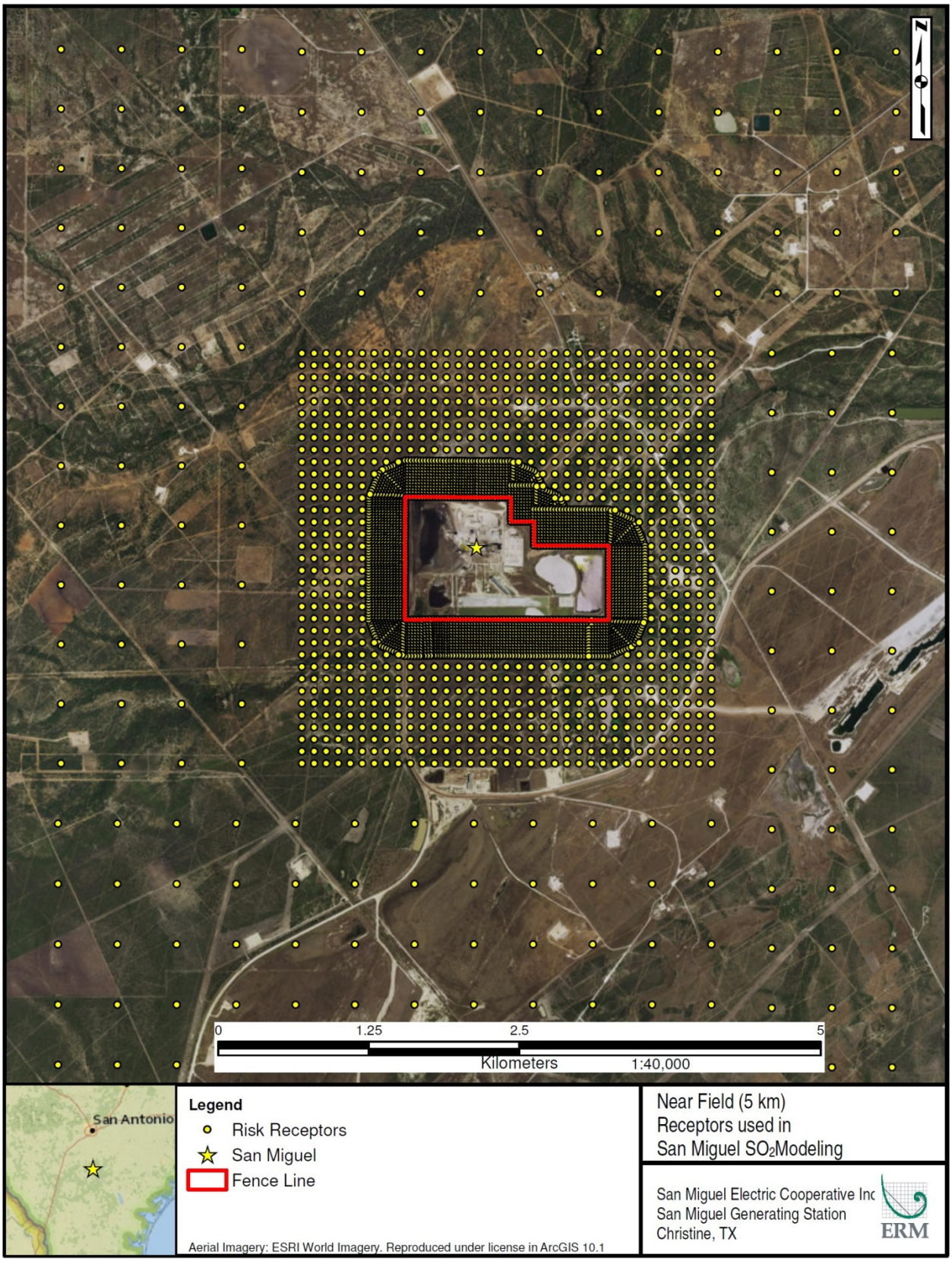


FIGURE 3-4: Far-Field Model Receptors

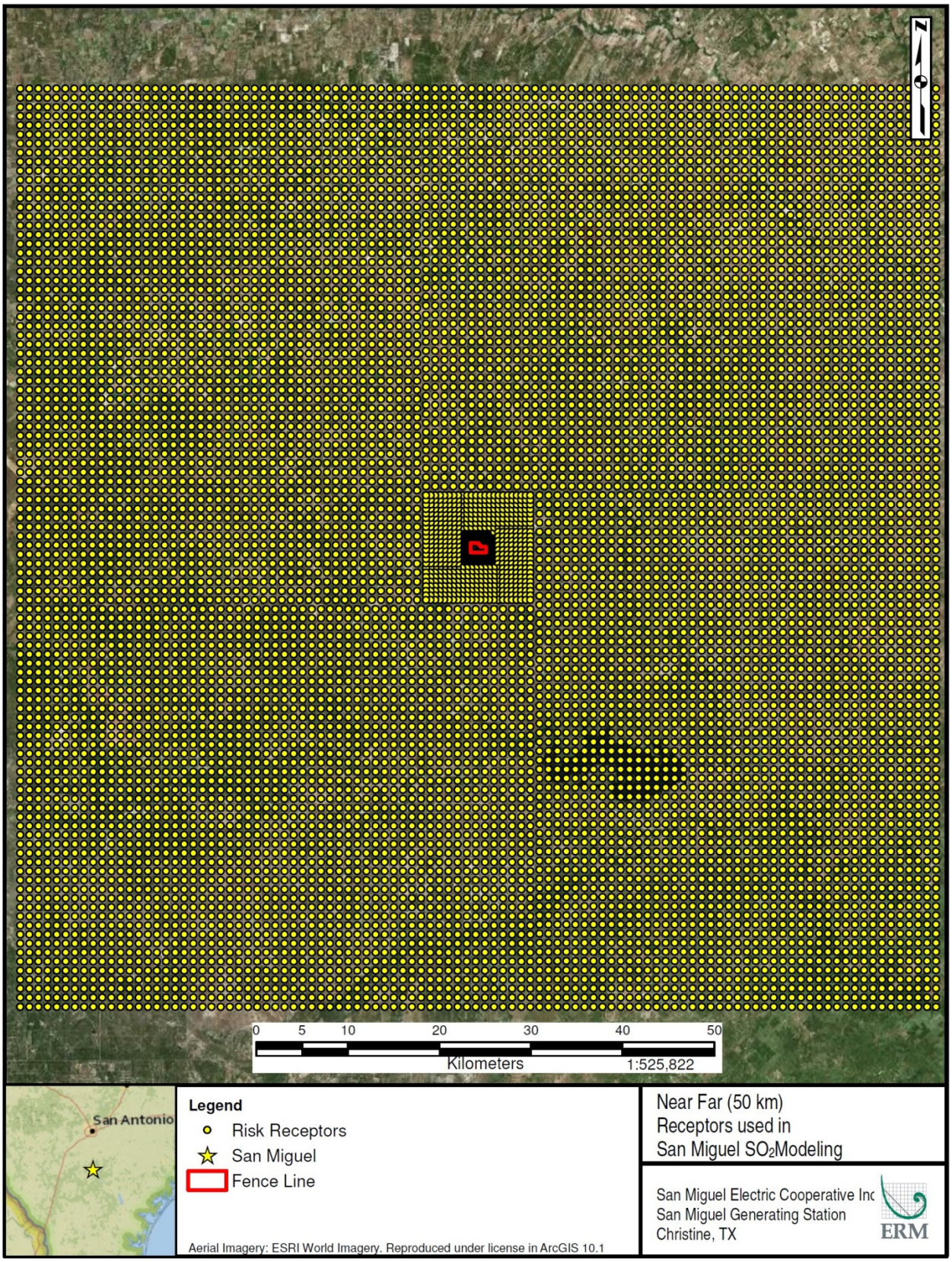


FIGURE 3-5: Structures Included in the San Miguel GEP Analysis

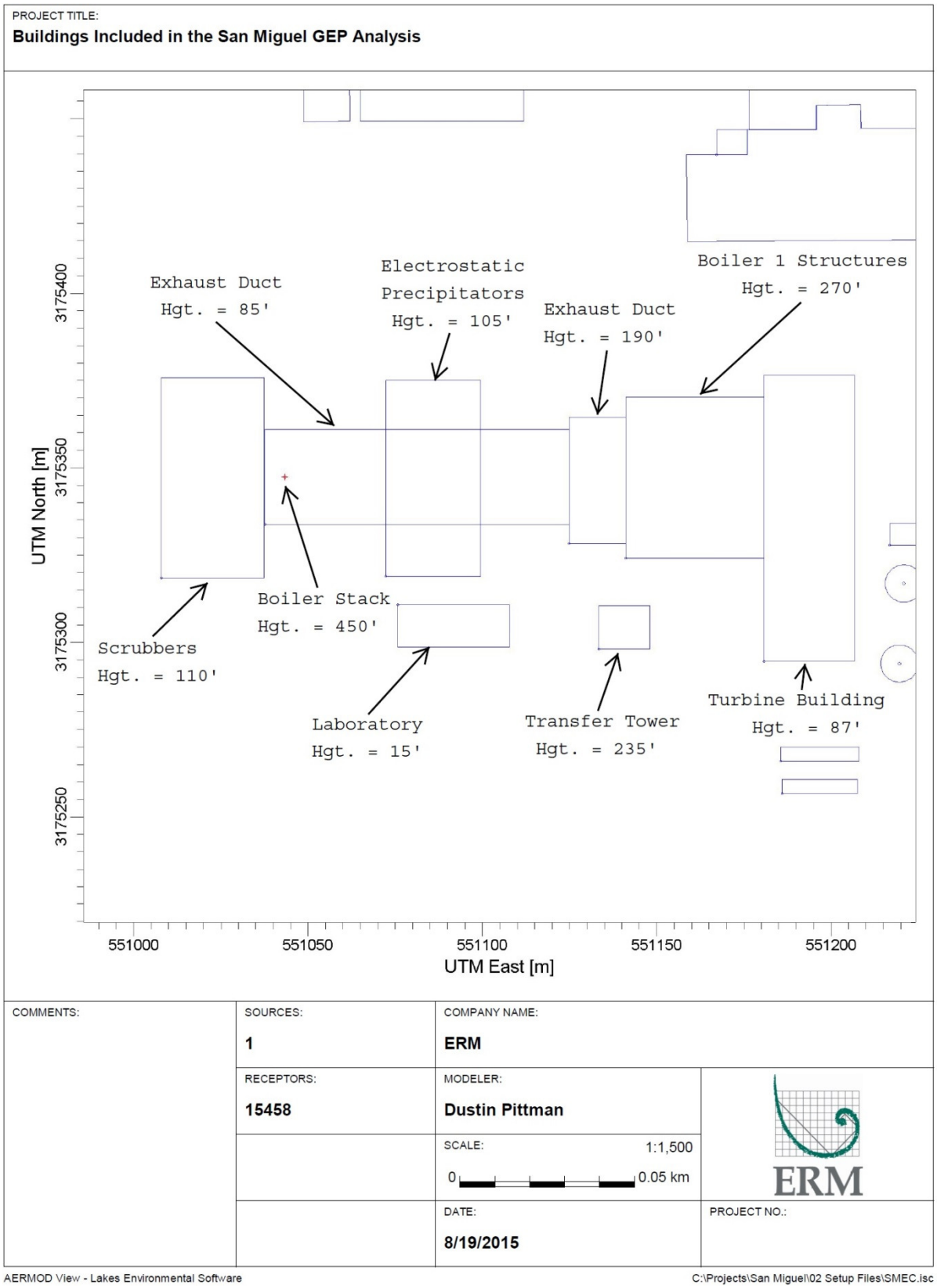


TABLE 3-2: Summary of San Miguel Station GEP Analysis

Emission Source	Stack Height (m)	Controlling Buildings / Structures	Building Height (m)	Projected Width (m)	GEP Formula Height (m)
STACK	137.16	Boiler 1 Structures	82.30	46.08	151.42

3.6 AMBIENT SO_2 BACKGROUND DATA FOR CUMULATIVE MODELING

In addition to assessing impacts from the San Miguel stack, the impact from other sources of SO_2 in the region was considered in order to demonstrate that the air quality in the region is in attainment with the NAAQS. In order to account for other sources of SO_2 in the area an ambient background concentration was added to model-predicted impacts from San Miguel for comparison to
the NAAQS.

The criteria for determining the monitor best suited to characterize air quality at a given location include:

- Stations with similar influencing SO_2 sources as the source being modeled (not necessarily the closest).
- Avoid stations influenced by the source being modeled to prevent double-counting impacts.
- Avoid stations influenced by sources not likely to interact with the source being modeled.
- Consider predicted concentration patterns for source being modeled, along with wind frequency, to assist in selection.

FIGURE shows the location of the ambient monitors in the vicinity of San Miguel, as well as the location of all other SO_2 sources in the region that emitted more than 2,000 tons of SO_2 according to the 2011 EPA National Emissions Inventory. The figure shows that there are no sources that emitted over 2,000 tons of SO_2 in 2011 within 50 km. of San Miguel. Additionally, all of the monitors sited in the region are located to the north of San Miguel, approaching the San Antonio area, or farther to the north of San Antonio, approaching the Waco area.

ERM evaluated 3 monitors to determine their representativeness: Calaveras Lake (Monitor ID# 48-029-0059) to the north of San Miguel, Heritage Middle School (Monitor ID# 48-029-0622), located north of San Miguel, and Waco (Monitor ID# 48-309-1037), located northeast of San Miguel.

The first monitor evaluated was the Calaveras Lake (CAMS 59) monitor. This monitor is the closest to San Miguel in terms of proximity, located 65.4 km to the

north northeast. A review of the most recent (2012-2014) years of hourly concentrations at the monitor vs. the wind direction at the time the concentration was reported, shown in Figure 3-6, shows that virtually all of the highest concentrations at the monitor occur when the wind is blowing from the direction of the Calaveras Power Plant (CPS Plant) towards the monitor.

The Calaveras Lake monitor is strongly influenced by impacts north of the monitor, specifically CPS Plant, which is the opposite direction of San Miguel to the monitor. The CPS Plant is much closer to the monitor than it is to San Miguel and therefore is having a greater impact on the monitor than any source in the vicinity of San Miguel would have. Thus, the monitor is not useful to represent non-facility related impacts in the region and would grossly overestimate San Miguel's contribution to the regional ambient air quality.

FIGURE 3-6: SO_2 Sources and Monitors in the Region

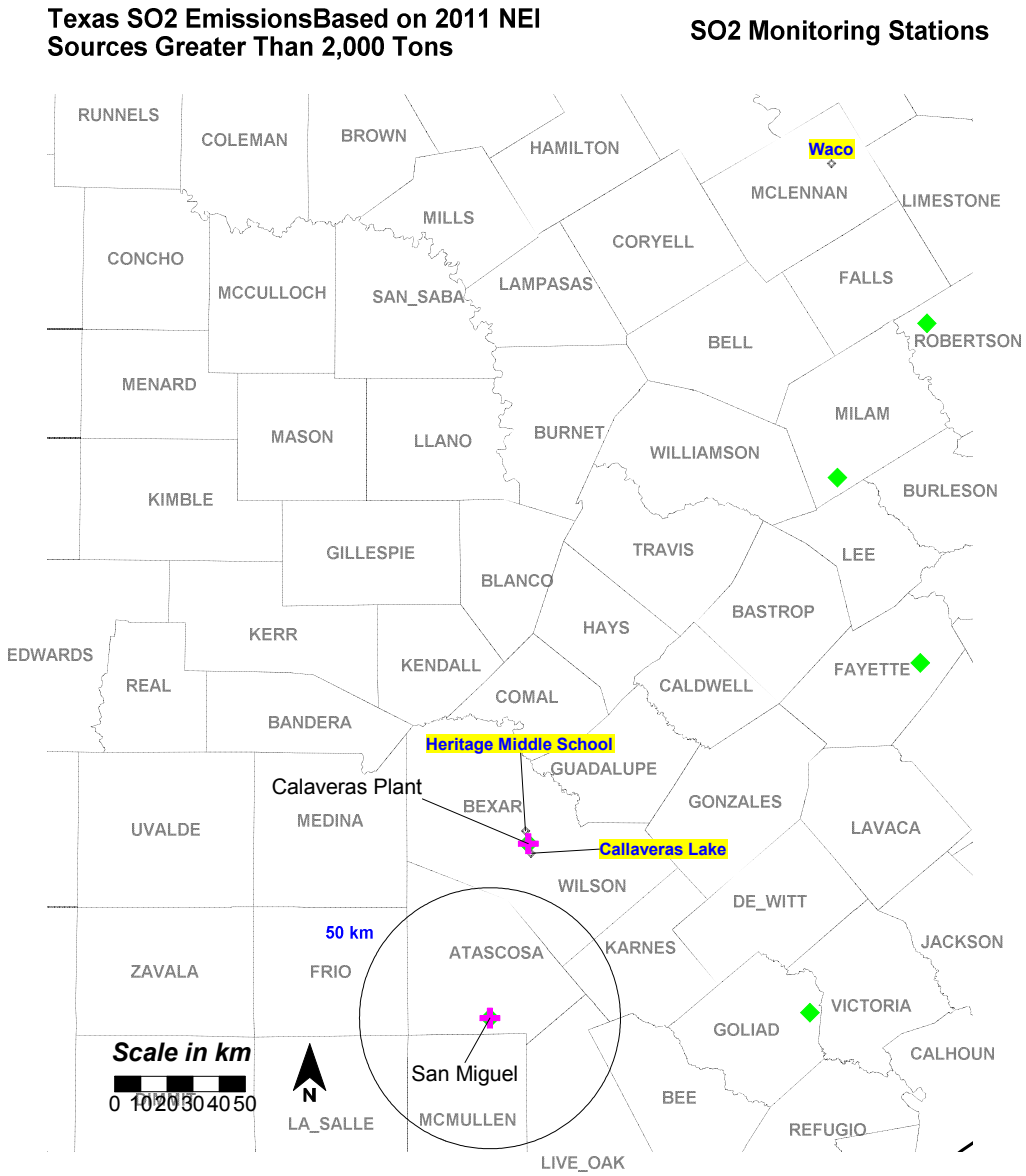
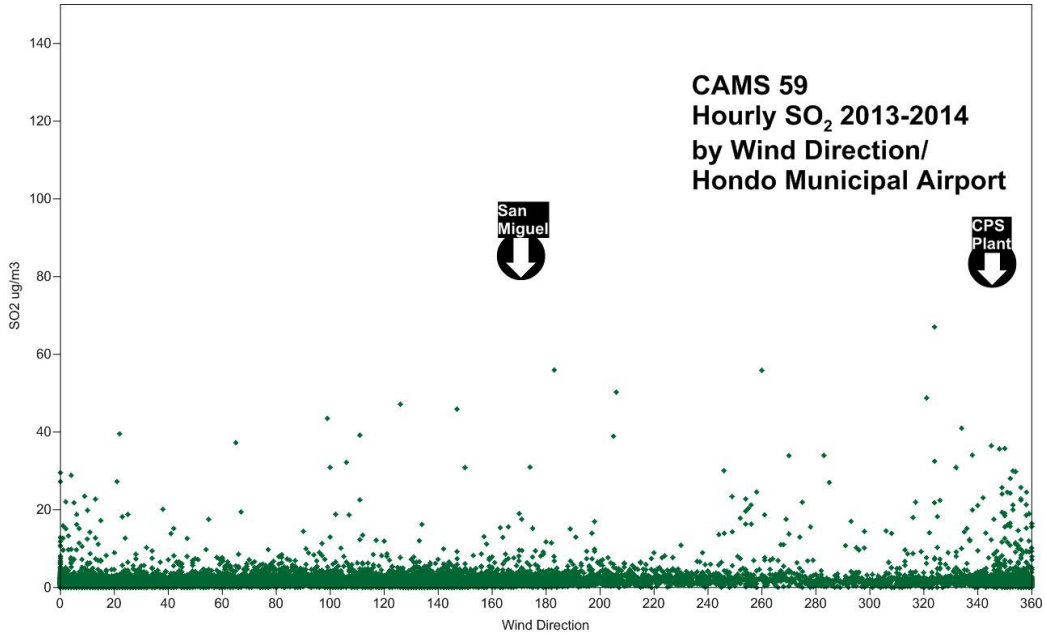


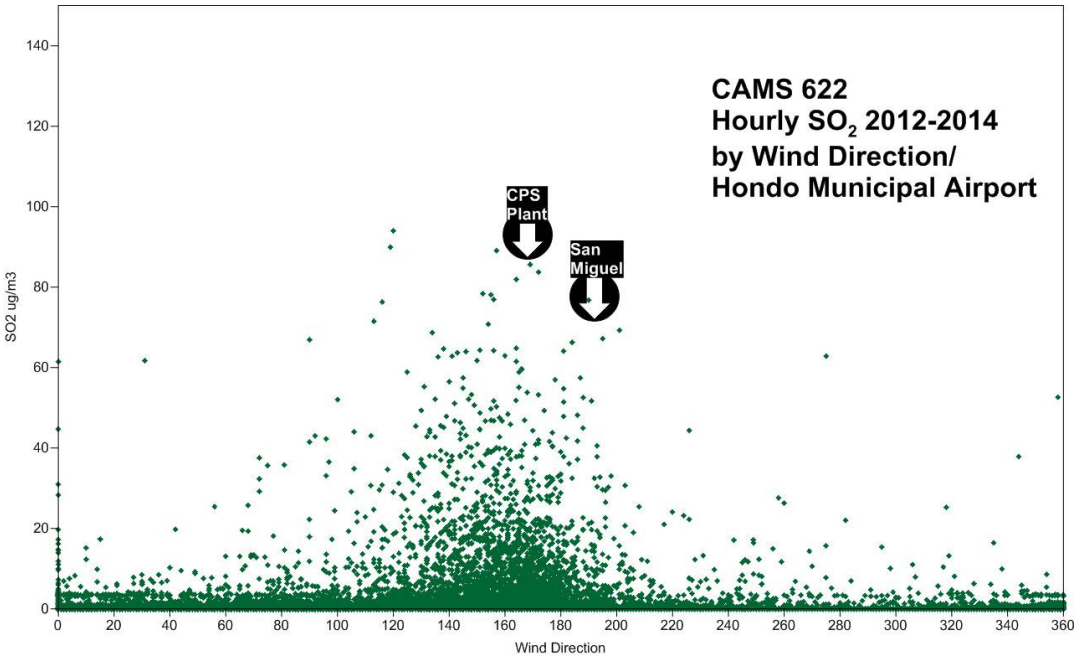
FIGURE 3-7: SO_2 Concentration vs. Wind Direction at Calaveras Lake Monitor



The second monitor evaluated was the Heritage Middle School (CAMS 622) monitor. This monitor is north northwest of the Calaveras Lake monitor and located 73.3 km to the north northeast of San Miguel. A review of the most recent (2012-2014) years of hourly concentrations at the monitor vs. the wind direction at the time the concentration was reported, presented in Figure 3-8, shows that virtually all of the highest concentrations at the monitor occur when the wind is blowing from the direction of CPS Plant towards the monitor, similar to the Calaveras Lake monitor.

The Heritage Middle School monitor is strongly influenced by impacts south of the monitor, specifically CPS Plant as shown in Figure 3-7. The CPS Plant is much closer to the monitor than it is to San Miguel and therefore CPS has a greater impact on the monitor than any source in the vicinity of San Miguel would have. Thus, the monitor is not useful to represent non-facility related (background) impacts in the region around San Miguel.

FIGURE 3-8: SO_2 Concentration vs. Wind Direction at Heritage Middle School Monitor



The final monitor reviewed was the Waco (CAMS 1037) monitor, located 354.6 km northeast of San Miguel as shown in Figure 3-8, and oriented in a downwind direction from San Miguel such that impacts from San Miguel itself are no longer noteworthy. As shown in Figure 3-9, the concentrations recorded at the monitor do not appear to be highly influenced by any large sources, as would be the case near San Miguel, and the CPS Plant slightly over 50 km from San Miguel.

FIGURE 3-9: Relative Location of San Miguel Station and Waco Monitor

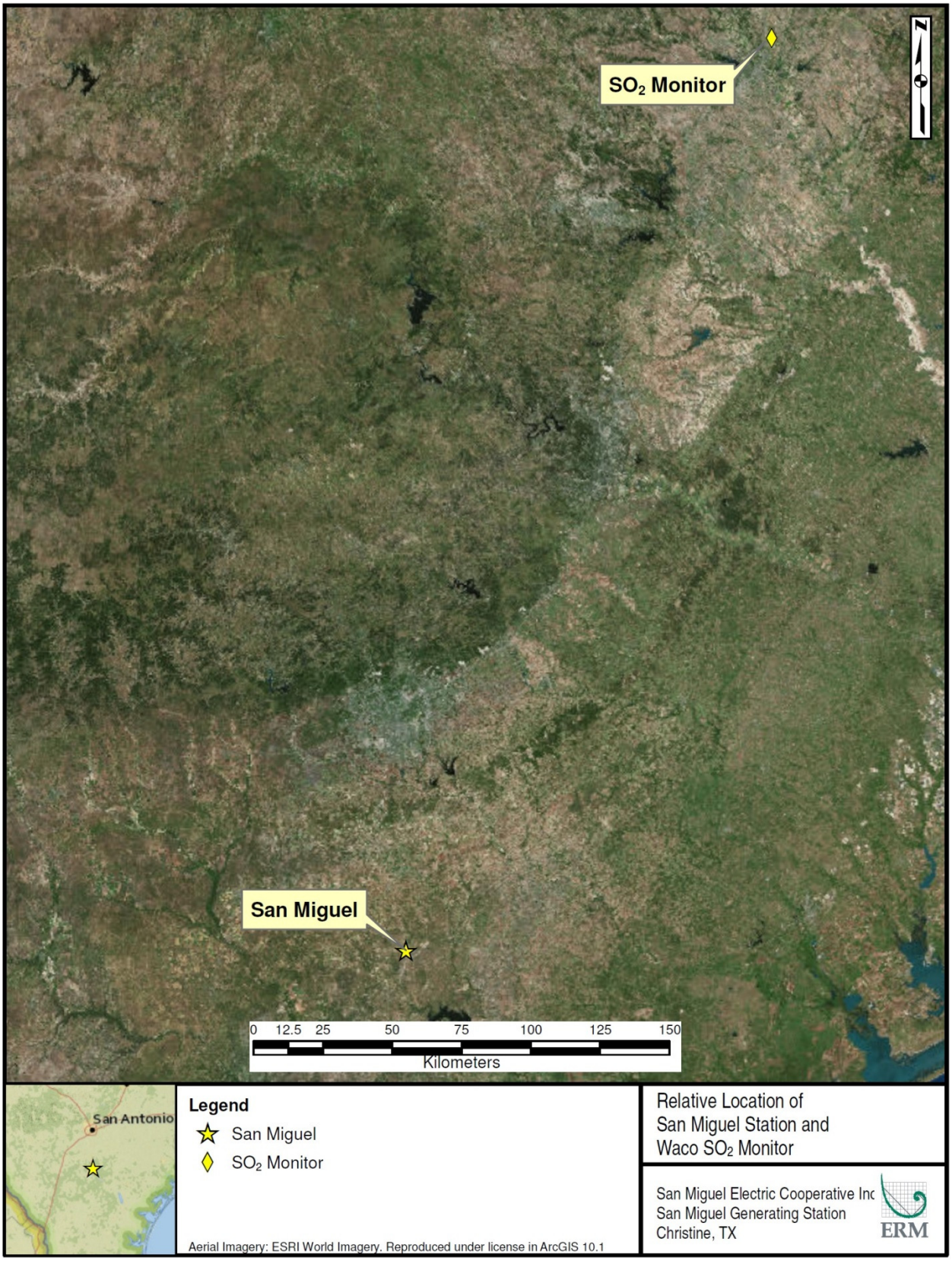
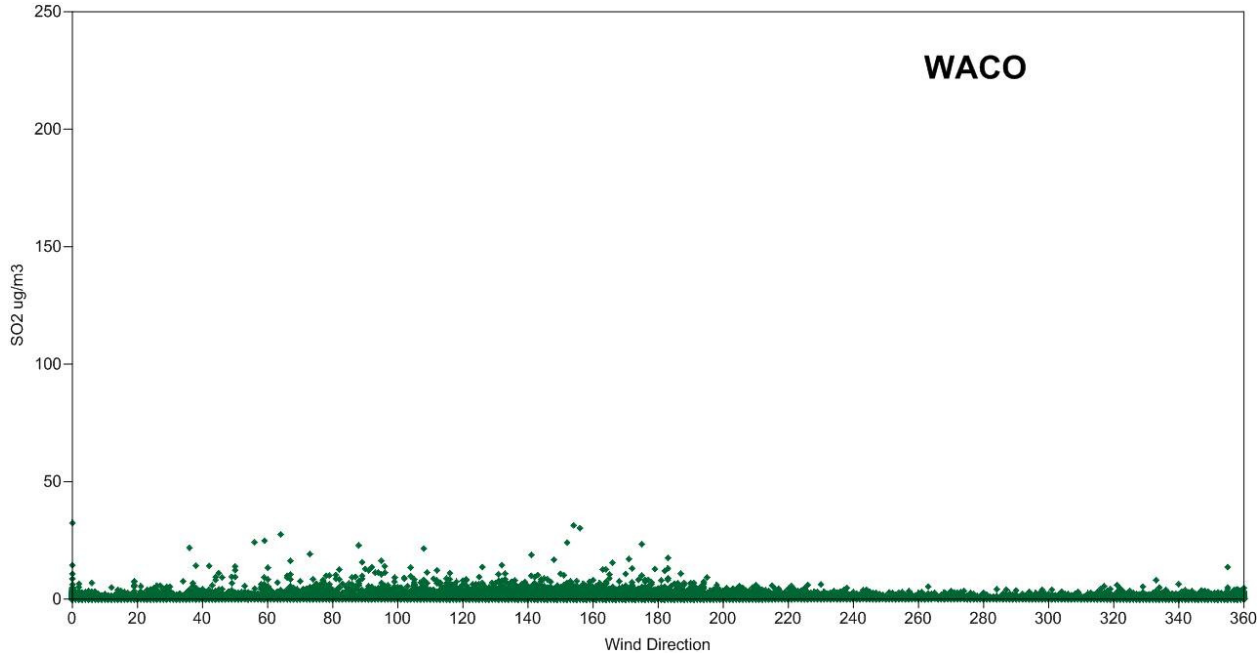


FIGURE 3-10: SO_2 Concentration vs. Wind Direction at Waco Monitor



Sources that do not meet the 2,000 tons/year level were also considered. The TAD recommends that smaller sources be reviewed to determine the total magnitude of emissions and whether the smaller sources can be considered to be accounted for by background concentrations and whether they are clustered in areas where collectively the total magnitude may reach or exceed the 2,000 ton level.

TABLE ***3-3*** provides a summary of the total SO_2 emissions within certain distance ranges of San Miguel, and a summary of the total SO_2 emissions within certain distance ranges of the monitors discussed above. Based on this analysis, the Waco monitor most closely matches the SO_2 emissions in the area around San Miguel.

TABLE 3-3: Comparison of SO_2 Emissions near San Miguel and Monitors

Site	*SO_2 tpy (NEI 2011) within:*		
	0-10 km	*10-25 km*	*25-50 km*
San Miguel	0.0	0.0	787.0
Calaveras Lake	23,269.0	9.0	1,213.0
Heritage Middle School	23,246.0	719.0	532.0
Waco Mazanec	0.0	1,020.0	387.0

Lastly, in the initial screening modeling for San Miguel the highest impacts were to the north and northwest of the plant. Thus any interaction with other sources

during these events would have to come from the south and southeast of San Miguel, and the Waco monitor is more representative than Lake Calaveras in representing ambient impacts coming from that direction. The Heritage Middle School monitor was also considered, but the monitor is heavily impacted by the CPS Plant which is greater than 50 km away from San Miguel and the pattern of SO_2 emissions is less similar to that of San Miguel than Waco. For all of the reasons described here, Waco was chosen as the monitor most representative of the ambient air quality in the area around San Miguel.

EPA guidance allows the use of background values that vary by season and hour of day. Combining background values that vary by season and hour of day with model predicted values, which also are variable, reduces the overly conservative approach of adding two maximum values together regardless of the time they occurred.

The modeling was performed with a set of seasonal diurnal values developed using the methodology described in the USEPA March 1st, 2011 Clarification Memorandum for 1-hour NO_2 Modeling. Though this memorandum primarily addresses NO_2 modeling, page 20 describes the process for developing seasonal diurnal background values for SO_2 as well. The seasonal diurnal values that were used in the modeling are shown on the next page in Table 3-4.

3.7 REVIEW OF NON-FACILITY SOURCES FOR CUMULATIVE INVENTORY

Section 4.1 of the SO_2 Modeling TAD discusses the criteria for the addition of major SO_2 sources in the region for cumulative modeling purposes when determining the recommended attainment status of the area surrounding a facility as described in the 1-hour SO_2 Data Requirements Rule. The TAD describes sources that should be included in the modeling as those expected to have an impact on the air quality in the vicinity of the source being studied, in this case San Miguel. Additionally, the TAD states that except in cases where numerous smaller sources are close together in the study area, consideration of sources to include should begin at sources with emissions in excess of the threshold selected in the Data Requirements Rule (2,000 tpy).

The 2011 EPA National Emissions Inventories (NEI) was reviewed to determine candidate major sources. For the purpose of this study, all major sources of SO_2 within 50 kilometers of San Miguel that had at least 2,000 tons of SO_2 emissions were considered for inclusion in the modeling. No facilities within 50 kilometers were found to have emitted at least 2,000 tons of SO_2 in 2011. In fact, the only source with greater than 100 tons of SO_2 within 50 km of San Miguel was Pawnee Gas Plant, located 48.6 km away in Pawnee, TX, with 480 tons. Pawnee Gas Plant was not explicitly included in the modeling for the following reasons:

- Pawnee Gas Plant had emissions far lower than that of the SO_2 Data Requirements Rule threshold.

TABLE 3-4: Seasonal Diurnal Ambient SO_2 Concentrations ($\mu g/m^3$)

Hour[1]	*Winter*	*Spring*	*Summer*	*Fall*
1	3.05	3.23	3.40	4.80
2	2.70	2.88	3.75	9.60
3	2.97	2.97	3.32	9.07
4	1.83	1.66	2.36	2.53
5	2.18	1.40	2.36	2.70
6	1.92	1.48	2.01	3.23
7	1.83	1.40	1.83	2.62
8	2.70	2.09	4.19	3.75
9	4.01	4.19	7.33	7.77
10	11.34	5.32	6.54	13.44
11	13.26	3.40	4.80	9.07
12	12.74	3.14	5.24	7.68
13	12.13	4.28	5.06	8.99
14	7.07	4.01	4.01	7.15
15	8.73	4.19	3.66	7.33
16	8.64	3.75	4.10	6.81
17	6.81	3.66	3.40	7.07
18	7.77	3.49	3.75	6.81
19	4.54	6.63	4.80	9.34
20	4.54	6.63	4.80	9.34
21	4.54	4.45	8.81	7.33
22	3.05	4.89	6.02	6.20
23	3.75	5.93	4.36	5.50
24	2.88	3.58	3.66	8.46

1. Hours in AERMOD are defined as hour-ending. i.e., Hour 1 is the period from midnight through 1 AM, etc.

- The March 1st, 2011 EPA clarification memorandum for modeling NO_2 and SO_2[4] states that "Even accounting for some terrain influences on the location and gradients of maximum 1-hour concentrations, these considerations suggest that the emphasis on determining which nearby sources to include in the modeling analysis should focus on the area within about 10 kilometers of the project location in most cases…" Pawnee Gas Plant is more than 4 times that distance from San Miguel.

[4]http://www.epa.gov/scram001/guidance/clarification/Additional_Clarifications_AppendixW_Hourly-NO2-NAAQS_FINAL_03-01-2011.pdf

- The relative locations of the facilities: Wind blowing from San Miguel to Pawnee Gas Plant is on a bearing of 100 degrees, while wind blowing from Pawnee Gas Plant to San Miguel would be on a bearing of 281 degrees. A review of the 3 years of wind data (2012-2014) used in the modeling shows that the wind blows between the two facilities only about 4 percent of the time, and of that 4 percent none of the hours during the 3 years of data had sufficient wind speed (13.4 m/s) to carry a plume from one facility to the other in one hour.
- The concentration gradient from San Miguel impacts drops sharply to the east of the facility (See Figure 4-1), such that the impacts from San Miguel would not be expected to interact with those from Pawnee Gas Plant.
- The Waco ambient monitor was shown to be conservative in Section 3.6

Therefore, no other facilities were explicitly included in the modeling, but instead the appropriate seasonal diurnal ambient concentration from the Waco monitor was added to the impacts from San Miguel to represent other sources in the area.

4.1 MODELING RESULTS

4.2 MODELING RESULTS FOR ACTUAL EMISSIONS

The design value represents the modeled 3-year average of the 99th percentile, maximum daily 1-hour average impact. Design values for both San Miguel alone and for San Miguel combined with monitored background values are presented in Table 4-1.

TABLE 4-1: 1-hour SO2 Modeling Results for San Miguel with Actual Emissions

Source	*San Miguel Only*	*San Miguel and Background*	*1-hr. SO_2 NAAQS*	*Below NAAQS?*
San Miguel	110.3	122.2	196.5	Yes

Contours of the predicted impacts, as well as the location of the maximum predicted impact of 122.6 µg/m^3, are shown in Figure 4-1. The table shows that model predicted impacts from San Miguel, when modeled using the most recent three years of actual emissions data and added to representative ambient background concentrations, are below the level of the 1-hour SO_2 NAAQS.

4.3 MODELING RESULTS FOR MSS EMISSIONS

The modeling results when the MSS emission rate is assumed throughout the modeling period are shown in Table 4-3 below. The design value represents the modeled 3-year average of the 99th percentile, maximum daily 1-hour average impact. Design values for both San Miguel alone and for San Miguel combined with monitored background values are presented in Table 4-2.

TABLE 4-2: 1-hour SO2 Modeling Results for San Miguel with MSS Emissions

Source	*San Miguel Only*	*San Miguel and Background*	*1-hr. SO_2 NAAQS*	*Below NAAQS?*
San Miguel	168.8	174.5	196.5	Yes

Contours of the predicted impacts, as well as the location of the maximum predicted impact of 174.0 µg/m^3, are shown in Figure 4-2. The table shows that model predicted impacts from San Miguel, when modeled using the most recent three years of MSS emissions data and added to representative ambient background concentrations, are below the level of the 1-hour SO_2 NAAQS.

4.4 CONCLUSIONS

The air dispersion modeling performed as described in this report shows that the SO_2 emissions from **San Miguel's Electric Generating Unit when combined with representative background concentrations result in maximum predicted impacts within the 1-hour SO_2 National Ambient Air Quality Standard.** Therefore, an attainment designation for Atascosa County and the surrounding area is recommended.

FIGURE 4-1: San Miguel Station Actual Emissions 1-hour SO_2 Impact Contours

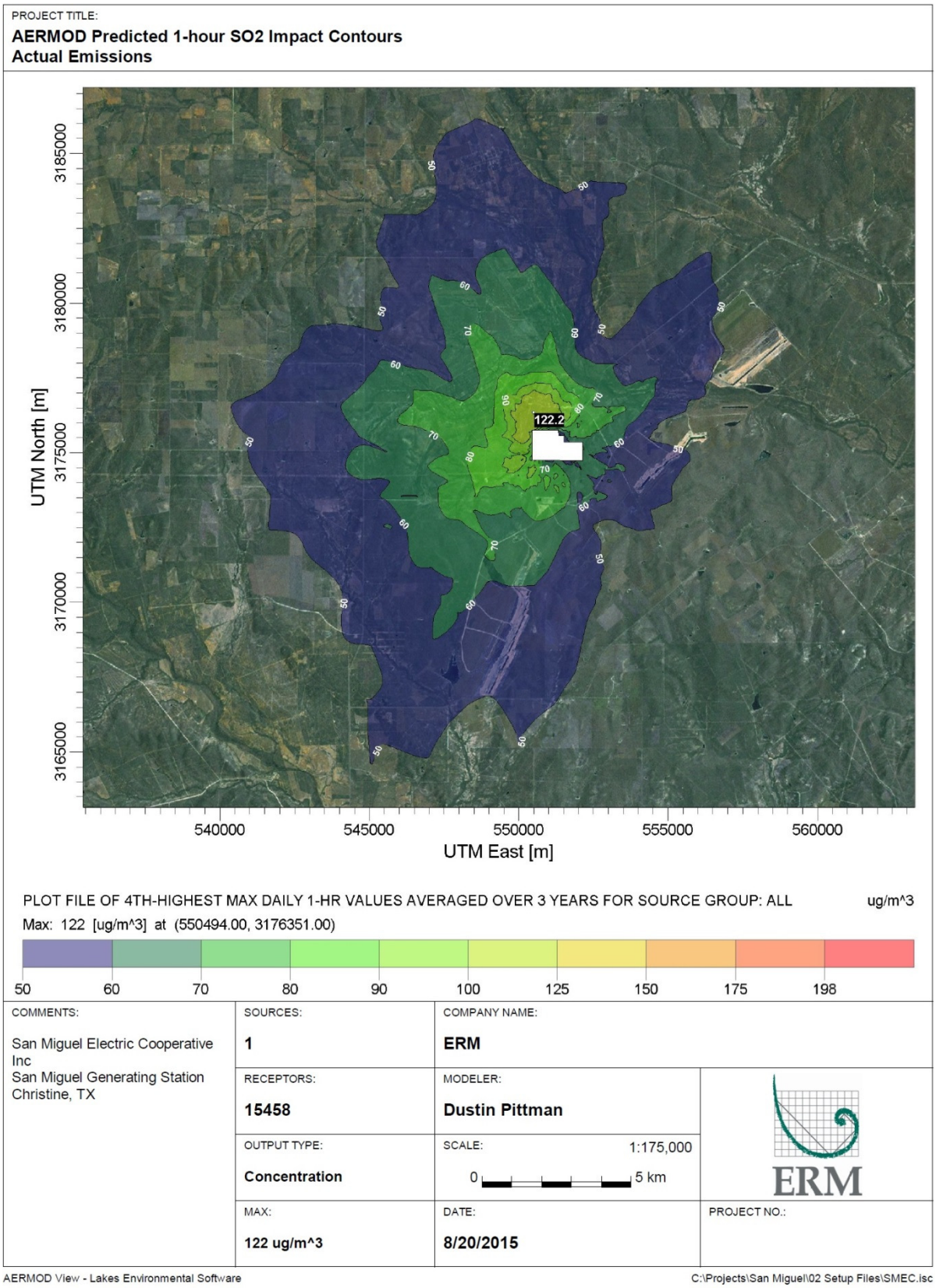
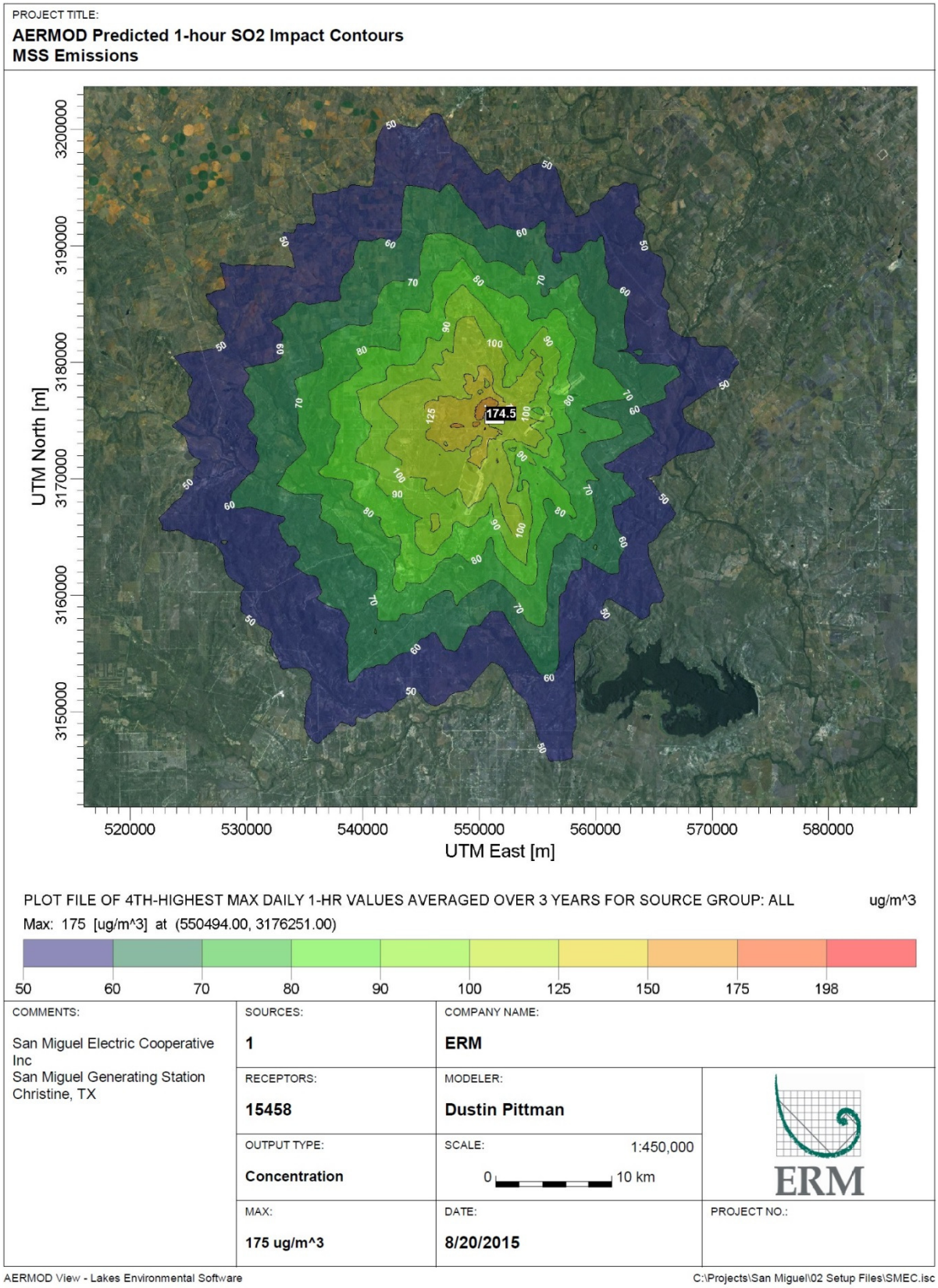


FIGURE 4-2: San Miguel Station MSS Emissions 1-hour SO_2 Impact Contours



5.0 REFERENCES

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Electronic Modeling Archive

Appendix A