

ENVIRONMENT

Title: Air Emissions Monitoring Protocol, NPB Project #04-126

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Abstract:

A research project was conducted from May 2004 through mid-September 2005 to investigate the concentration of hydrogen sulfide (H_2S) at the perimeter of nine swine operations across the state of Iowa, and, to investigate the ammonia (NH_3) and H_2S concentrations near and inside residences located in the community of swine operations and in one area of the state not associated with animal agriculture. The nine sources monitored ranged from sites that housed 1,200 to 4,800 finishing animals. The results indicated that at the perimeter of all nine sources monitored, the overall average H_2S concentration ranged from a low of 1.9 ± 2.7 ppb to a high of 26.3 ± 32.3 ppb. If a sampler was determined to be in the downwind plume, or the meteorological conditions were calm, the average measured results ranged from a low of 7.4 ± 6.9 ppb to a high of 45.8 ± 31.8 ppb. In both cases, the maximum H_2S concentration was recorded at a finishing site where an earthen basin and a concrete formed below-grade basin existed in close proximity to the livestock housing. As a frame of reference, the State of Iowa is currently considering a Health Effects Value (HEV) for H_2S of 30 ppb *at a residence located at or beyond the regulated separation distance*, not to be exceeded more than seven 1-hour averages per year (the Health Effects Standard, HES).

Measurements of H_2S and NH_3 were also collected at five residences, four of which were located near four of the sites monitored for perimeter H_2S levels, with one located in an urban setting far removed from animal agriculture. The results, based on the daily averages, indicate that the overall average NH_3 concentration measured inside the homes ranged from a low of 28.6 ± 12.8 ppb to a high of 94.7 ± 28.1 ppb. The overall average NH_3 concentration measured in the ambient air outside the homes ranged from a low of 11.7 ± 5.3 ppb to a high of 55.1 ± 20.6 ppb. The NH_3 concentration inside the homes were significantly higher than in the ambient air outside of the homes ($p < 0.01$). H_2S concentration inside the homes ranged from a low of 0.7 ± 0.2 ppb to a high of 2.5 ± 1.5 ppb. H_2S concentration in the ambient air outside the home ranged from a low of 0.4 ± 0.2 ppb to a high of 2.4 ± 2.4 ppb. The highest ambient air average for H_2S (2.4 ± 2.4 ppb) and NH_3 (55.1 ± 20.6 ppb) was recorded for a residence located 251 ft to the east of a 4,800-hd deep-pit finishing site and served as the home for the tenants of the farm. For the residence monitored in an urban setting far removed from animal agriculture, the overall average H_2S concentration outside the home was 0.4 ± 0.2 ppb with the inside home averaging 0.7 ± 0.2 ppb. The highest average inside home concentration for NH_3 and H_2S was

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94.7±28.1 ppb and 2.5±1.5 ppb, respectively, both from a residence where the occupants smoked and in which cats were kept inside. The next highest inside home NH₃ concentration was 85.7±15.3 ppb. For this residence the occupants did not smoke but cats were kept inside. The two inside home NH₃ levels specified above are

close to the currently recommended Minimum Risk Level (MRL) for NH₃, established by the Agency for Toxic Substances and Disease Registry (ATSDR), where a chronic MRL of 100 ppb for NH₃ has been established. If the levels recorded for the two residences specified above would persist for 365 days or more, the ATSDR guidelines for the protection of sensitive populations would be very close to exceeding the ATSDR MRL for ammonia. The results from the residence ambient air monitoring indicate that the concentration and duration for either NH₃ or H₂S fall well below the MRLs as defined by the ATSDR. This was true even for the residence located 251 feet from the nearest swine source.

III. Introduction:

The state of Iowa is currently considering the adoption of an ambient air Health Effects Standard (HES) for hydrogen sulfide of 30 parts-per-billion (ppb) not to be exceeded more than 7 one-hour averages per year. This HES is intended to be enforced at a neighboring residence at or beyond the state mandated separation distance at the time of a facilities construction. It is important to know the concentration of H₂S near various styles of swine operations to gain a better understanding of the expected concentrations, and, ultimately the potential impact at neighboring residences. In addition, it is extremely important to understand the resulting concentration and duration present at neighboring residences to quantify the health impact potential related to living near swine operations. Further, what happens inside the home is of interest as well. That is, if a gas is present in the air surrounding a home, is it a foregone conclusion that this gas will be present in the home, or, is the home's air quality predominately a function of home activity and therefore lacks a link between the ambient air and the true indoor air quality that residences are exposed to? This final question is extremely important as the issues surrounding animal agriculture and human health continue to surface.

IV. Objectives:

The objectives of this research project were to:

1. Collect and analyze the necessary data to further understand H₂S concentrations near swine operations and at a neighboring residence.
2. Identify potential causes of higher emissions and develop strategies to address those causes.
3. Conduct simultaneous air quality measurements inside the home of a neighboring residence to determine the effect, if any, that swine operations have on indoor air quality.

Terminology

Several terms are used interchangeably throughout this report. An explanation is given here to avoid confusion.

Receptor. Receptor in this report refers to the residence being monitored. Therefore receptor and residence will be used interchangeably throughout.

Ambient. Ambient refers to any air outside of an enclosed space. Therefore, the term ambient refers to any sample taken outside of a residence or source. If a comment is made regarding the concentration outside the home, the meaning is ambient air.

H₂S. The chemical symbol for hydrogen sulfide. This term is used without explanation throughout.

NH₃. The chemical symbol for ammonia. This term is used without explanation throughout.

MAL. Refers to our Mobile Ambient Laboratory used to house monitoring equipment at the residence.

V. Materials & Methods:

Our procedures for this research project were as follows. Two swine finishing operations at various locations across the state were identified by the National Pork Board (NPB) for evaluation. The desired criteria for selection was that one of the operations had to use deep-pit manure storage and the other companion site had to use some form of outside manure storage. The intention was to select a pair of sites, located within approximately five miles of each other, to be monitored at the same time of the year. For all sites monitored, eight Single Point Monitors (SPM; Zellweger, Inc) were placed at the four compass points in pairs (N,S,E,W), located at the perimeter of the site. For some of the sites the corner-compass locations were used instead (NE,SE,SW,NW). SPM placement decisions were based on the relation between the source and a near-by residence identified by the NPB for monitoring. In most cases the distance from any SPM monitoring location was within 50 ft of the building or manure storage facility. In addition, a weather tower was installed at each site, monitoring temperature, relative humidity, solar insolation, wind speed, wind direction, rain, and barometric pressure. A typical collocated SPM set-up at a source is shown in Figure 1. Two independent SPM monitors were placed in a protective container along with the necessary data acquisition equipment. Teflon coated sample tubes, one from each SPM, were placed at 3 ft above the ground with funnels used as intake line protectors. A solar panel, two batteries, and a solar charging regulator were used to power the SPMs and data loggers (Figure 2). A total of eight SPMs were used for each source. The SPMs record the 15-minute average H₂S concentration. All eight SPMs at a source were started at the 15-minute mark to coordinate sampling. In this manner, all eight SPMs recorded their 15-minute average at the same time throughout the monitoring period.

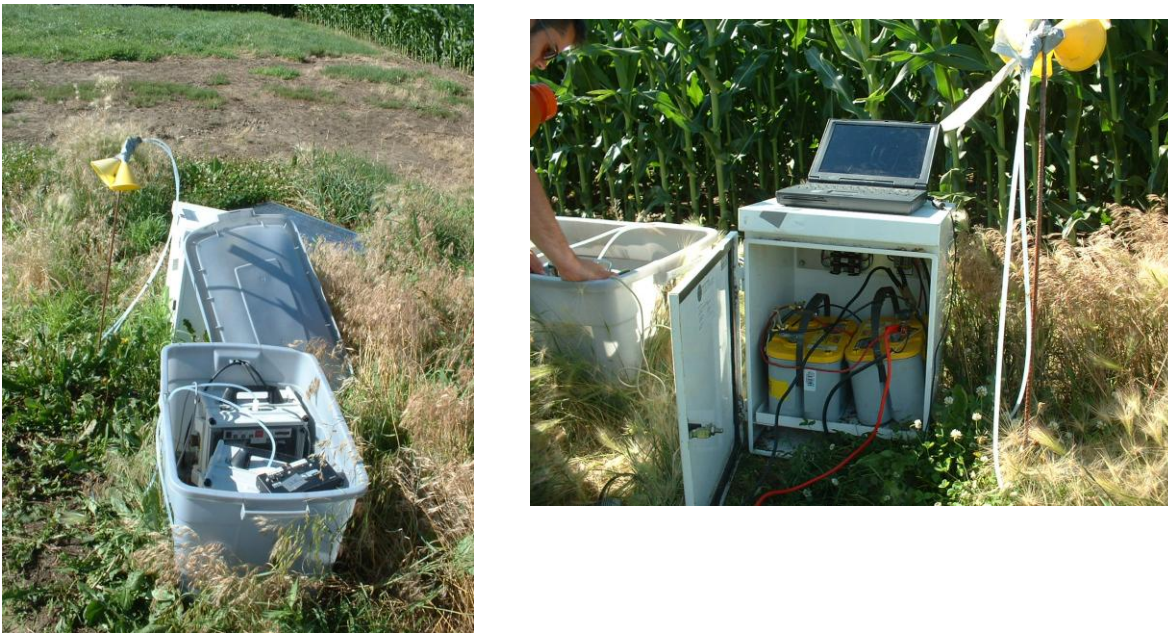


Figure 1.

Example collocated SPM set-up at one of the compass points for one of the sources monitored.



Figure 2. Complete collocated SPM set-up at one compass point and placement of the weather tower at a source.

A total of four paired-sites were monitored with one additional single site monitored, yielding a total of nine monitored swine finishing sites. At four of the sources monitored, a near-by residence was identified for monitoring as well. In addition, a fifth residence was monitored within an urban setting, far removed from animal agriculture.

At each residence, a fully-instrumented Mobile Ambient Laboratory (MAL) was placed equipped to monitor H₂S and NH₃ inside the home at one sample location and at the ambient air surrounding the home with a line-of-sight to the monitored swine finishing operation (Figure 3). As with each of the monitored swine sources, a portable weather tower was placed at the monitored residence and this data was collected simultaneously with the H₂S and NH₃ gas levels.



Figure 3. Example MAL set-up at one of the five residences monitored for this study.

The H_2S and NH_3 data collected at a residence was collected on a 1-second basis with the 1-minute average stored for analysis. Residence monitoring was conducted by sampling from the ambient air location for a fixed period of time of no less than 30-minutes, followed by the inside residence sampling for a time of no less than 30-minutes. The sampling was conducted using a series of vacuum pumps and solenoids, controlled automatically by the data acquisition and control system. The gas sampling system, or GSS, incorporated by-pass pumping implying that sampled air flowed continuously through each sample line before being routed to the analyzers. In this manner, sample air was constantly flowing from each sample location, improving the response time of the analyzers. The sampled air was routed into the MAL and this air was presented simultaneously to analyzers for H_2S (Model 45C, TEI, Inc) and NH_3 (Model 17C, TEI, Inc). Both analyzers used were EPA-approved methods for measuring low-level hydrogen sulfide and ammonia concentrations. The analyzers were calibrated before and after each monitoring session using double certified EPA-protocol calibration gases.

Each pair of swine sources and the residence were monitored for approximately three weeks, although two of the sites were monitored for four and five weeks respectively. Monitoring began in May 2004 and continued through August 2004, and was reinitiated in May 2005 and continued through mid-September 2005. Due to the limitations in operating temperature of the SPM monitors, all monitoring was conducted between May and mid-September.

In addition to the data collection described above, each residence and each manager of each source were given a log sheet to record any unusual events or practices that could be used to help explain the monitoring

results. This proved to be ineffective as the information received back was sporadic and incomplete. As a result, the information received from these log sheets is not included in this report.

In summary, a total of nine sources were monitored for this project in five regions of the state. A total of five residences were monitored as well, with four of these residences associated with four of the nine monitored sources. The fifth residence monitored was located in an urban setting near Des Moines with no animal agriculture within five miles of this residence. The table below summarizes all of the monitoring conducted.

Source	Location	Residence Monitored?	Sample Duration
1	LKV	Yes	5/13/2004-6/3/2004
2	LKV		
3	STR		6/17/2004-7/8/2004
4	STR	Yes	
5	GLD	Yes*	7/20/2004-8/12/2004
6	GLD		
7	STC		5/12/2005-6/30/2005
8	STC	Yes	
9	DWS		7/20/2005-8/9/2005
none	GRN	Yes	8/16/2005-9/11/2005

*The GLD Sources 5 and 6 were within 450 ft of each other and therefore the residence monitored was monitored against both Sources 5 and 6.

VI. Results:

The results are grouped into a logical order that attempts to blend the relationship between the perimeter H₂S results collected from the sources and the gas levels measured at each of the monitored residences. First, the perimeter H₂S results for each of the nine sites monitored is presented along with the pertinent statistics related to this phase of the project. Next, four of the sources monitored were associated with a single monitored residence. For these sources, the perimeter H₂S results are compared to the H₂S results measured in the ambient air at the residence using our MAL. Third, each monitored residence is then investigated for gas levels inside the home versus outside the home for both H₂S and NH₃ concentrations measured with the MAL. Finally, results are presented that attempt to blend the relationship between inside home gas levels and the ambient air surrounding the home.

Source Perimeter H₂S Concentrations

Tables 1 A&B summarize the SPM results for each of the nine sources monitored at the five locations of the state. The sources are referred to as Sources 1 to 9 throughout this report and the source locations are referred to as LKV, STR, GLD, STC, and DWS. Table 1 specifies the manure management type, the manured surface area, the ratio of outside manure area to the total, the animal numbers, the monitoring period for each site, basic SPM concentration statistics measured for each of the four compass locations, and the overall average H₂S concentration averaged across all eight SPMs for each site. For each of the compass location statistics, the

average of two collocated SPMs was used for analysis. The manure management designations are; DP=deep-pit, EB=earthen basin, and CB=concrete basin. Figure 4A summarizes the overall average and median H₂S concentrations for the perimeter monitoring. As shown in Table 1, every source with the exception of 4, 8 and 9 had at least one 15-minute average reading that exceeded the measurement limit of the SPM (90 ppb).

As shown in Table 1, the standard deviations for any of the sampling locations was high relative to the average. These are typical results encountered when air sampling near a source as concentrations are very much influenced by weather patterns which in turn vary considerably. It was not uncommon to experience one 15-minute average concentration near 90 ppb followed by the next 15-minute average near 0 ppb as a result of downwind versus non-downwind patterns. As shown in Figure 4A and Table 1, the average source perimeter H₂S concentrations ranged from a low of 1.9±2.7 ppb for Source 7 to a high of 26.3±32.3 ppb for Source 3 with variations in the median as shown in Figure 4A and Table 1. Source 3 had nearly the largest overall manured surface area (37,254 ft²) with the highest fraction of outdoor manured surface area at 0.34. Table 2 summarizes the SPM results when any of the samplers at a given source were determined to be in the plume of the source, as determined by the on-site weather station installed. The average of the 15-minute measurements ranged from a low of 7.4±6.9 ppb at Source 7 to a high of 45.8±31.8 ppb at Source 3 (Figure 4B). Source 7 was a deep-pit swine finisher and Source 3 was a swine finishing site using two outdoor storage units consisting of earthen and concrete basins. Source 3 represented the source with the largest outside manured surface area (12,650 ft²) and Source 7 represented the source with the smallest total manured surface area (16,800 ft²). As shown in Table 2, when any sampler was downwind of the source, the upper quartile of results ranged from a low of 7.3 ppb for Source 7 to a high of 85.4 ppb for Source 3.

The perimeter SPM concentrations were analyzed to determine the influence of manure management type and total manured surface area on the average concentration measured. These results are given in Figure 5. The results were grouped by manure management method where all deep-pit sources only were summarized (Figure 5A) and all sources with any amount of outside manure storage were summarized (Figure 5B). In Figure 5B, the outside manure storage area (OMSA) as a ratio of the total manured storage area (TMSA) is given. In general, the average perimeter H₂S concentration for the deep-pit sources followed a moderate trend with total manured surface area (TMSA) as (R²=0.41);

$$\text{Ave H}_2\text{S, ppb} = 0.0002 * \text{TMSA, ft}^2 + 0.5$$

valid for deep-pit TMSA sources below 34,000 ft². For all sources with any form of outside manure storage, the relationship found was (R²=0.56);

$$\text{Ave H}_2\text{S, ppb} = 53.6 * (\text{OMSA/TMSA}) - 2$$

valid for OMSA/TMSA ratios below 0.34.

Detailed plots showing the SPM concentration profiles for each of the nine sites monitored are given in Figures 6 to 10. These plots have a consistent format that needs explanation. For each figure, two plots are given representing the perimeter H₂S results for the two sources monitored at each sampling location. For example, Figure 6 shows Source 1 (Figure 6A) and Source 2 (Figure 6B) results for the LKV location. Within each plot a color scheme was used to discretize the large amount of data collected. The color scheme was chosen to indicate the compass point of monitoring at the perimeter of the source, or, to designate the SPM monitors that were positioned between the source and the monitored residence, which was applicable to Sources 1, 4, 5, 6 and 8. This method was found to discretize the data the best although this method requires color copies to read effectively. The color scheme is as follows:

SPM Location Relative to Source	Plot Color
W or NW	pink
E or SE	green
S or SW	blue
N or NE	orange
S-R line-of-sight	black

The “S-R line-of-sight” designator corresponds to the SPM results recorded for the collocated SPMs placed between the source and the monitored residence. In addition to the H₂S results, each plot shows the solar radiation (W/m²) to distinguish between day and night periods, a result that has significance in later discussions. The results given in Figures 6-10 were presented as a matter of record and further results that are summarized will use the results presented in Figures 6-10 in more detail. Therefore, at this point a limited discussion of the specifics shown in Figures 6-10 is reserved for later discussion.

A general review of the SPM H₂S results given in Figures 6 to 10 highlights some general trends. First off, the majority of elevated H₂S results occurred during night-time (low solar) hours. This is clearly evident in Figure 6A but this trend persisted throughout for all sources monitored. These results agree with expectations since the gases emitted during summer nights are emitted into a relatively stable atmosphere compared with emissions during the day. A stable atmosphere is one that results in low vertical mixing with the atmosphere resulting in lower dilution air with the atmosphere at any given horizontal distance from the source. A close-up view of three consecutive days for Source 9 showing the effect of solar radiation on H₂S concentration is given in Figure 11. Note that as shown in Figure 11, the daytime conditions had a suppressing effect on the

concentration of H₂S measured at the perimeter, a direct result of the instability in the atmosphere at these high-solar conditions.

The influence of solar radiation on perimeter H₂S levels was so compelling that further analysis was conducted. Figure 12 A&B shows the relationship between the exceeded perimeter H₂S concentration and the average solar radiation coinciding with these exceedance levels for Sources 1 and 2, respectively. Figure 12 addresses the following question: If the average perimeter H₂S concentration exceeded a given level (ppb), what was the corresponding average solar radiation (W/m²) during these occurrences? These plots show that the elevated concentrations of H₂S were in fact influenced by atmospheric stability *via* solar radiation. Clearly, as solar radiation increases, the maximum H₂S concentration measured at the source perimeter decreases dramatically. To extend this analysis further, the exceeded perimeter H₂S concentration as a function of solar radiation was evaluated for all nine sources monitored and the results are shown in Figure 13. Clearly, low solar conditions play a dominant role regarding the maximum H₂S concentration expected at the perimeter of the source.

Source Perimeter H₂S Concentrations in Relation to the Monitored Residence

Along with four of the sources monitored, a near-by residence was monitored as well to determine the source-receptor characteristics. Sources 1, 4, 5&6 and 8 were near one each of four residences monitored, specifically residences LKV, STR, GLD and STC, respectively. The relation between source and receptor is given in Table 3. The residence GRN will be discussed separately at the end of this section. This section will show the relationship between the source perimeter H₂S concentration measured with the SPMs and the H₂S concentration measured in the ambient air near the residence and inside the residence, measured with the Mobile Ambient Laboratory (MAL). These results are given in Figures 14 to 21 for the LKV, STR, GLD, and STC residences, respectively. Figures 14 to 21 summarize the perimeter H₂S concentrations for those SPMs located between the source and the monitored residence. These concentrations are given in light gray. Superimposed on each graph is the H₂S concentration measured at the near-by residence for both the ambient (blue) and inside home air (red).

Figure 14 summarizes the findings for the LKV residence in relation to Source 1. For the period monitored for the LKV residence, there were three very distinct periods where the H₂S concentration in the ambient air measured near the LKV residence was elevated, and these elevated H₂S concentrations coincided with elevated H₂S concentrations measured with the collocated source perimeter SPMs located between Source 1 and the LKV residence (Figure 14A). It is also interesting to note that several more elevated H₂S concentrations were measured at the perimeter of Source 1 that did not result in any discernable elevated H₂S levels in the ambient air near the residence. Figure 14B helps clarify this trend. In all three elevated cases

shown in Figure 14A, the solar radiation was low corresponding to nighttime conditions and simultaneously the wind speed fell to calm or near-calm conditions (<3mph). Therefore, even though several elevated perimeter H₂S levels were measured between Source 1 and the LKV residence, an elevated ambient concentration near the LKV residence required a combination of low wind speed and low solar conditions. Note that between 5/14/2004 and 5/21/2004 the sample line was fixed to ambient air to try and capture as much ambient air detail as possible during this time period. Therefore, no inside home concentration data is available for this time period.

Figure 15 summarizes the source and residence concentration trends for Source 4 and the STR residence. Several elevated perimeter H₂S concentration events were recorded for the collocated SPMs between Source 4 and the STR residence, but no corresponding events were recorded at the residence, both in the ambient and inside home locations. This was most likely the combined influence of separation distance and Source 4 size. The STR residence was 3,886 ft from Source 4 and Source 4 had the second smallest total manured surface area at 17,963 ft².

Figure 16 shows two plots related to the GLD residence monitored. Figure 16A shows the perimeter H₂S concentrations for Source 5 and Figure 16B shows the perimeter H₂S concentrations for Source 6. Both sources were close to each other, separated on an east-west axis by 450 ft and both located south of the GLD residence with Source 5 being 2,149 ft due south of the GLD residence and Source 6 being 2,228 ft from the GLD residence, at 20 degrees west of south. As shown in Figures 16 A&B several elevated perimeter H₂S concentration events existed for both Sources 5 and 6 for those SPMs collocated between each source and the GLD residence. Correspondingly, elevated H₂S concentrations in the ambient air near the GLD residence were recorded as well, associated with some of these elevated source perimeter events. A close-up view of the time period from 7/22/2004 to 8/1/2004 is shown in Figure 17 for Source 5. The results shown in Figure 17 indicate that each and every elevated H₂S event in the ambient air near the GLD residence occurred under very low solar and wind speed conditions, with the peak H₂S concentration occurring at sundown. This was a consistent trend as shown in Figure 17. The elevated ambient levels did not however correspond to elevated inside home concentrations as shown in Figure 17.

Figure 18 shows the results for Source 8 and the STC residence. For Source 8, all eight SPMs were placed between the source and the STC residence, collocated at three distances between Source 8 and the STC residence. Recall that the STC residence was 251 ft to the east of Source 8 and served as the residence for the tenants of this source. Due to problems encountered with our MAL, limited data is available between 5/19/2005 and 6/2/2005. As shown in Figure 18, distinct periods of time existed where elevated levels in the ambient air and inside the home were measured, corresponding to elevated SPM concentrations measured between Source 8 and this residence. Figure 19 highlights one particular elevated event that occurred between

5/27/2005 and 5/28/2005. Again, the elevated H₂S concentration sensed in the ambient air at the residence was associated with a low solar and low wind speed event. The maximum ambient H₂S concentration during this time period was 44 ppb with a maximum inside home concentration of 16 ppb measured during this same event. The combination of Source 8 size and the small separation distance with the STC residence contributed to these elevated residence levels. As shown in Figure 19, the suppressing effect on perimeter H₂S concentration with high solar conditions is again very evident.

Source Perimeter H₂S Concentrations in Relation to the NH₃ Concentration Measured at the Near-By Residence

Figures 20 to 24 summarize the perimeter H₂S concentrations at the source for the collocated SPMs located between the source and the residence, compared to the NH₃ concentrations measured at the residence ambient and inside home locations.

Figures 20 and 21 summarize the results obtained from Source 1 and the LKV residence. As shown in Figure 20, the NH₃ concentrations measured at the residence exhibited some unexpected behavior. In all of the cases where an elevated NH₃ concentration was measured inside the home, a corresponding elevated ambient air measurement was not recorded, and more importantly, very little response in terms of H₂S was measured for the SPMs located between Source 1 and the LKV residence. A closer view of this trend is given in Figure 21 for 5/19/2004 to 5/29/2004. One would expect that if an elevated NH₃ level was found inside the home, and the source of this NH₃ was from Source 1, a corresponding elevated NH₃ concentration would be sensed at the ambient air outside the home. However, this expectation did not occur for any of the elevated NH₃ concentrations measured inside the home. In fact, the elevated NH₃ concentrations recorded on 5/25/2004 and 5/26/2004 occurred during the day during high solar conditions, which is opposite the trend recorded for the H₂S results discussed earlier.

Figure 22 summarizes the results obtained from Source 4 and the STR residence. As shown in Figure 22, the NH₃ concentrations measured at the residence exhibited no elevated NH₃ concentrations in the ambient air outside the residence, but experienced a very consistent elevated NH₃ concentration inside the home, with no relation to outside ambient air conditions.

Figure 23 summarizes the results obtained from Sources 5 and 6 and the GLD residence. As shown in Figures 23 A&B, several elevated NH₃ concentration events were measured in both the ambient air and inside the residence for the GLD residence. A careful review of Figures 23 A&B show that most all of the elevated inside NH₃ concentrations measured did not correspond to elevated ambient air NH₃ concentrations. This is especially evident for the days between 8/10/2004 and 8/21/2004. Clearly, many elevated NH₃ concentration events existed inside the residence, but many of these events were not associated with elevated H₂S concentrations at the perimeter of either Source 5 or 6. There is an almost predictable and consistent spike in

inside home NH_3 concentrations, especially for the period between 8/10/2004 and 8/21/2004. The reasoning for these elevated inside home NH_3 levels is not known.

Figure 24 summarizes the results obtained from Source 8 and the STC residence. As shown in Figure 24, several elevated NH_3 concentration events were measured, with some of these events corresponding to ambient air elevated concentrations and elevated H_2S concentrations sensed at the SPMs. These events indicate that at times the STC residence, during downwind events, experienced an elevated inside home NH_3 concentration in response to these downwind events. The fact that the STC residence was so close to Source 8 (251 ft separation) resulted in an impact from Source 8 to the quality of air inside the STC residence. It is also interesting to note however that in many more of the cases measured, an elevated inside home NH_3 concentration was recorded, that was not associated with an elevated ambient air concentration or an elevated H_2S concentration response from the SPM monitors located between Source 8 and the STC residence. Figure 25 is a more detailed look at these effects. For example, as shown in Figure 25 for 6/5/2005, there was an obvious downwind event captured by the SPMs, followed by an elevated ambient air NH_3 concentration, followed by an almost duplicated response inside the home. This same trend existed for the time near midday on 6/6/2005. For all other elevated inside home NH_3 events shown in Figure 25, no obvious elevated H_2S concentration was recorded by the SPM monitors and no elevated NH_3 concentration was measured in the ambient air near the residence.

As has been the case for the other source-receptor events, there appears to be a disjunction between the inside home NH_3 concentration and the events occurring outside the home, except in the case of Source 8 and the STC residence where the separation distance was so small that for this residence inside home elevated NH_3 concentrations were detected during periods of elevated H_2S concentrations from the SPM monitors located between Source 8 and the STC residence.

Residence NH_3 Concentration as a Function of Upwind Events

The characteristics regarding inside home NH_3 concentration and the relation to ambient air needs further investigation. Figures 26 to 29 summarize the ambient air NH_3 concentration and the inside home NH_3 concentration for those wind events where there was no chance of an animal-related source from influencing the concentration of ammonia (ie. upwind events). In every case the ambient level NH_3 concentration was low as expected and the inside home NH_3 concentration was higher, adding further evidence that most all of the elevated NH_3 concentrations measured were most likely the result of inside sources. Distinct elevated NH_3 concentrations during these upwind events were evident with the LKV (Figure 26) and GLD (Figure 28) residences with a consistently higher elevated NH_3 concentration relative to ambient for the STR (Figure 27)

and STC residences (Figure 29). This again requires further investigation as will be done in the following section.

Residence NH₃ Concentration Details

To further investigate the trends outlined above, the raw data was investigated to see if in fact the trends outlined for inside versus ambient residence NH₃ concentrations could be further supported. To help with this analysis, the STR and STC residences were reviewed in detail. Figures 30 to 32 show details related to the sampled data using the MAL. As mentioned in the Materials and Methods section, two sample lines were used, one for ambient air sampling near the residence and one used for inside home sampling. These two sample lines could not be sampled simultaneously because only one set of analyzers for NH₃ and H₂S were available. Therefore, a switching routine was incorporated using solenoids, allowing each sample line to be analyzed for a period of time, then switching to the other sample line, and continuing throughout the study. Figure 30A represents a typical plot showing the raw data generated from this protocol. The darkened periodic square wave represents the sample line indicator, and for this case is a snapshot of data from the STR residence. For this residence, sample line 1 indicates ambient air sampling and sample line 2 indicates inside home sampling. The period of time chosen for Figure 30 was a time where it was assured *via* weather patterns that the residence was not downwind of any animal source (ie. upwind events). Clearly, and quite dramatically, when sampling is switched to the inside home location (Sample Line=2), a clear increase in both NH₃ and H₂S were measured, and a similar and convincing drop in concentrations were found when sampling was switched to ambient air (Sample Line=1). In Figure 30B, a detailed look was made for a period of time where long-term sampling was allowed to take place at both sample locations. This was done because as shown in Figure 30A, the sample time was in a few cases insufficient to capture the true maximum and true minimum concentrations, especially for NH₃. As shown in Figure 30B, the inside home NH₃ concentration was elevated to an average of about 85 ppb and when switched to ambient air, fell dramatically to a level of about 2 ppb.

Figure 31A shows a one-day snap-shot (6/11/2005) of the STC residence monitoring and Figure 31B shows the following day (6/12/2005). Figure 31A was a day where the wind patterns were such that the residence would not have been in the downwind direction of Source 8. Figure 31B however was a day where the wind patterns were such that the residence was in the downwind direction from Source 8 from about 2:30 am to 3:15 am (6/12/2005). For the STC residence, the ambient air sample line was 4 and the inside home sample line was 5. As shown in Figures 31 A&B, the STC residence exhibited a predictable pattern of increasing NH₃ during the day, beginning at about 7 or 8 am and continuing for several more hours throughout the day. Figure 31B shows another interesting feature, that being the elevated ambient H₂S concentration just after 3 am. Note that this elevated level corresponded to sample line 4, or the ambient sample location

indicating a downwind event from Source 8, agreeing with the wind patterns given above. Figure 32 represents a period of time where the sample line was fixed to the inside home location and the results indicate consistent elevated NH₃ and H₂S concentrations inside the home.

It is apparent from Figures 30 to 32 that in most cases not enough time was allowed for either the inside or outside samples to stabilize with the analyzers used. This was an area that was reviewed and it was decided to leave the sampling time lower in an attempt to try and capture as many simultaneous ambient air/inside home interactions as possible, which required a shorter sampling time, but one that would allow for sufficient time to capture the majority of the gas concentration levels. What has been learned is that for most all of the measurements, especially for NH₃, the inside home concentrations were most likely higher than reported here and the ambient air concentrations were most likely lower than reported here due to the interaction of sample and analyzer stabilization times. Figure 30B clearly pointed this out.

Daily Average Residence H₂S and NH₃ Concentrations

The residence monitoring data was summarized by looking at the daily averages measured for each residence, separated by inside home versus outside home sampling locations. Table 3 summarizes the average daily statistics for each of the five residences monitored separated by sample location. The residences labeled GLD, LKV, STC, and STR were residences monitored near four of the sources monitored and these were discussed in detail earlier. The residence GRN was located in an urban setting far removed from animal agriculture. Figure 33A summarizes the GRN residence daily average H₂S and NH₃ concentrations. The overall average inside NH₃ concentration was 36.0±6.9 ppb and the ambient air was 24.1±4.0 ppb. For H₂S, the inside residence was 0.7±0.2 ppb and the ambient air was 0.4±0.2 ppb. Figure 33B shows a typical real-time NH₃ and H₂S concentration profile in response to switching between sample locations. For inside the home (Sample Line=5) the elevated response for NH₃ is quite noticeable relative to ambient air sampling (Sample Line=6).

Analyzing the five residences and comparing all inside versus outside daily average measurements indicated that the average inside NH₃ concentration, averaged across all five residences, was 68.0±28.3 ppb with the outside averaging 36.8±26.1 ppb (Figures 34 and 35). These differences were significant (p<0.01). For H₂S, the daily average inside concentration, averaged across all five residences, was 1.2±1.0 ppb with the outside averaging 1.1±1.4 ppb. These differences were not significant (p>0.50). Analyzing the data relative to residence, sample location (inside vs outside) and the interaction between residence and sample location indicated that for ammonia all were found to be significant (p<0.01) with hydrogen sulfide significant only for the residence effect (p<0.01). The results indicate, as shown in Table 3, that the overall average NH₃ concentration measured inside the home ranged from a low of 28.6±12.8 ppb for the LKV residence to a high of

94.7±28.1 ppb for the STC residence. The overall average NH₃ concentration measured in ambient air near a residence ranged from a low of 11.7±5.3 ppb for the LKV residence to a high of 55.1±20.6 ppb for the STC residence. The NH₃ concentration inside the homes was significantly higher than in the ambient air (p<0.01). H₂S concentration inside the homes ranged from a low of 0.7±0.2 ppb to a high of 2.5±1.5 ppb. H₂S concentration in the ambient air outside the home ranged from a low of 0.4±0.2 ppb to a high of 2.4±2.4 ppb. The highest ambient H₂S (2.4±2.4 ppb) and NH₃ (55.1±20.6 ppb) concentrations were recorded for the STC residence, again located 251 ft to the east of a 4,800-hd deep-pit finishing site (residence STC and Source 8).

The highest average inside home concentration for NH₃ and H₂S was 94.7±28.1 ppb and 2.5±1.5 ppb, respectively from the STC residence. The next highest inside home NH₃ concentration was 85.7±15.3 ppb recorded for the STR residence. These two inside home daily average NH₃ concentration levels measured for the STC and STR residences are close to the currently recommended Minimum Risk Level (MRL) for NH₃, established by the Agency for Toxic Substances and Disease Registry (ATSDR), where a chronic MRL of 100 ppb for NH₃ has been established. If the levels recorded for the two residences specified above would persist for 365 days or more, the ATSDR guidelines for the protection of sensitive populations would be very close to exceeding the ATSDR MRL for ammonia. The results from the residence ambient air monitoring indicate that the concentration and duration for either NH₃ or H₂S fall well below the MRLs as defined by the ATSDR. This was true even for the residence located 251 feet from the nearest source.

VII. Discussion:

This research project attempted to quantify concentrations of hydrogen sulfide at the perimeter of swine operations in the state of Iowa, differing by animal number and manure management strategies. In addition, the concentration of hydrogen sulfide and ammonia at a near-by residence was evaluated and the influence of a near-by swine operation on the air quality inside the residence and in the ambient air was analyzed to determine the influence, if any, of the swine operation on the residence air quality.

The perimeter H₂S concentration results indicated that the average perimeter concentration was highest for swine operations using outside manure storage systems, and that overall the H₂S concentration was greatest in stable atmospheres, typical of low-solar and low wind speed conditions. Reviewing all perimeter H₂S concentration results, a very clear trend was found where the exceeded H₂S level measured was an exponentially decaying function with solar radiation. A moderate trend in H₂S concentration with the manured surface area was found, but this relationship was not nearly as strong as the relationship with atmospheric stability *via* solar radiation effects.

Comparing the H₂S concentrations at one near-by residence located near each of four monitored swine operations revealed that elevated H₂S concentrations were found near the LKV, GLD, and STC residences

during downwind or calm periods only when the atmosphere was stable due to low solar and wind speed conditions, or, as was the case for the STC residence when the separation distance was very small (251 ft).

Comparing inside ammonia concentrations versus ambient air revealed some interesting trends. In general, the concentration of ammonia measured inside all five homes monitored was higher than that measured in the ambient air, and this finding had very little to do with the concentration of ammonia measured outside the home. This trend was still very evident when concentration data associated with upwind events only was analyzed. Additionally, although at a much smaller difference, the inside home ammonia concentration measured versus outside was higher for the residence located in an urban setting far removed from animal agriculture. These results were consistent and work is currently proceeding to help determine what could cause this trend. Some theories exist based on the residences monitored, which include one residence where both adults smoked (STC) and one residence where multiple cats were kept indoors (STR).

Several studies confirm that ammonia is actually added to cigarettes to increase the availability of nicotine present in cigarette exhaust smoke (Pankow, et al., 1997) and certainly can be present in animal litter boxes. These are areas that are currently being investigated by the PI. The evidence is strong though suggesting that inside home sources are causing elevated ammonia concentrations that are being measured close to the chronic exposure limit established by the ATSDR. This finding from this study is not unique. A short-term study conducted in Missouri in 2002, directed by the ATSDR, reported elevated levels of ammonia inside homes compared to ambient air for residences in an area of large swine operations (US Department of Health and Human Services). In that study though, the reported NH_3 levels inside the home were 5-10 times higher than those reported in this study. This area will require much more investigation to develop a clear picture of inside home air quality as influenced by possible inside home sources.

These results point out the futility in assessing potential air quality impacts on our citizens based on outdoor, ambient measurements. A better approach would be to identify the confined locations where we spend most of our time, and then to conduct an extensive and exhaustive air quality evaluation over long periods of time to assess chronic air quality challenges to potentially sensitive occupants such as the elderly and children. A natural progression to this study would be a long-term air quality evaluation of homes and schools for children located in regions of the state or country where asthma incidences are high.

VIII. Lay Interpretation:

H_2S concentrations measured at the perimeter of nine swine operations across the state indicated that for the sizes of operations investigated with this study, the dominating influence on perimeter H_2S concentration was the influence of atmospheric stability, which in turn was a function of solar radiation and wind speed. The perimeter H_2S concentration measured decreased dramatically with increased solar radiation. During the

summer months, the sun will heat the ground causing air near the earth to rise. This rising air takes with it exhaust air from barns and outside manure storages expelling this air vertically, thereby decreasing the concentration measured near the ground at any given distance from the source. The highest average source perimeter H₂S concentration was measured for a source with the highest ratio of total manured surface area as outside storage.

If an elevated H₂S concentration was measured with monitors placed between a source and a near-by residence, an elevated H₂S concentration in the ambient air near the residence was measured only if the separation distance was less than 2,149 ft from the source (GLD residence, Sources 5&6). These elevated levels measured at the residence required low solar and low wind speed conditions however. The time-weighted average H₂S concentration measured in the ambient air surrounding residences did not reach a level even close to the Iowa proposed HEV of 30 ppb. The highest daily average H₂S concentration in the ambient air near a residence was 11.4 ppb for the STC residence which was located 251 ft from a 4,800-hd deep-pit finishing site.

The NH₃ concentrations measured at a residence in the ambient air and inside the home indicated that the inside home concentrations were higher and that these levels were in most every case not associated with downwind events from a source or elevated concentrations measured in the ambient air surrounding the residence. These results agree with one known short-term study conducted in Missouri where residences were monitored near a large swine finishing operation. The evidence suggests that inside home sources caused these elevated NH₃ concentrations which is the topic of on-going research being conducted by the PI. The highest inside home NH₃ concentrations were measured for residences where the occupants smoked or housed pets, both potential sources for NH₃. If NH₃ is being considered in the future for regulation, the results presented here make it mandatory that inside home NH₃ concentrations must be considered before results measured in the ambient air surrounding a residence are assessed for compliance.

Citations

Pankow, J.F., B.T. Mader, L.M. Isabelle, W. Luo, A. Pavlick, and C. Liang. 1997. Conversion of Nicotine in Tobacco Smoke to its Volatile and Available Free-Base Form Through the Action of Gaseous Ammonia, *Environmental Science Technology*, 31(8): 2428-2433.

U.S. Department of Health and Human Services, Final Report on Exposure Investigation Findings, "Valley View Concentrated Animal Feeding Operations, Green Castle, Sullivan County, Missouri", August 8, 2003.

(http://www.atsdr.cdc.gov/HAC/PHA/valleyview/caf_toc.html)

Acknowledgements

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Table 1A. SPM hydrogen sulfide concentrations for Sources 1 to 4. All results based on the 15-minute average.

Source	Location	Manure Storage	Manured Surface Area, ft ² *	Source Spaces	Start	Stop	SPM H2S Concentration							Equiv. Monitoring Days
							Location	Ave	SD	Max	Min	Median	N	
1	LKV	DP	27,000 0	3,000	5/13/2004	6/3/2004	North	4.1	8.0	89.1	1.0	1.0	1,977	20.6
							South	10.1	13.7	90.2	0.9	6.2	1,046	10.9
							East	9.7	12.9	78.7	0.9	3.0	2,016	21.0
							West	14.5	20.9	90.1	0.0	1.0	1,903	19.8
							<i>Overall</i>	<i>9.5</i>	<i>15.1</i>	<i>90.2</i>	<i>0.0</i>	<i>1.0</i>	<i>6,942</i>	<i>72.3</i>
2	LKV	EB	24,254 0.32	2,400	5/13/2004	6/3/2004	North	6.1	7.6	90.1	0.9	4.1	1,981	20.6
							South	6.1	6.2	66.9	1.0	4.5	1,046	10.9
							East	10.6	13.2	90.0	0.9	8.8	2,014	21.0
							West	4.9	5.2	61.1	0.9	2.7	1,904	19.8
							<i>Overall</i>	<i>7.1</i>	<i>9.3</i>	<i>90.1</i>	<i>0.9</i>	<i>4.8</i>	<i>6,945</i>	<i>72.3</i>
3	STR	CB+EB	37,254 0.34	3,000	6/17/2004	7/8/2004	North	14.6	21.6	90.1	1.0	3.8	1,981	20.6
							South	12.5	10.4	74.8	0.9	12.1	1,046	10.9
							East	65.1	29.0	90.1	0.9	80.9	2,014	21.0
							West	5.0	8.6	78.6	0.9	1.0	1,904	19.8
							<i>Overall</i>	<i>26.3</i>	<i>32.3</i>	<i>90.1</i>	<i>0.9</i>	<i>9.0</i>	<i>6,945</i>	<i>72.3</i>
4	STR	DP+CB	17,963 0.11	1,200	6/17/2004	7/8/2004	Northwest	3.7	6.9	48.3	0.9	2.4	1,980	20.6
							Southwest	4.2	4.8	28.2	0.9	2.4	1,046	10.9
							Northeast	3.6	3.9	35.6	1.0	1.0	2,014	21.0
							Southeast	3.5	3.1	41.5	0.9	2.8	1,904	19.8
							<i>Overall</i>	<i>3.7</i>	<i>4.9</i>	<i>48.3</i>	<i>0.9</i>	<i>2.2</i>	<i>6,944</i>	<i>72.3</i>

* ratio shown below total manured surface area is the factor of the total in outside manure storage area.

Table 1B. SPM hydrogen sulfide concentrations for Sources 5 to 9. All results based on the 15-minute average.

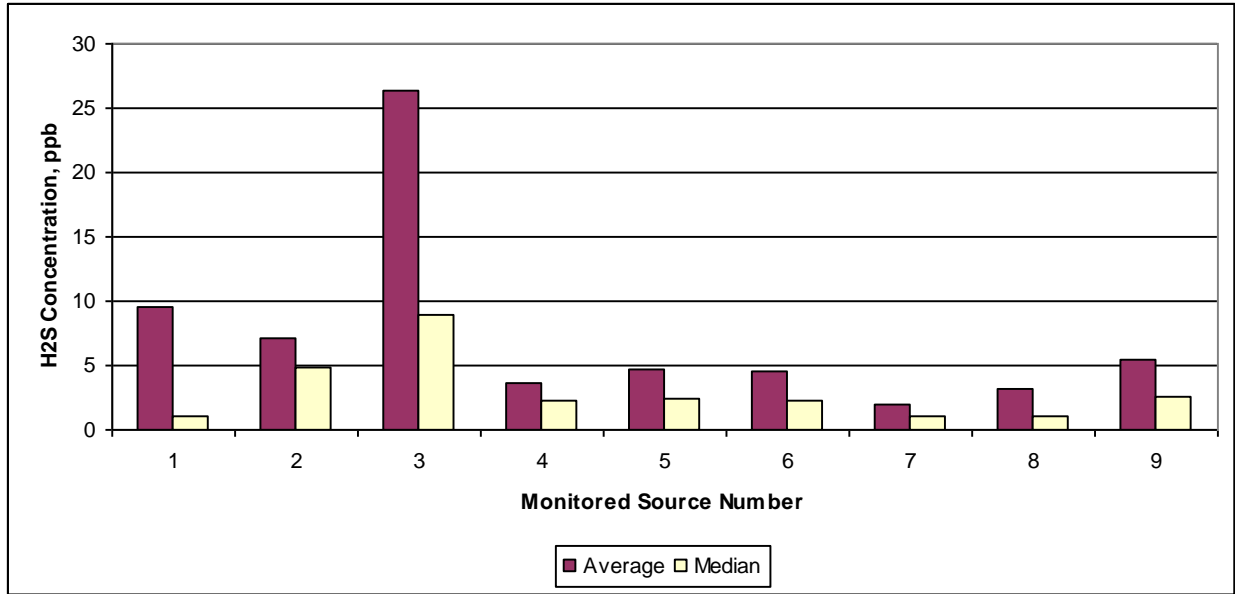
Source	Location	Manure Storage	Manured Surface Area, ft ²	Source Spaces	Start	Stop	SPM H2S Concentration							Equiv. Monitoring Days
							Location	Ave	SD	Max	Min	Median	N	
5	GLD	CB	40,254 0.2	3,600	7/20/2004	8/12/2004	Northwest	4.1	4.8	49.7	0.9	2.4	1,878	19.6
							Southwest	4.3	6.5	80.7	0.5	1.0	1,878	19.6
							Northeast	5.7	8.2	90.1	0.9	3.1	1,877	19.6
							Southeast	4.7	5.9	40.2	0.7	2.6	1,679	17.5
							<i>Overall</i>	<i>4.7</i>	<i>6.5</i>	<i>90.1</i>	<i>0.5</i>	<i>2.4</i>	<i>7,312</i>	<i>76.2</i>
6	GLD	DP	21,600 0	2,400	7/20/2004	8/12/2004	Northwest	3.9	5.0	89.6	1.0	1.0	1,979	20.6
							Southwest	5.7	4.9	38.6	0.9	4.0	1,046	10.9
							Northeast	2.7	3.2	45.6	0.9	1.0	2,012	21.0
							Southeast	6.5	11.5	90.2	0.9	2.6	1,902	19.8
							<i>Overall</i>	<i>4.5</i>	<i>7.2</i>	<i>90.2</i>	<i>0.9</i>	<i>2.2</i>	<i>6,939</i>	<i>72.3</i>
7	STC	DP	16,800 0	2,000	5/12/2005	6/30/2005	North	2.8	2.4	18.4	1.0	1.0	3,069	32.0
							South	1.8	4.1	90.0	0.9	0.9	4,987	51.9
							West	1.8	1.6	30.3	0.9	1.0	4,895	51.0
							East	1.7	1.7	21.6	1.0	1.0	5,284	55.0
							<i>Overall</i>	<i>1.9</i>	<i>2.7</i>	<i>90.0</i>	<i>0.9</i>	<i>1.0</i>	<i>18,235</i>	<i>189.9</i>
8	STC	DP	33,600 0	4,800	5/12/2005	6/30/2005	East 1	4.9	8.6	79.3	1.0	1.0	5,275	54.9
							East 2	3.8	6.2	55.2	1.0	1.0	4,096	42.7
							East 3	0.5	3.1	71.1	0.0	0.0	3,815	39.7
							<i>Overall</i>	<i>3.3</i>	<i>6.9</i>	<i>79.3</i>	<i>0.0</i>	<i>1.0</i>	<i>13,186</i>	<i>137.4</i>
9	DWS	DP	33,600 0		7/20/2005	8/9/2005	North	5.1	6.1	38.5	0.5	3.1	1,921	20.0
							South	5.7	8.3	61.1	1.0	2.6	1,046	10.9
							East	2.2	2.1	19.1	1.0	1.0	1,969	20.5
							West	10.1	11.5	70.7	0.9	5.2	1,559	16.2
							<i>Overall</i>	<i>5.5</i>	<i>8.0</i>	<i>70.7</i>	<i>0.5</i>	<i>2.6</i>	<i>6,495</i>	<i>67.7</i>

Table 2. SPM hydrogen sulfide concentration for the nine sites monitored when any of the SPM samplers were in the downwind plume of the swine operation. All results based on the 15-minute average. The 1st and 3rd quartile results are also shown (Q1 and Q3).

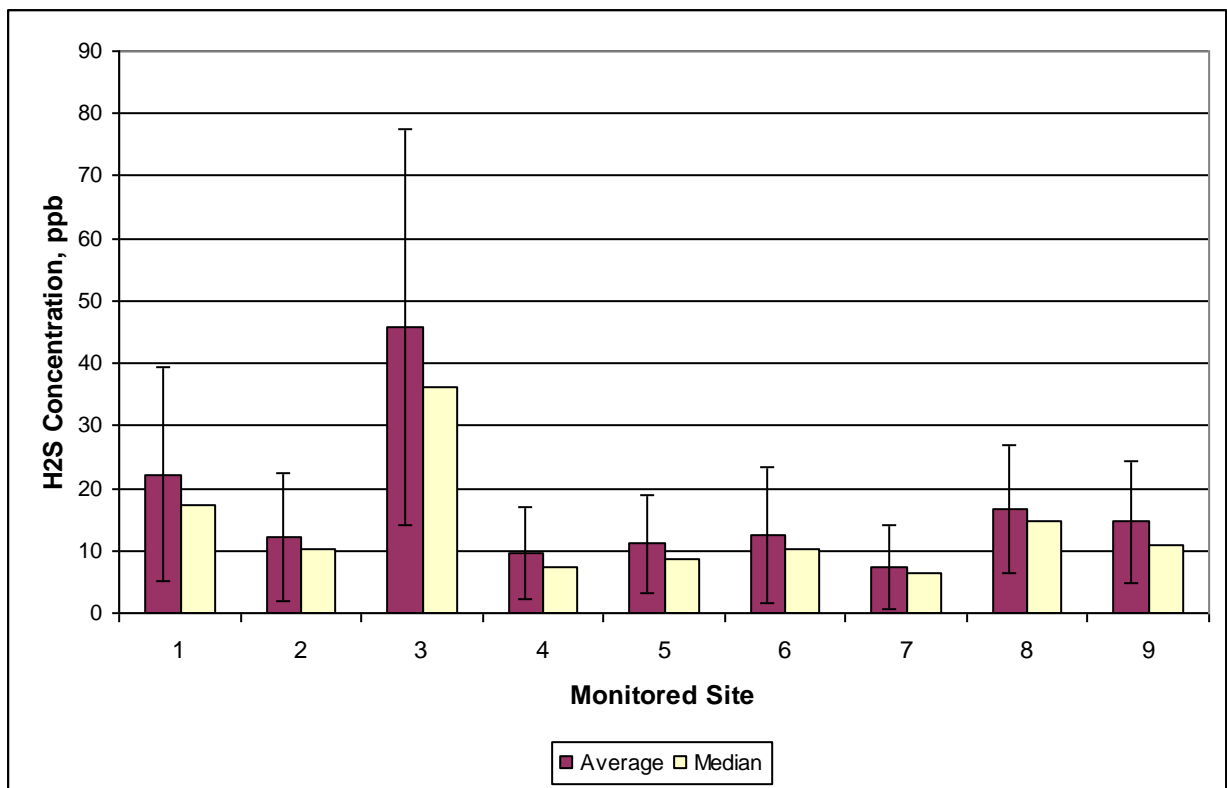
Site	Average H2S, ppb	SD, ppb	Maximum, ppb	Median, ppb	Q1, ppb	Q3, ppb
1	22.2	17.1	90.2	17.3	10.5	27.7
2	12.2	10.3	90.1	10.3	7.0	12.4
3	45.8	31.8	90.1	36.2	17.7	85.4
4	9.6	7.5	48.3	7.4	6.0	10.0
5	11.1	7.9	90.1	8.7	6.5	13.2
6	12.6	10.8	90.2	10.1	7.2	12.9
7	7.4	6.9	90.0	6.5	5.8	7.3
8	16.8	10.3	90.1	14.6	9.8	19.9
9	14.6	9.9	70.7	10.9	7.6	18.4

Table 3. Summary of daily average ammonia and hydrogen sulfide concentrations for the five residences monitored.

Residence	Distance from		Start	Stop	Sampling Condition	NH3 Concentration					H2S Concentration				
	Nearest Source, ft					Average	SD	Max	Min	Median	Average	SD	Max	Min	Median
LKV (Source 1)	1,167		5/13/2004	6/3/2004	Overall Residence	28.6	12.8	54.1	10.4	28.2	0.8	0.2	1.2	0.6	0.8
					Overall Ambient	11.7	5.3	24.0	4.2	10.5	0.9	0.8	3.1	0.3	0.6
					Overall	18.0	11.9	54.1	4.2	13.8	0.9	0.6	3.1	0.3	0.8
STR (Source 4)	3,886		5/13/2004	6/3/2004	Overall Residence	85.7	15.3	112.3	52.2	89.2	0.7	0.2	1.1	0.4	0.7
					Overall Ambient	18.1	4.1	32.9	10.1	17.5	0.4	0.2	1.2	0.3	0.4
					Overall	54.7	35.9	112.3	10.1	57.7	0.6	0.2	1.2	0.3	0.5
GLD (Sources 5&6)	2,149		6/17/2004	7/8/2004	Overall Residence	57.8	16.0	114.5	30.4	56.7	1.1	0.3	2.3	0.7	1.1
					Overall Ambient	49.8	31.4	155.2	16.4	36.5	1.1	0.4	2.2	0.5	1.0
					Overall	53.8	25.1	155.2	16.4	50.3	1.1	0.3	2.3	0.5	1.1
STC (Source 8)	251		5/19/2005	6/30/2005	Overall Residence	94.7	28.1	141.7	33.9	96.7	2.5	1.5	6.5	0.7	2.2
					Overall Ambient	55.1	20.6	112.7	30.1	51.0	2.4	2.4	11.4	0.6	1.7
					Overall	74.9	31.5	141.7	30.1	67.2	2.5	2.0	11.4	0.6	2.0
GRN > 26,000			8/15/2005	9/11/2005	Overall Residence	36.0	6.9	46.7	22.2	37.0	0.7	0.2	1.3	0.4	0.6
					Overall Ambient	24.1	4.0	30.5	16.5	22.9	0.4	0.2	1.0	0.2	0.4
					Overall	31.0	8.3	46.7	16.5	29.6	0.6	0.2	1.3	0.2	0.5

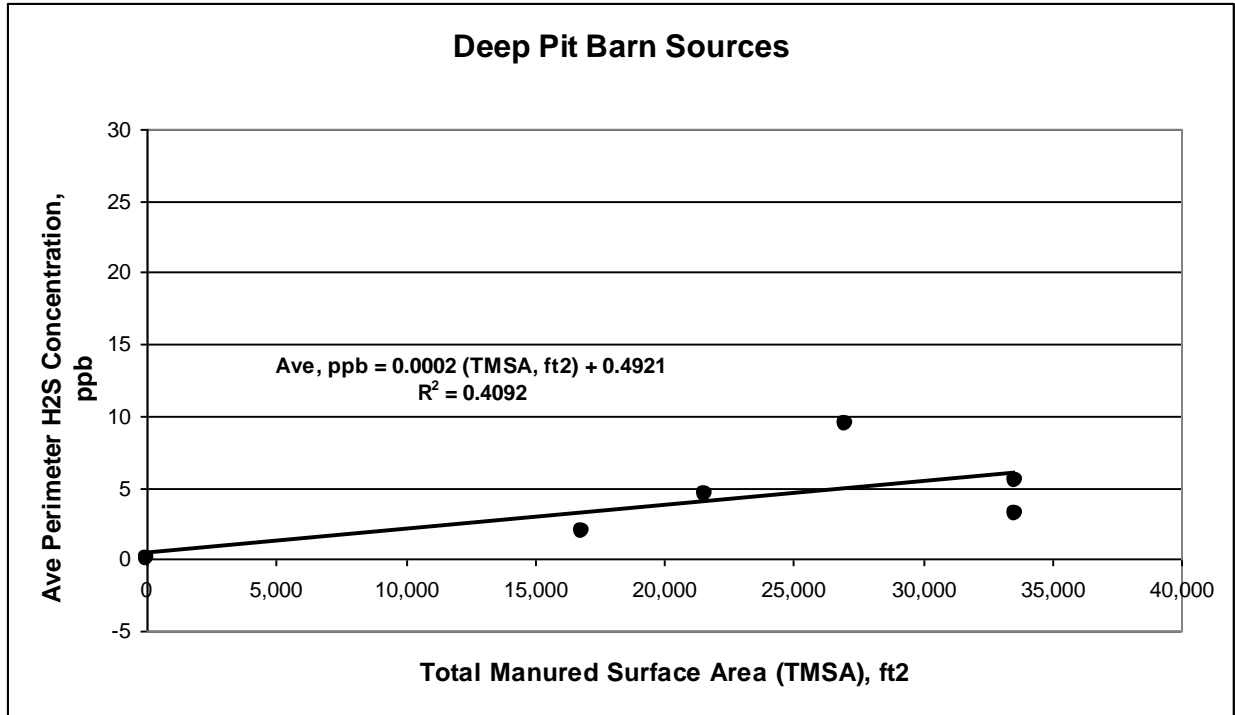


A

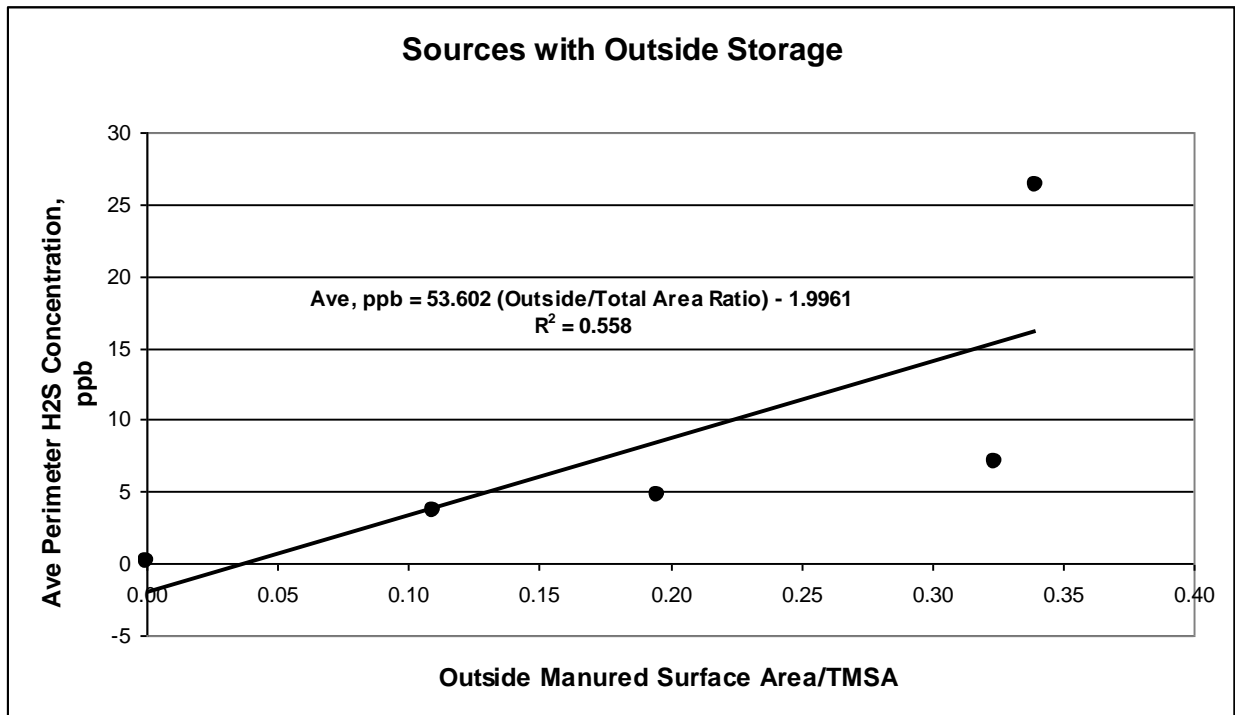


B

Figure 4. (A) Average and median perimeter H₂S concentrations for all nine sources monitored and (B) the average (\pm SD) and median concentrations when an SPM monitor was downwind of the source.

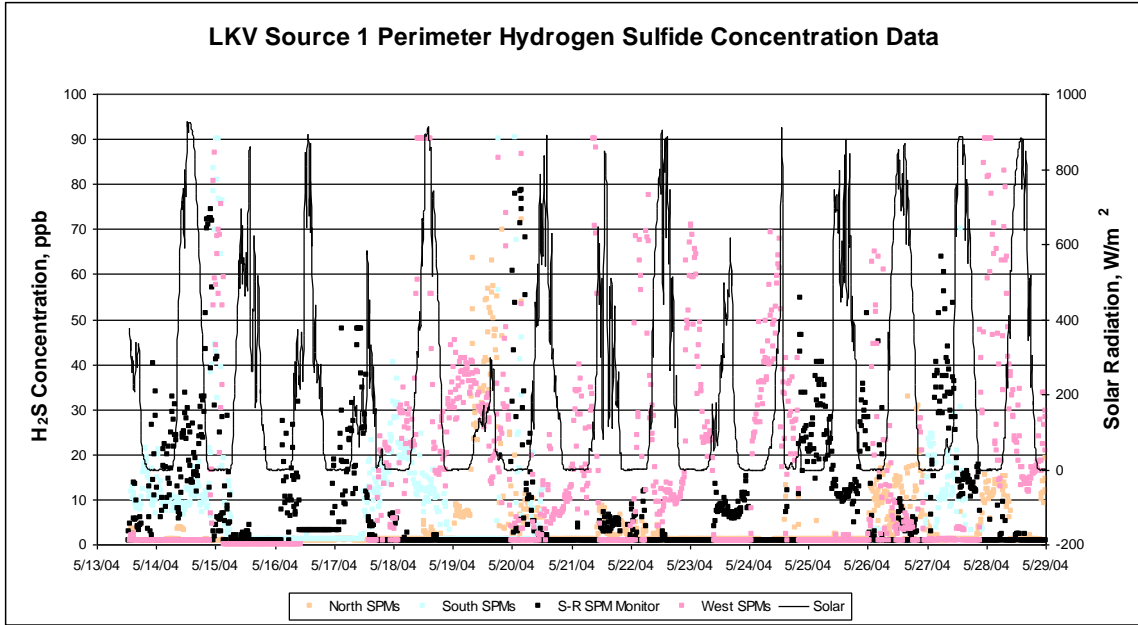


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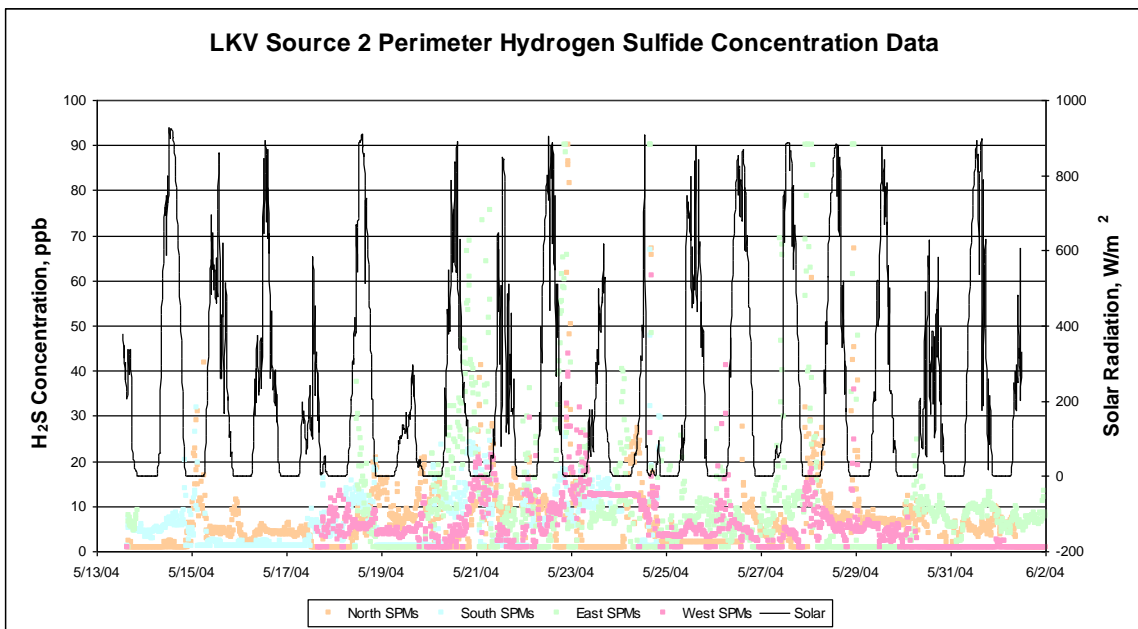


B

Figure 5. Average perimeter H₂S concentration for (A) all deep-pit only sources (Sources 1,6,7,8,9) and (B) those sources with outside manure storage (Sources 2,3,4,5).

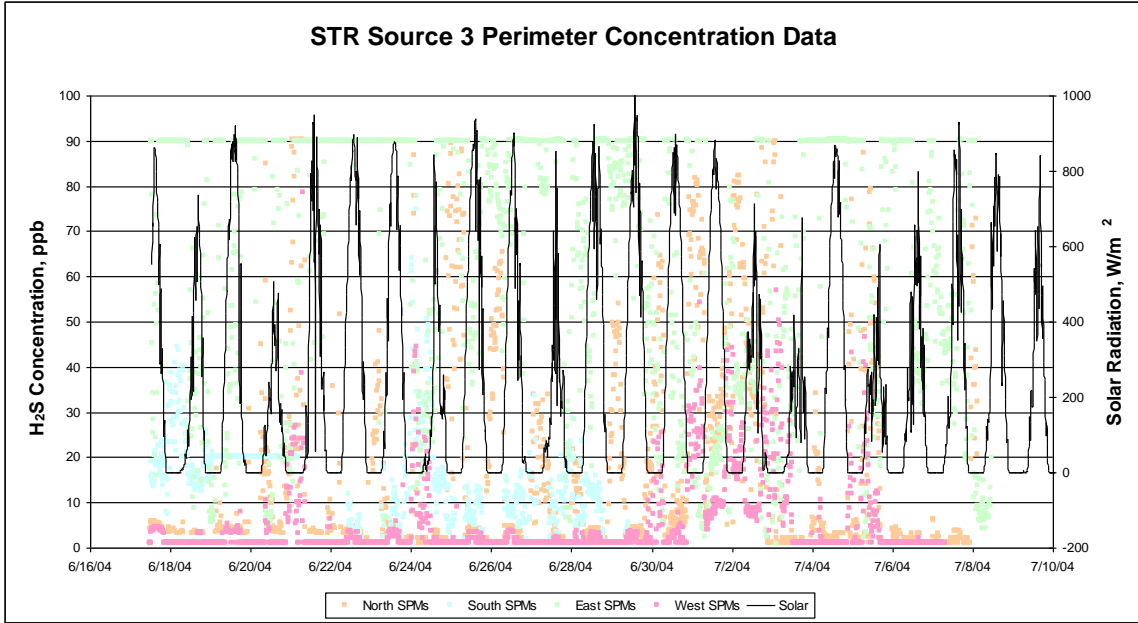


A

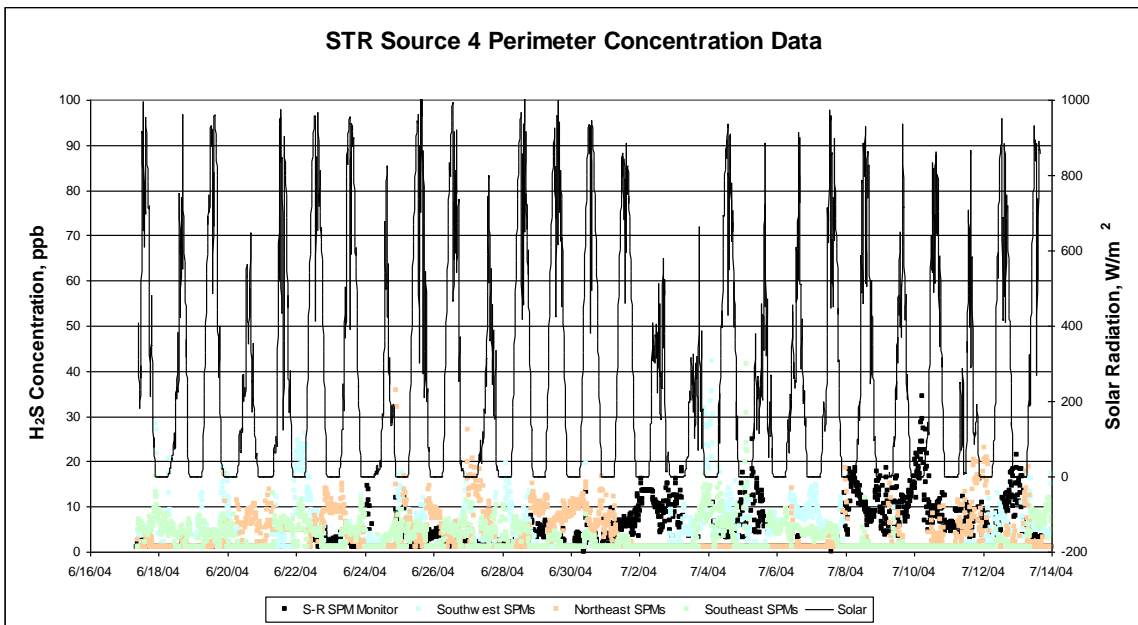


B

Figure 6. Perimeter H₂S concentration data for the two LKV sources monitored (A=Source 1, B=Source 2). Solar radiation data given to identify night and day periods. LKV source 1 was the source monitored nearest the monitored residence. The collocated SPM monitors between this source and the residence is identified in black and labeled “S-R SPM Monitor”.

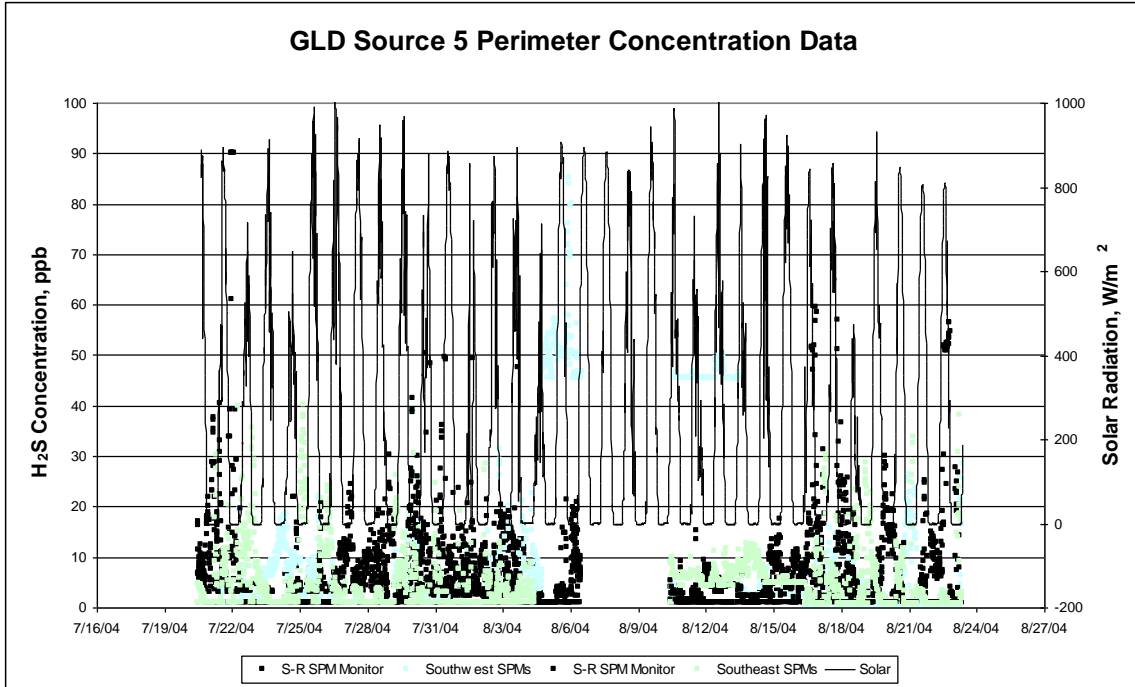


A

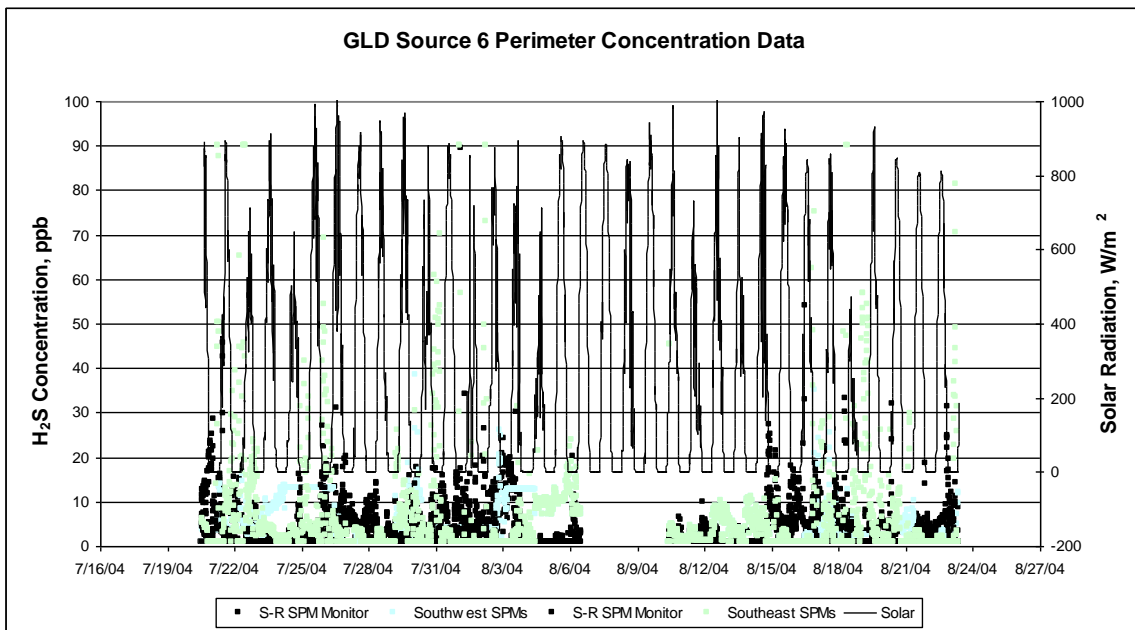


B

Figure 7. Perimeter H₂S concentration data for the two STR sources monitored (A=Source 3, B=Source 4). Solar radiation data given to identify night and day periods. STR source 4 was the source monitored nearest the monitored residence. The collocated SPM monitors between this source and the residence is identified in black and labeled “S-R SPM Monitor”.

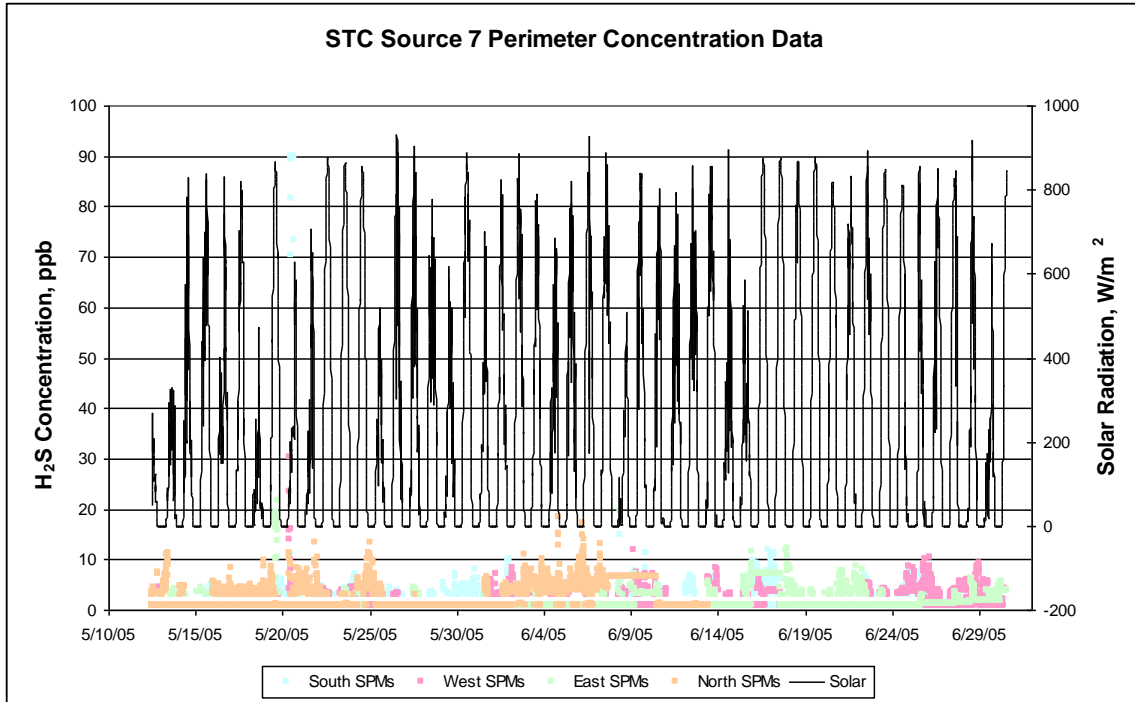


A

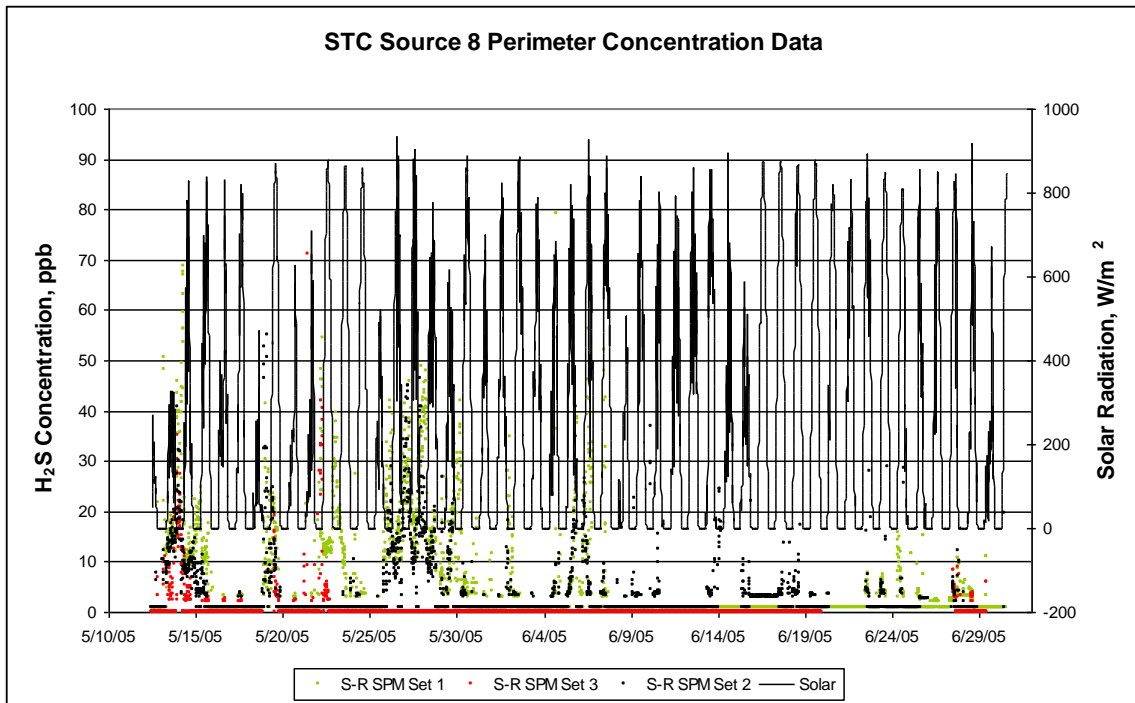


B

Figure 8. Perimeter H₂S concentration data for the two GLD sources monitored (A=Source 5, B=Source 6). Solar radiation data given to identify night and day periods. GLD sources 5 and 6 were located within 450 ft of each other on an E-W axis at a location south of the monitored residence. The SPM monitors located between each source and the residence is identified in black and labeled “S-R SPM Monitor”.



A



B

Figure 9. Perimeter H₂S concentration data for the two STC sources monitored (A=Source 7, B=Source 8). Solar radiation data given to identify night and day periods. STC source 8 was the source monitored nearest the monitored residence. For this source, all SPM monitors were placed between the source and the residence, at decreasing distances from the residence. Data labeled “S-R SPM Set 1” was located 40 ft from the closest point of source 8 and “S-R SPM Set 3” was located 185 ft from the source which was 67 ft from the residence. The data labeled “S-R SPM Set 2” was located midway between source 8 and the residence at 90 ft from source 8 and 161 ft from the residence.

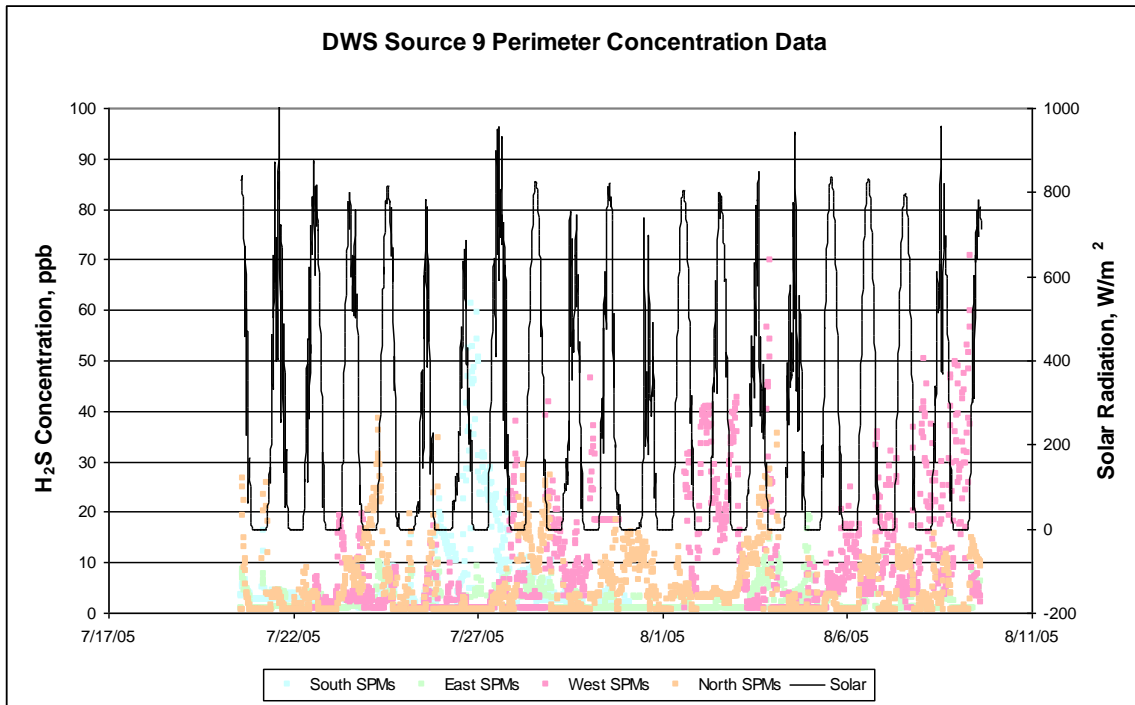


Figure 10. Perimeter H₂S concentration data for the single DWS source monitored. Solar radiation data given to identify night and day periods.

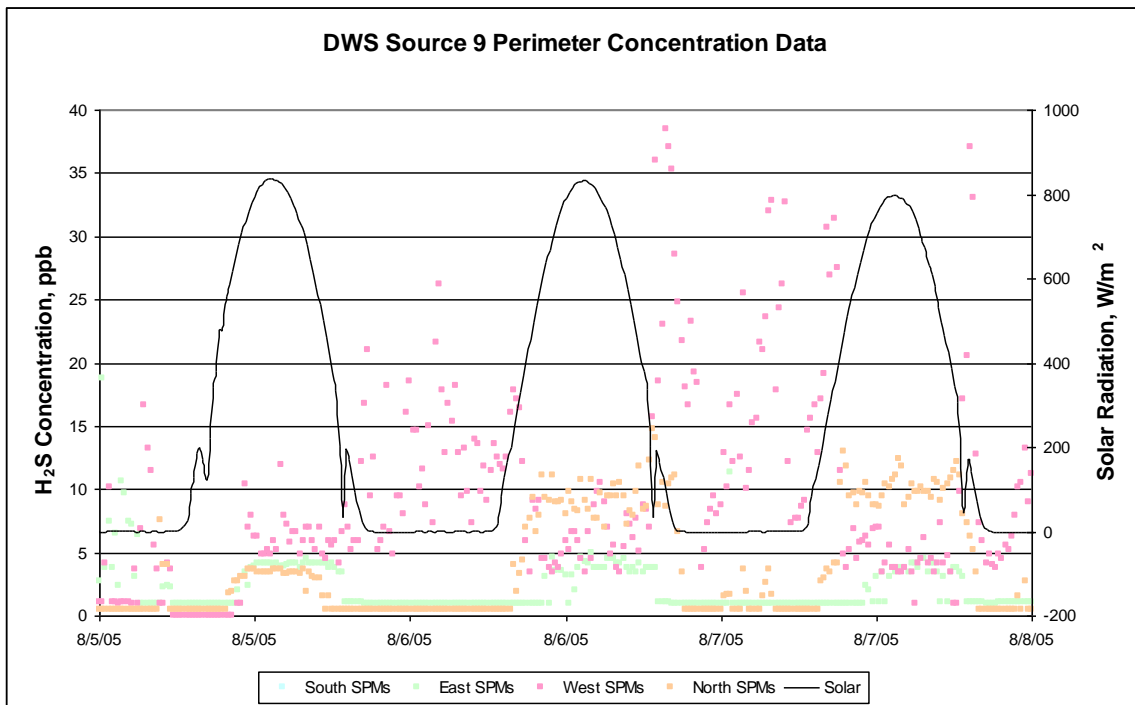
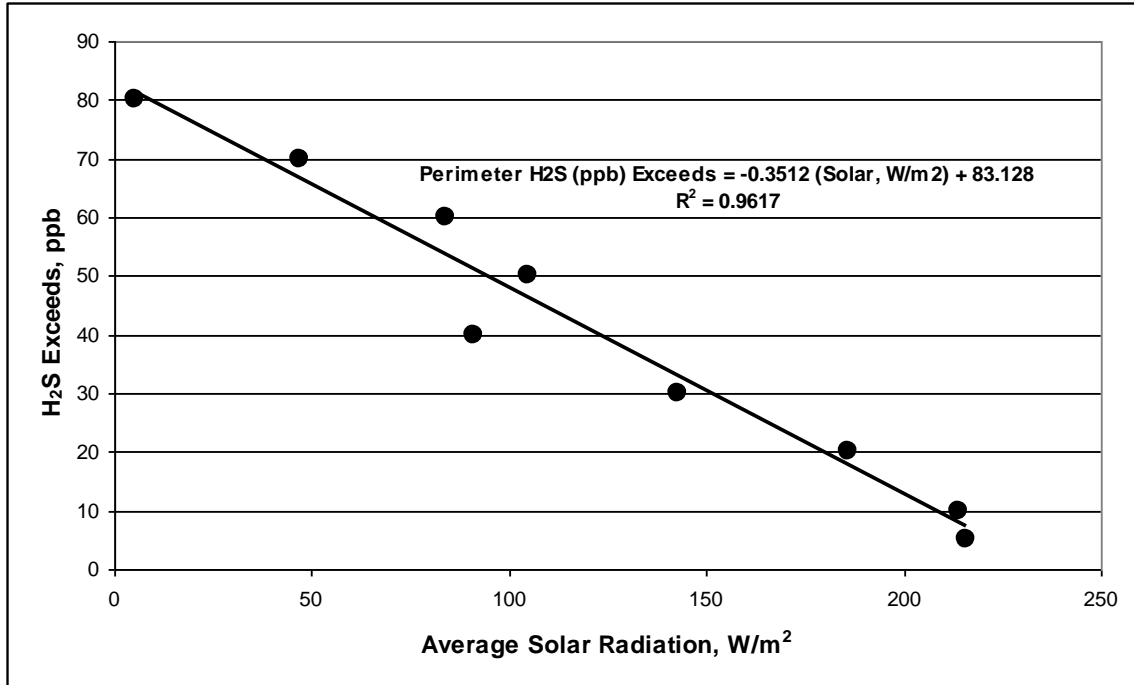
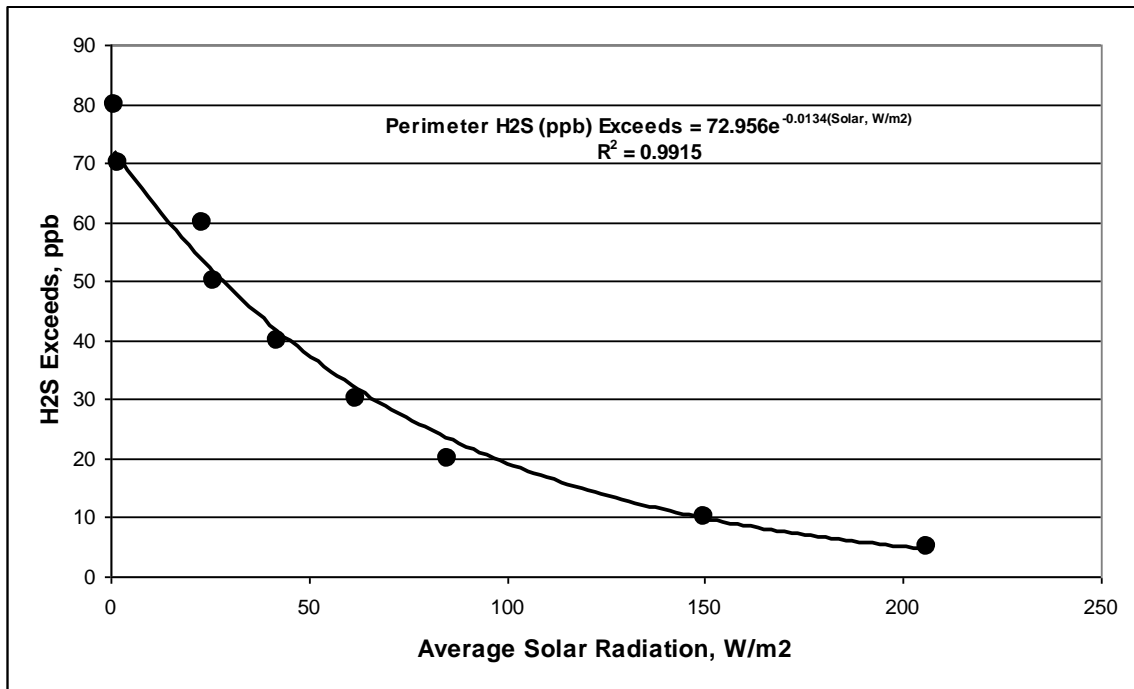


Figure 11. Perimeter H₂S concentration data for the single DWS source monitored highlighting three consecutive days and the influence of solar radiation on H₂S concentration.



A



B

Figure 12. Perimeter H₂S concentration exceedance concentration level as a function of solar radiation for (A) Source 1 and (B) Source 2.

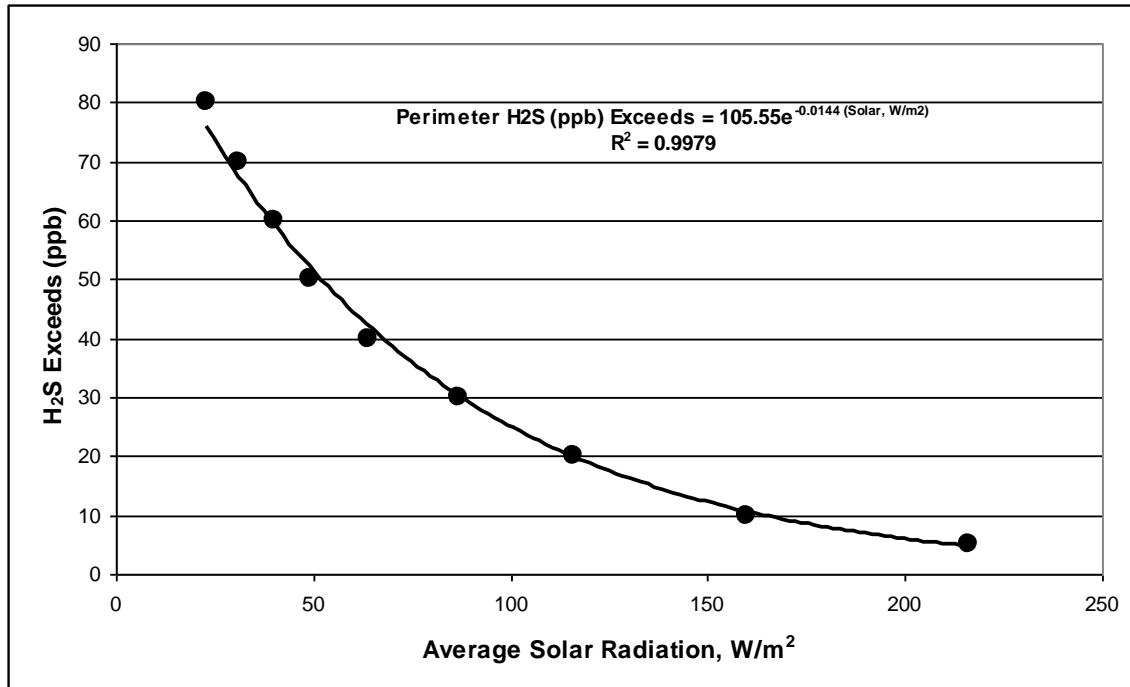
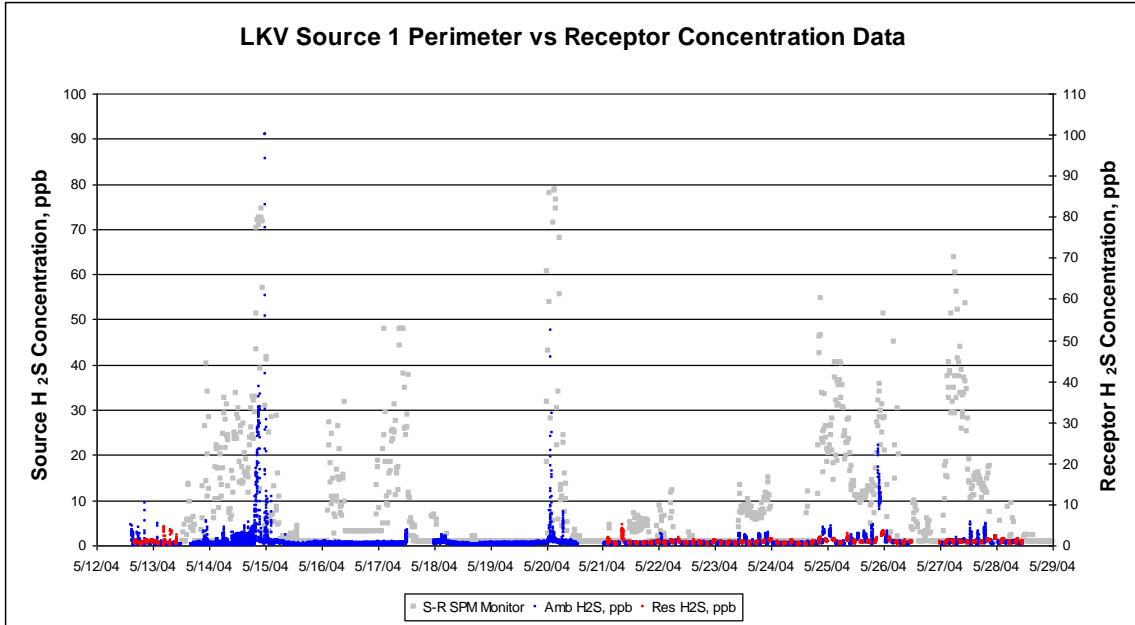
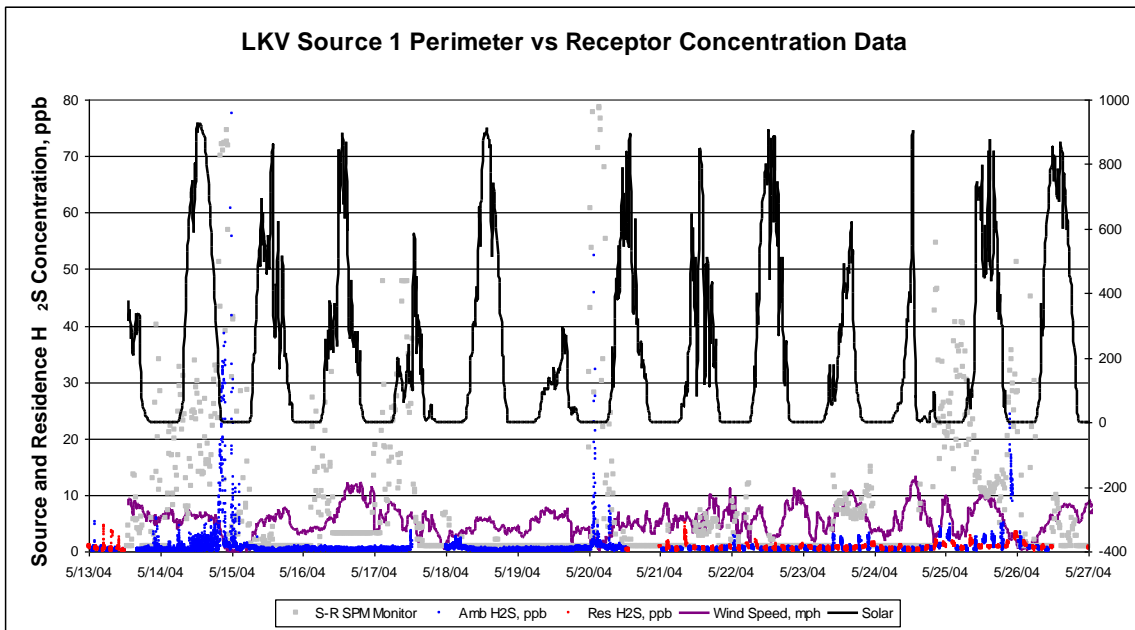


Figure 13. Perimeter H₂S concentration exceedance concentration level as a function of solar radiation for all nine sources monitored.



A



B

Figure 14. LKV Source 1 perimeter H₂S concentration for the SPM monitors located between this source and the monitored LKV residence. (A) Superimposed on this graph is the H₂S concentration measured with the MAL for the ambient (blue) and inside house (red) sample locations and (B) the additional information provided by solar and wind speed for the three distinct elevated residence H₂S concentrations.

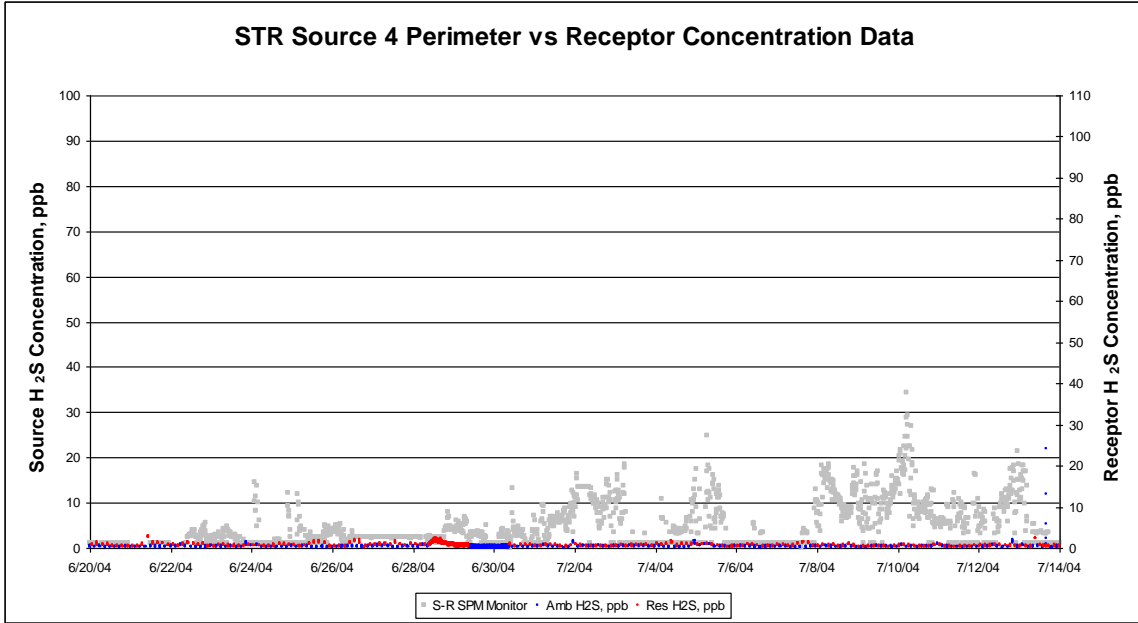
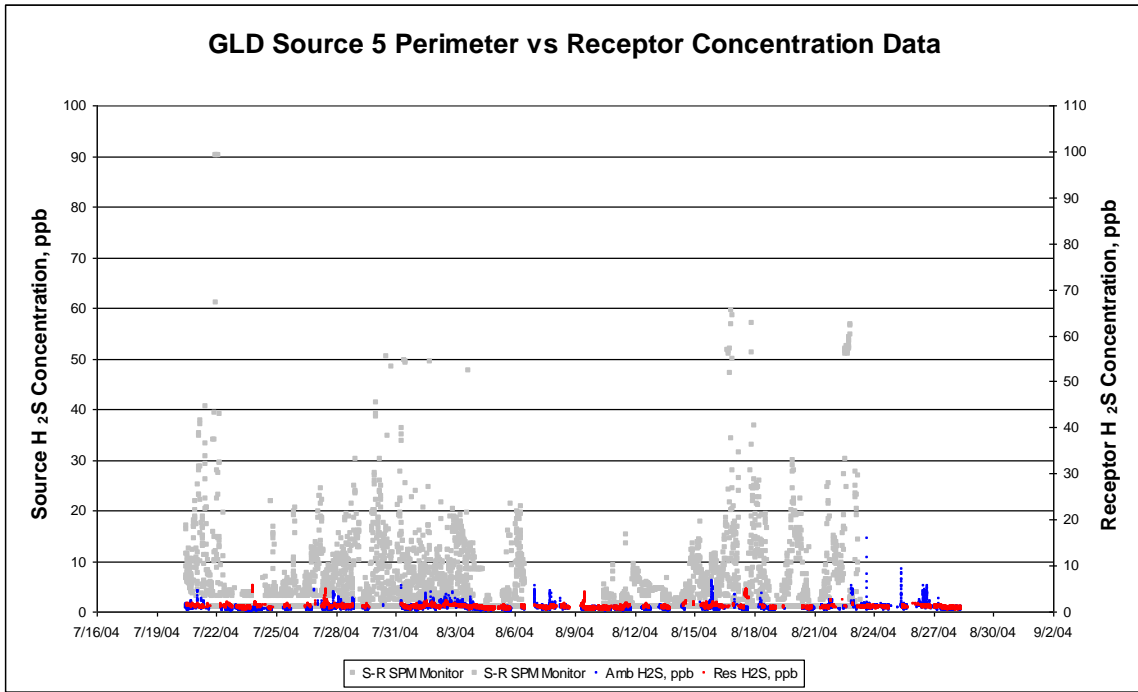
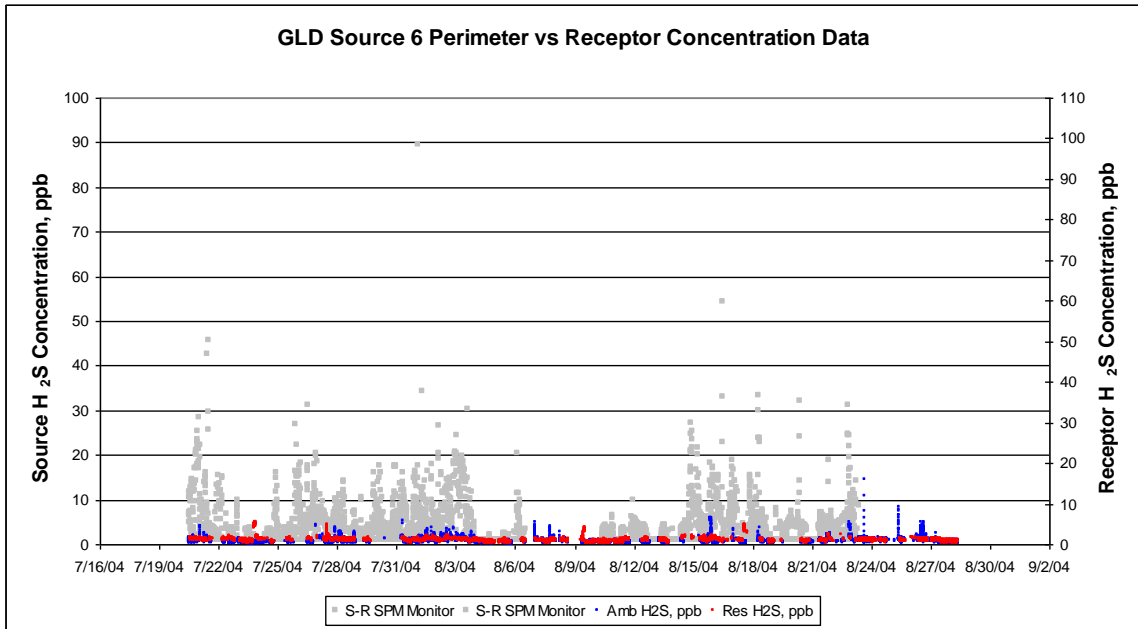


Figure 15. STR source 4 perimeter H₂S concentration for the SPM monitors located between this source and the monitored STR residence. Superimposed on this graph is the H₂S concentration measured with the MAL for the ambient (blue) and inside house (red) sample locations.



A



B

Figure 16. GLD Sources 5 (A) and 6 (B) perimeter H₂S concentrations for the SPM monitors located between these two sources and the monitored GLD residence. Superimposed on each graph is the H₂S concentration measured with the MAL for the ambient (blue) and inside house (red) sample locations.

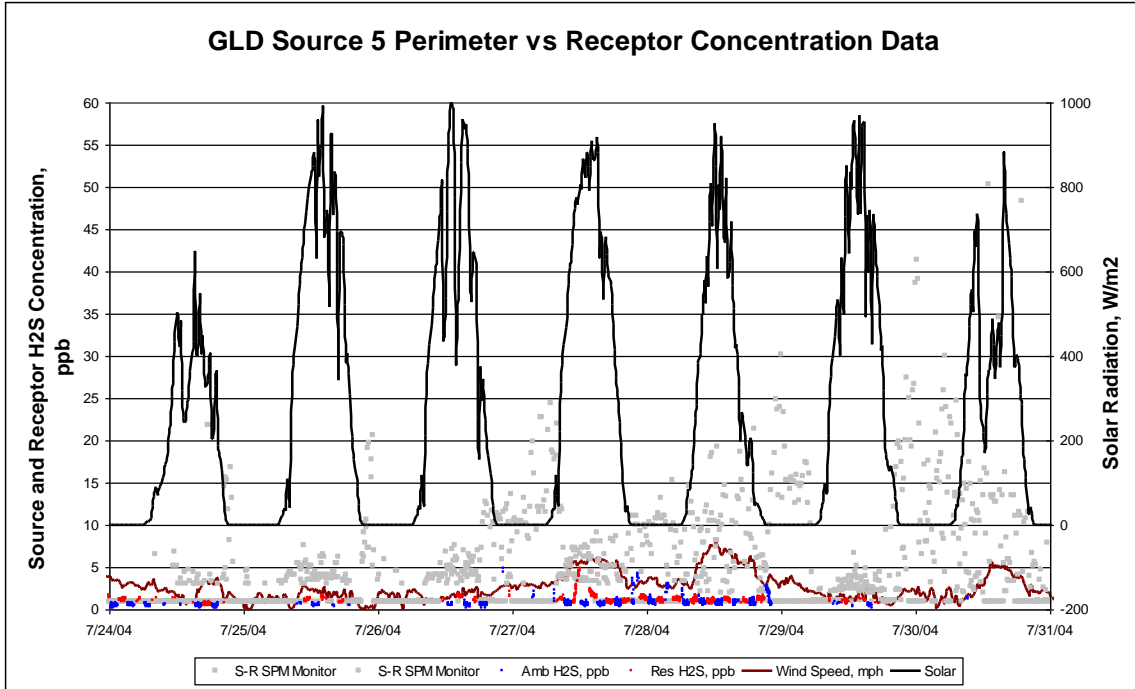


Figure 17. GLD Source 5 perimeter H₂S concentrations for the SPM monitors located between this source and the monitored GLD residence in relation to solar radiation and wind speed.

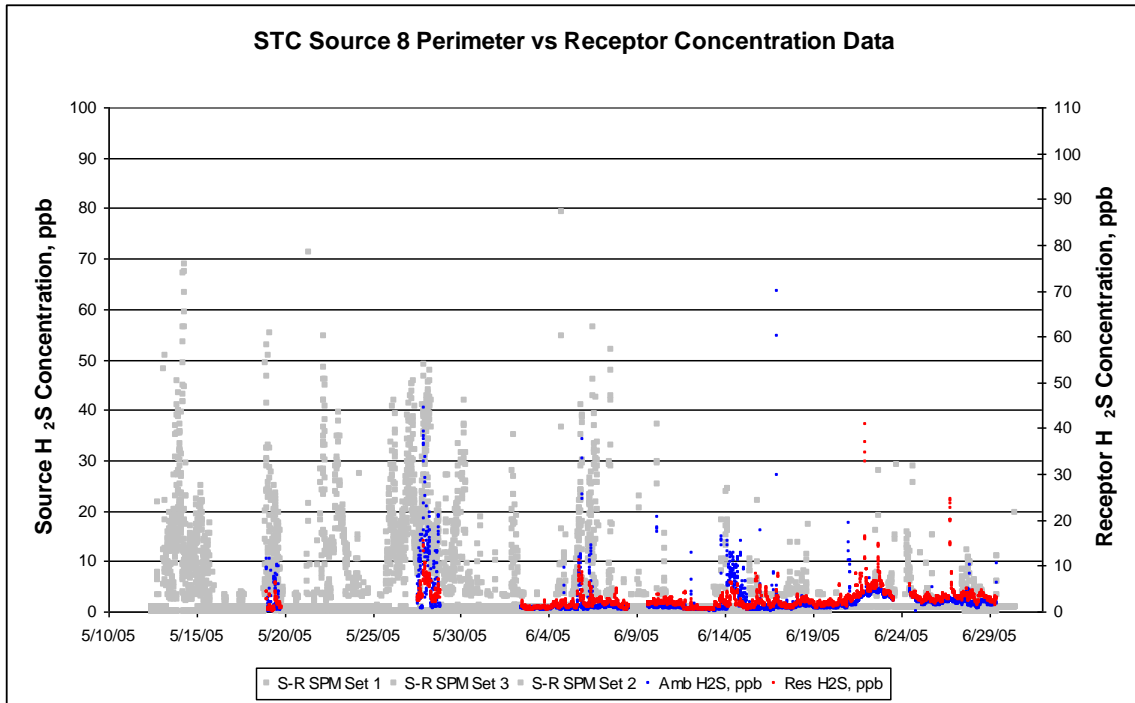


Figure 18. STC source 8 perimeter H₂S concentration for the SPM monitors located between this source and the monitored STC residence. Superimposed on this graph is the H₂S concentration measured with the MAL for the ambient (blue) and inside house (red) sample locations.

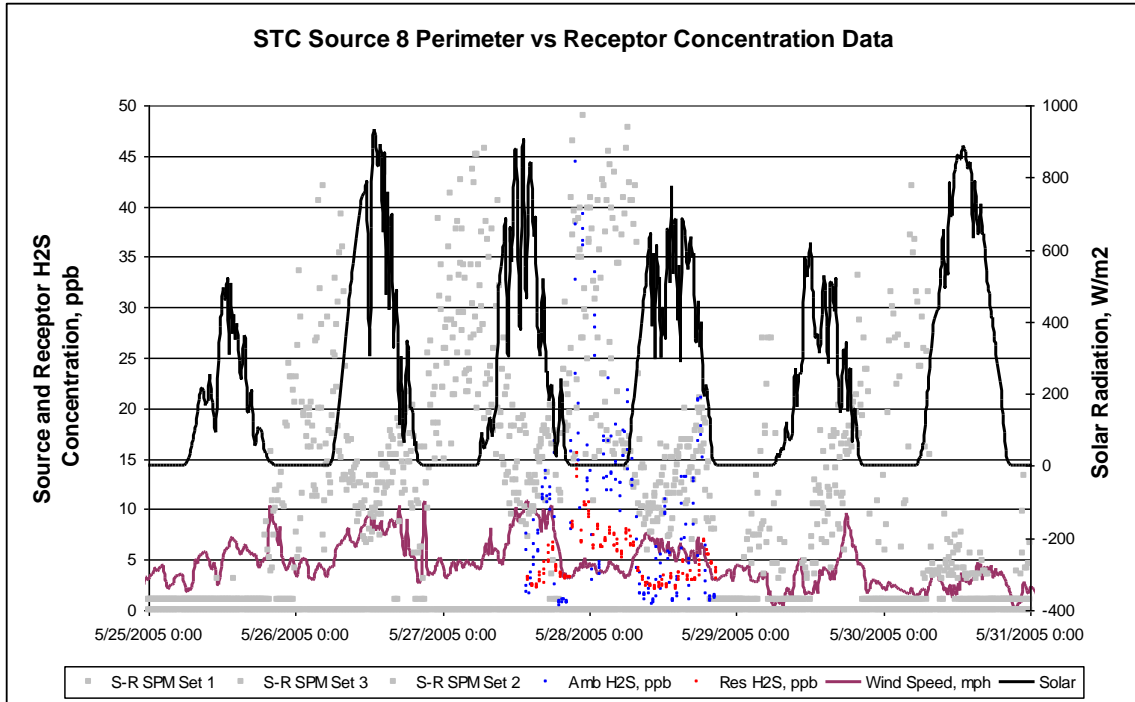


Figure 19. STC Source 8 perimeter H₂S concentrations for the SPM monitors located between this source and the monitored STC residence in relation to solar radiation and wind speed.

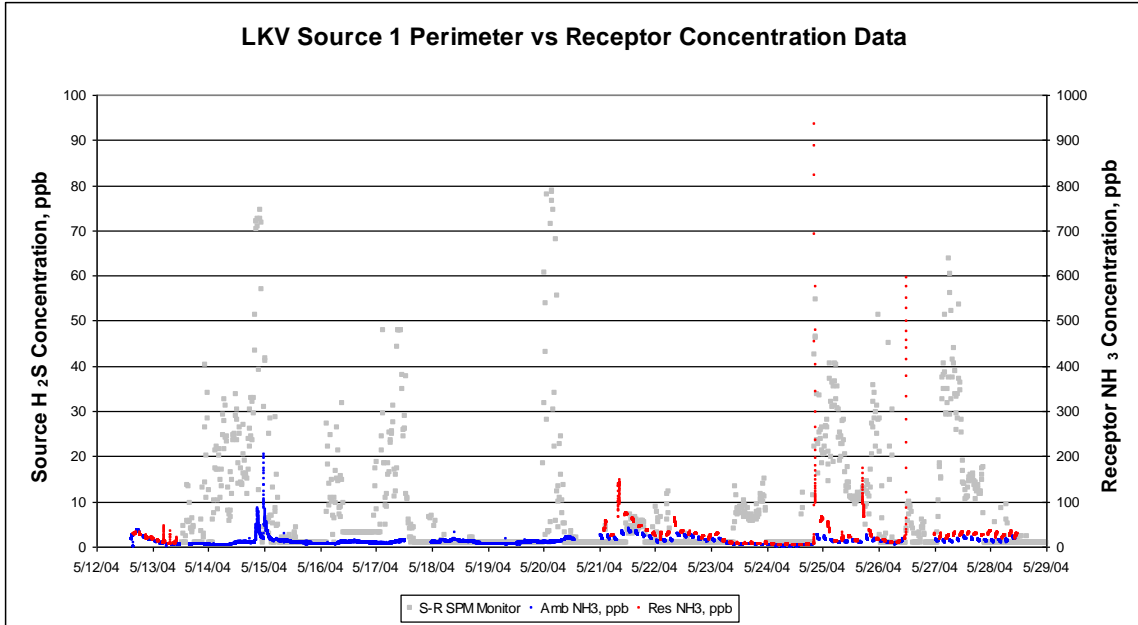


Figure 20. LKV Source 1 perimeter H₂S concentration for the SPM monitors located between this source and the monitored LKV residence. Superimposed on this graph is the NH₃ concentration measured with the MAL for the ambient (blue) and inside house (red) sample locations.

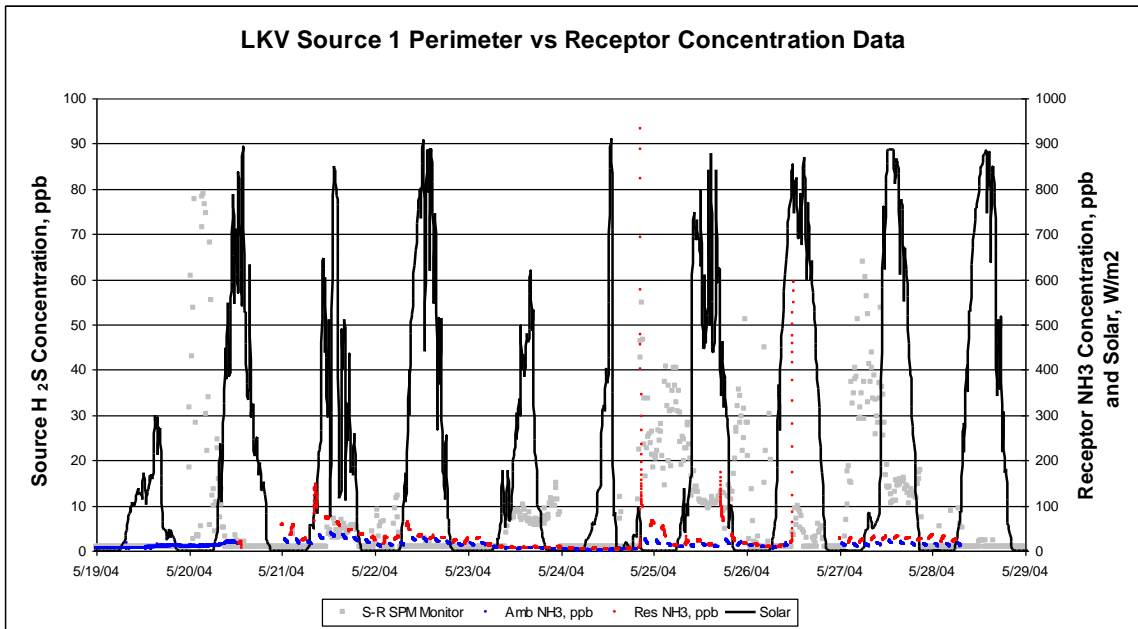


Figure 21. LKV Source 1 perimeter H₂S concentration for the SPM monitors located between this source and the monitored LKV residence. Superimposed on this graph is the NH₃ concentration measured with the MAL for the ambient (blue) and inside house (red) sample locations and the solar conditions during these time period.

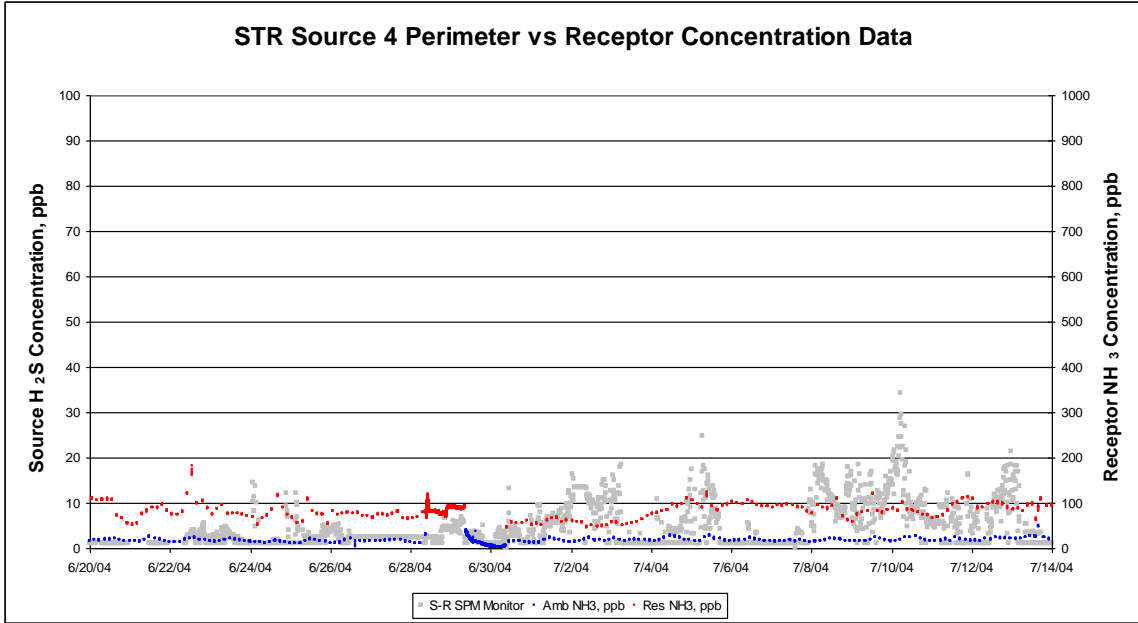
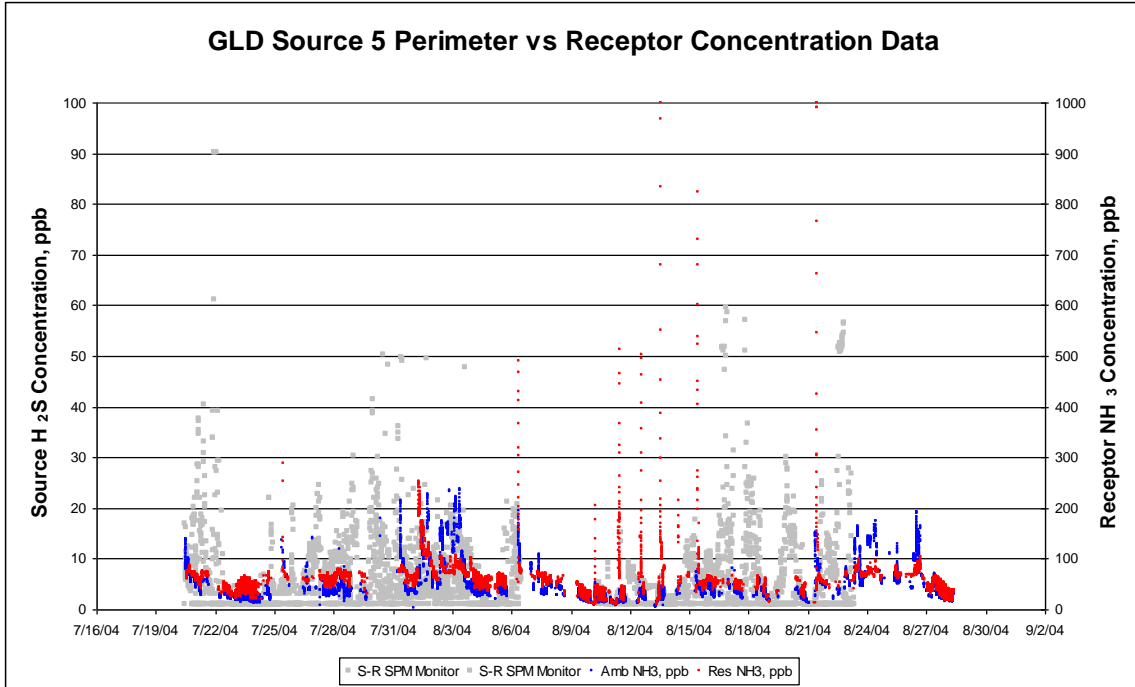
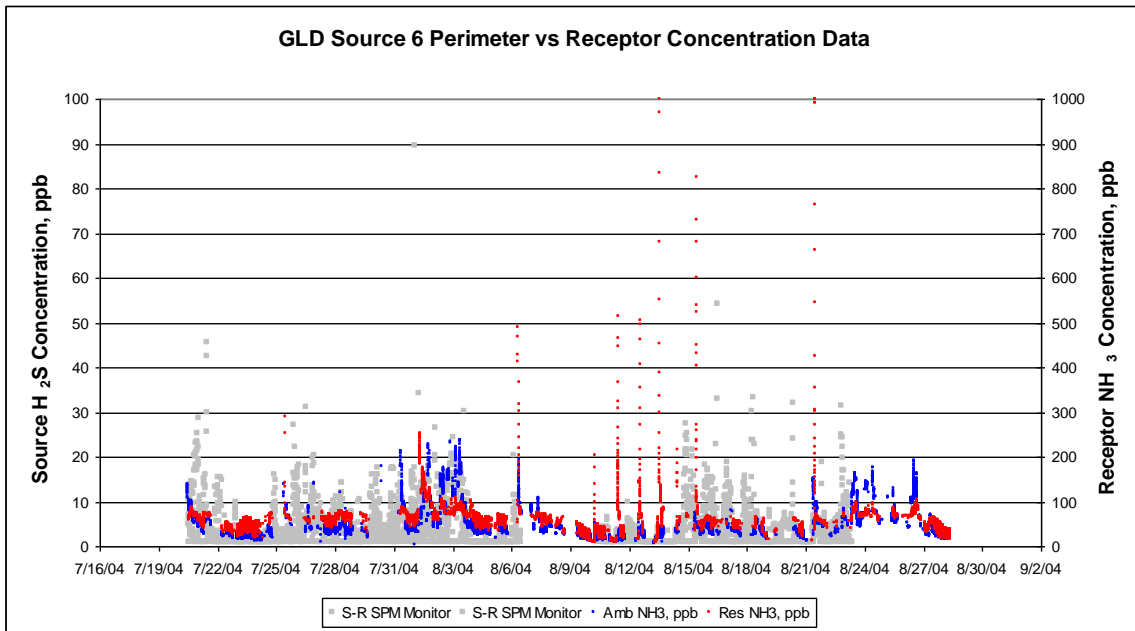


Figure 22. STR Source 4 perimeter H₂S concentration for the SPM monitors located between this source and the monitored STR residence. Superimposed on this graph is the NH₃ concentration measured with the MAL for the ambient (blue) and inside house (red) sample locations.



A



B

Figure 23. GLD Sources 5 (A) and 6 (B) perimeter H₂S concentrations for the SPM monitors located between these sources and the monitored GLD residence. Superimposed on this graph is the NH₃ concentration measured with the MAL for the ambient (blue) and inside house (red) sample locations.

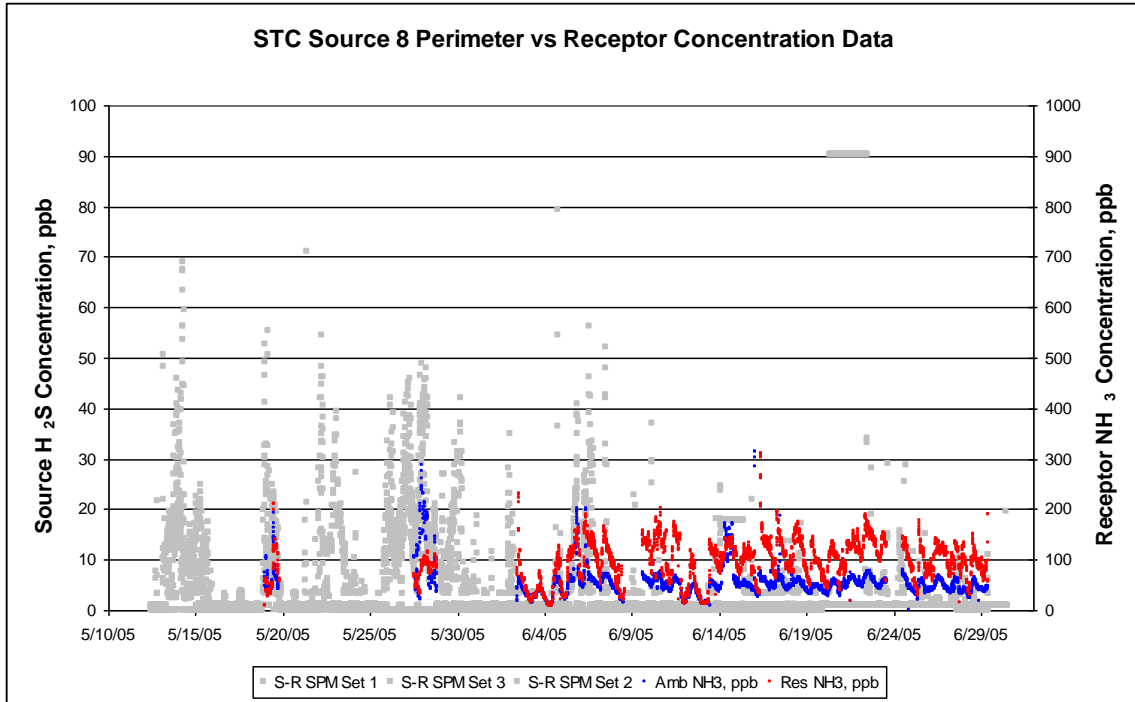


Figure 24. STC Source 8 perimeter H₂S concentration for the SPM monitors located between this source and the monitored STC residence. Superimposed on this graph is the NH₃ concentration measured with the MAL for the ambient (blue) and inside house (red) sample locations.

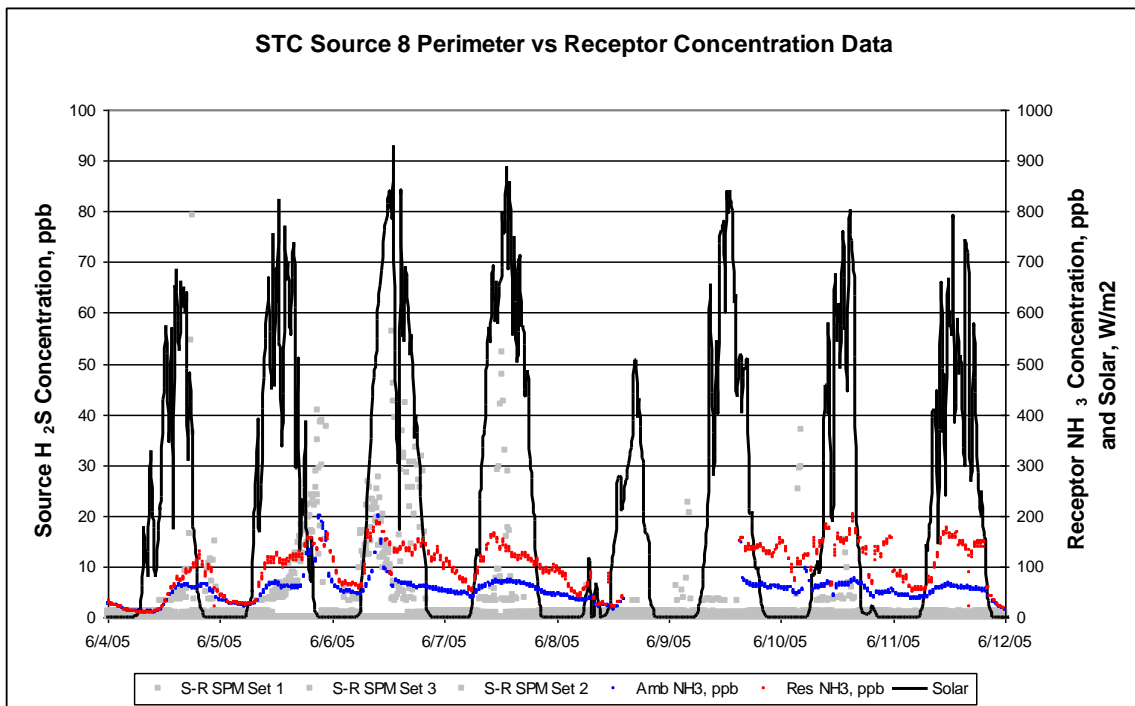


Figure 25. STC Source 8 perimeter H₂S concentration for the SPM monitors located between this source and the monitored STC residence. Superimposed on this graph is the NH₃ concentration measured with the MAL for the ambient (blue) and inside house (red) sample locations along with the solar radiation.

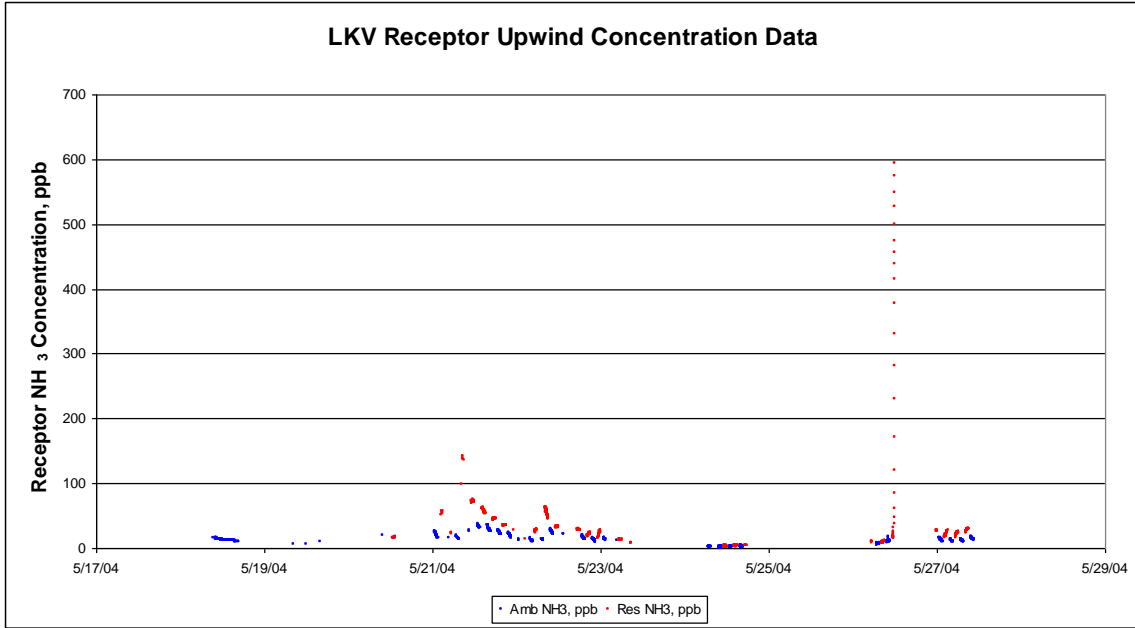


Figure 26. LKV residence ambient (blue) and inside residence (red) NH₃ concentration recorded when the residence was upwind of any animal-related source.

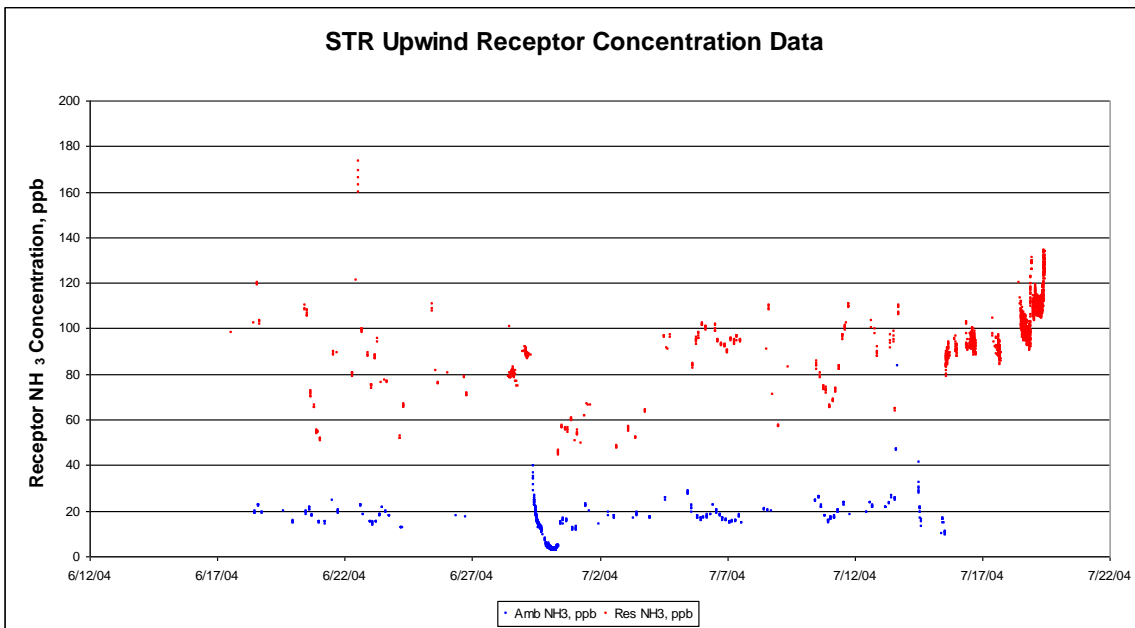


Figure 27. STR residence ambient (blue) and inside residence (red) NH₃ concentration recorded when the residence was upwind of any animal-related source.

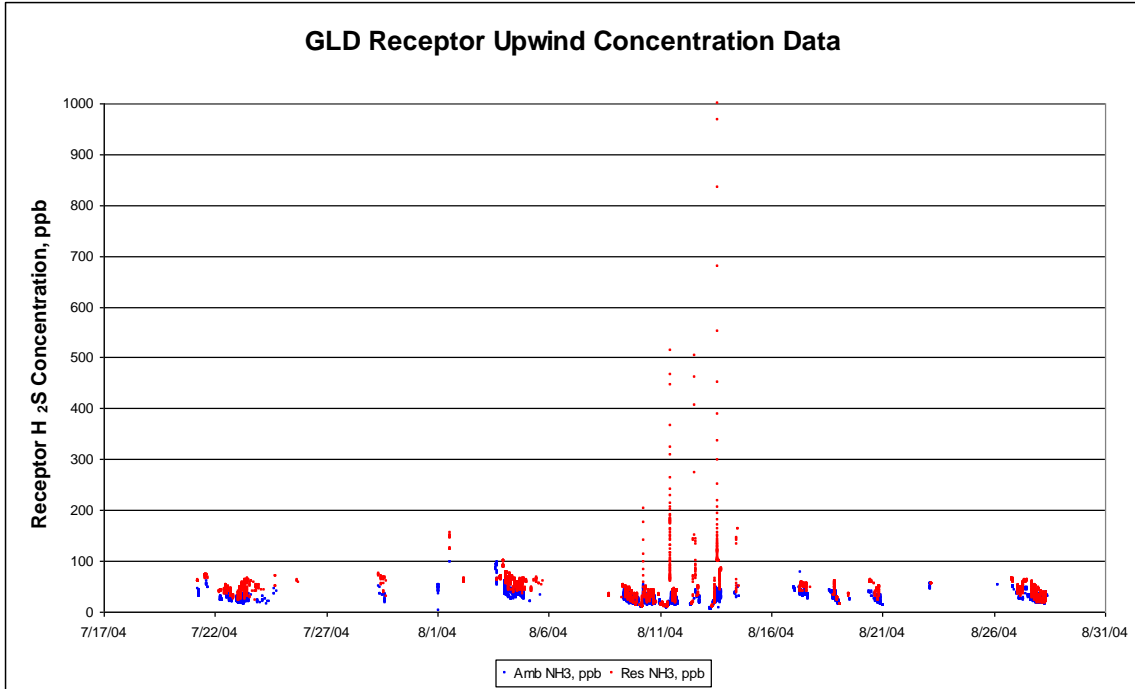


Figure 28. GLD residence ambient (blue) and inside residence (red) NH₃ concentration recorded when the residence was upwind of any animal-related source.

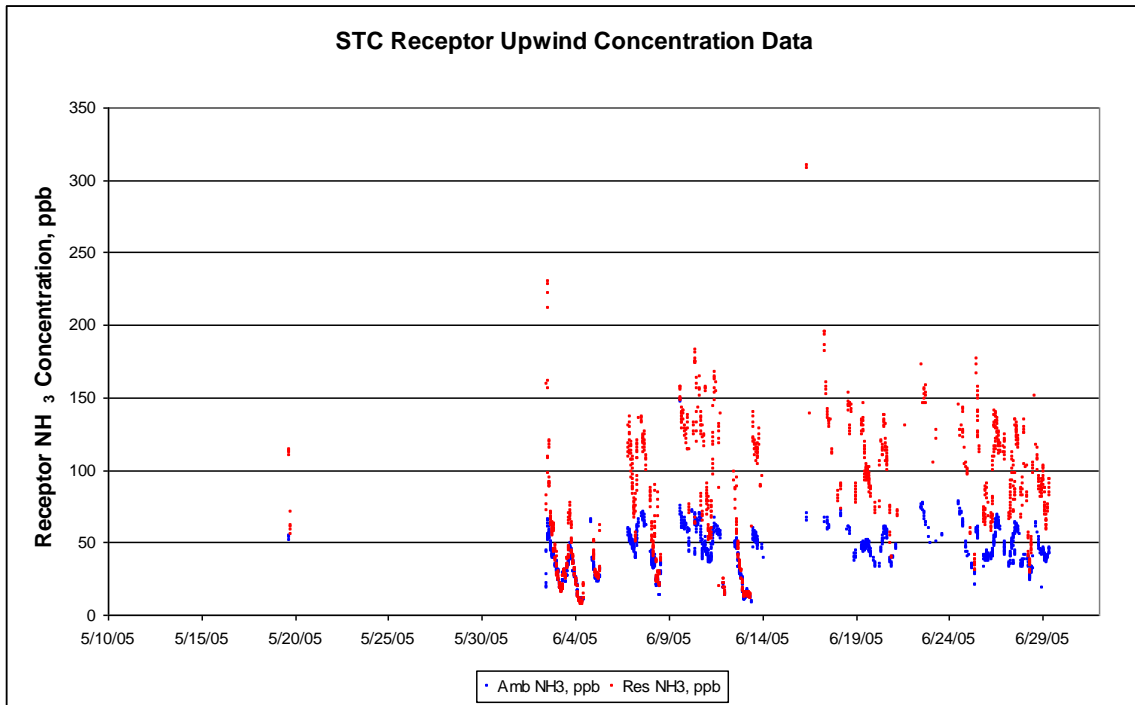
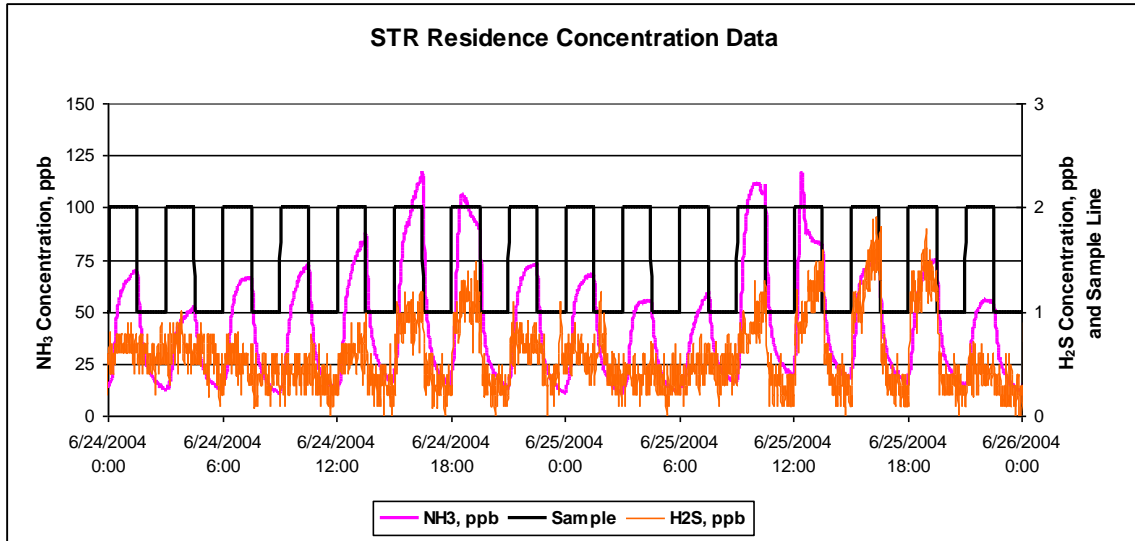
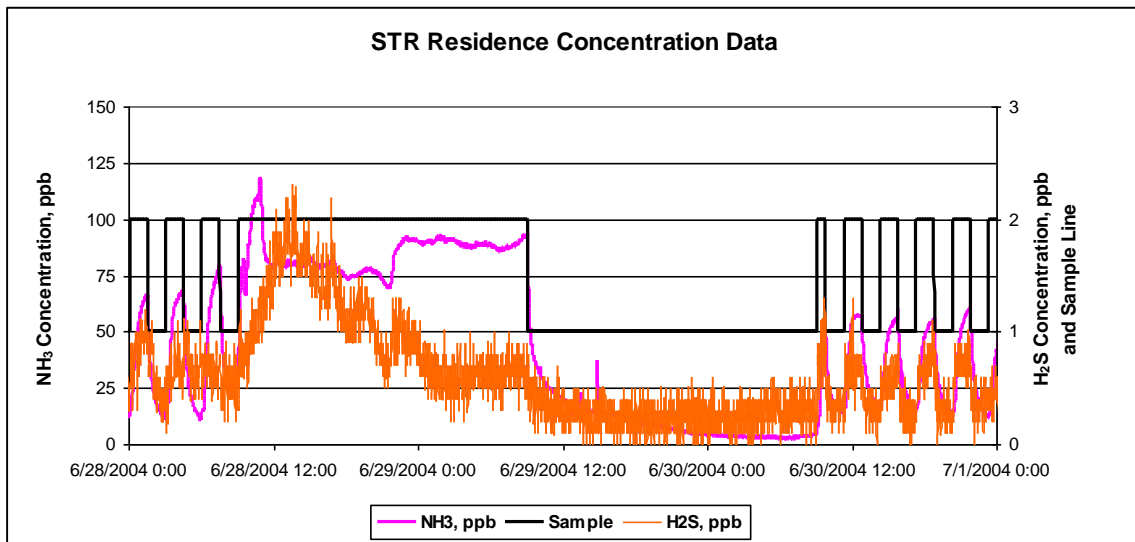


Figure 29. STC residence ambient (blue) and inside residence (red) NH₃ concentration recorded when the residence was upwind of any animal-related source.

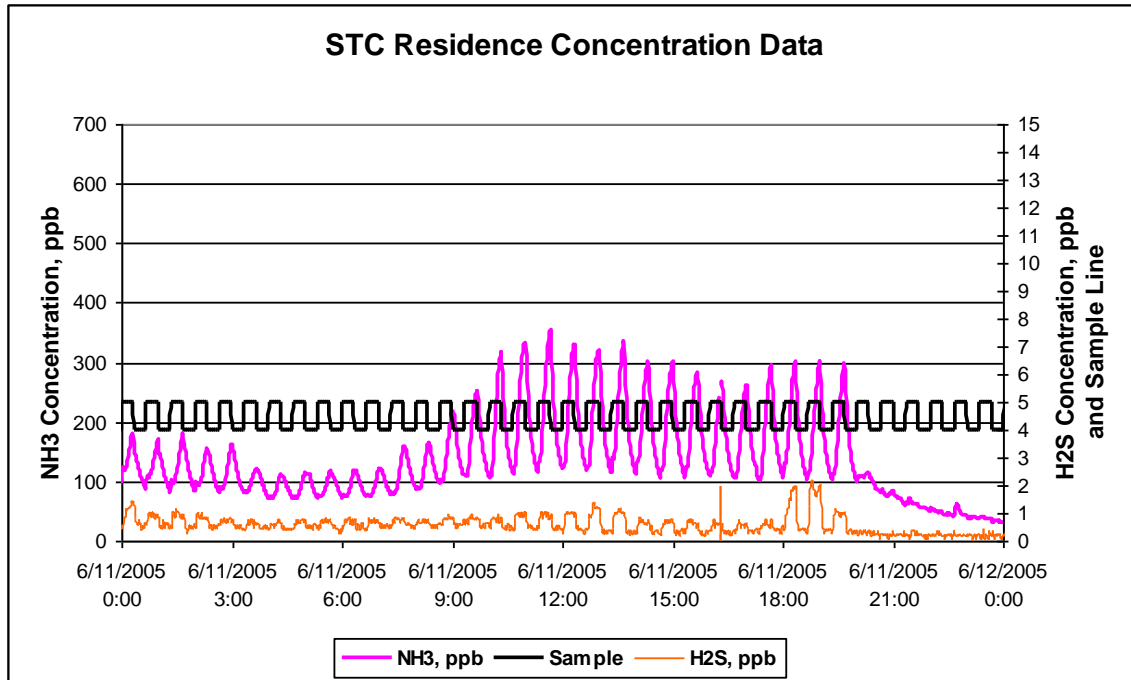


A

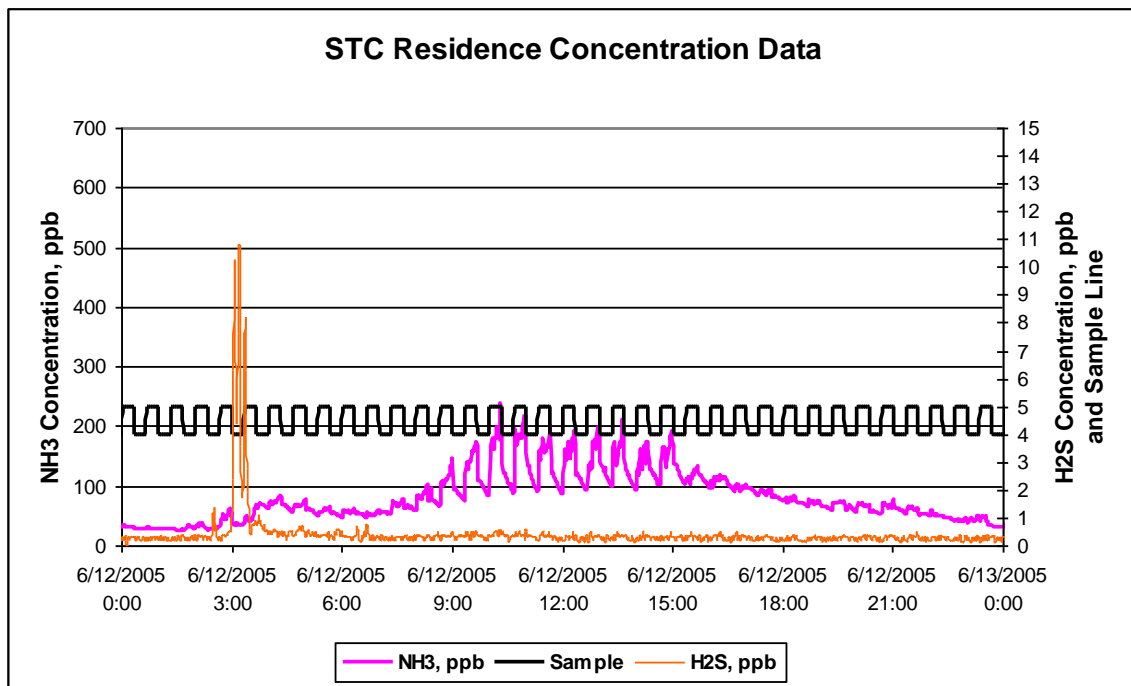


B

Figure 30. STR residence monitoring showing real-time data collected as the sampling system switched from inside to outside home sampling. The sample lines are identified with ambient or outside home air sampling (Sample=1) and inside home sampling (Sample=2). In (A) the sampling sequence was 90 minutes sampling for each sample location. In (B) a longer term sampling was initiated to verify the steady-state concentrations achieved at both sample locations.



A



B

Figure 31. STC residence monitoring showing real-time data collected as the sampling system switched from inside to outside home sampling. The sample lines are identified with ambient or outside home sampling (Sample=4) and inside home sampling (Sample=5). For the STC monitoring, the sampling sequence was fixed at 20 minutes sampling for each sample location.

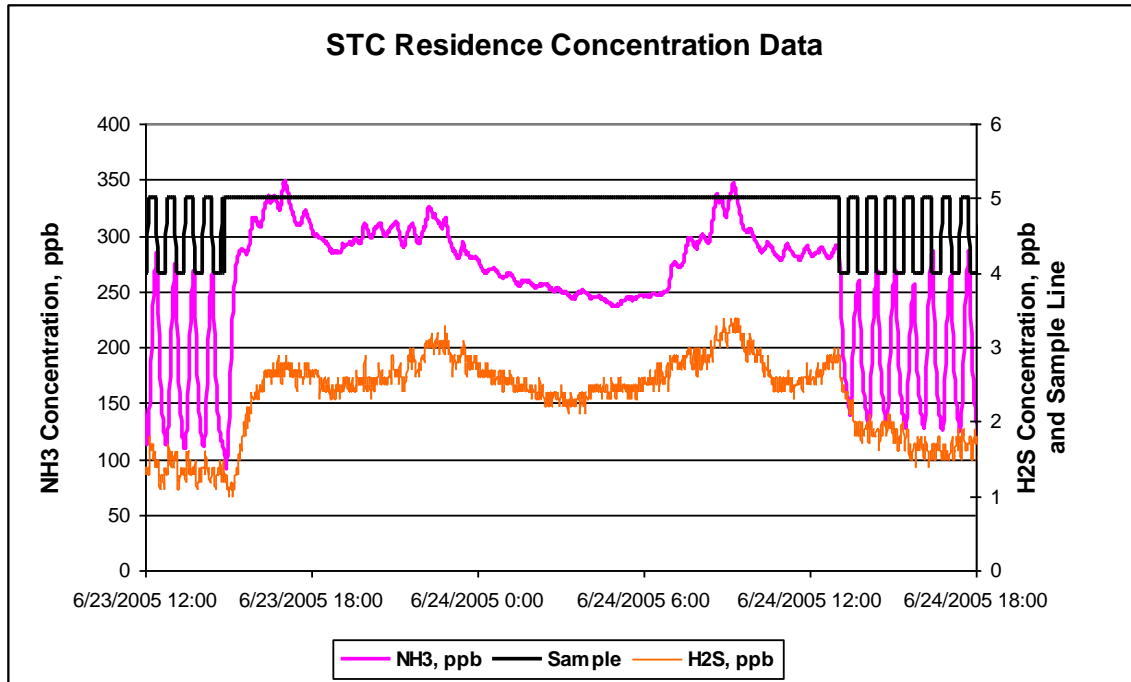
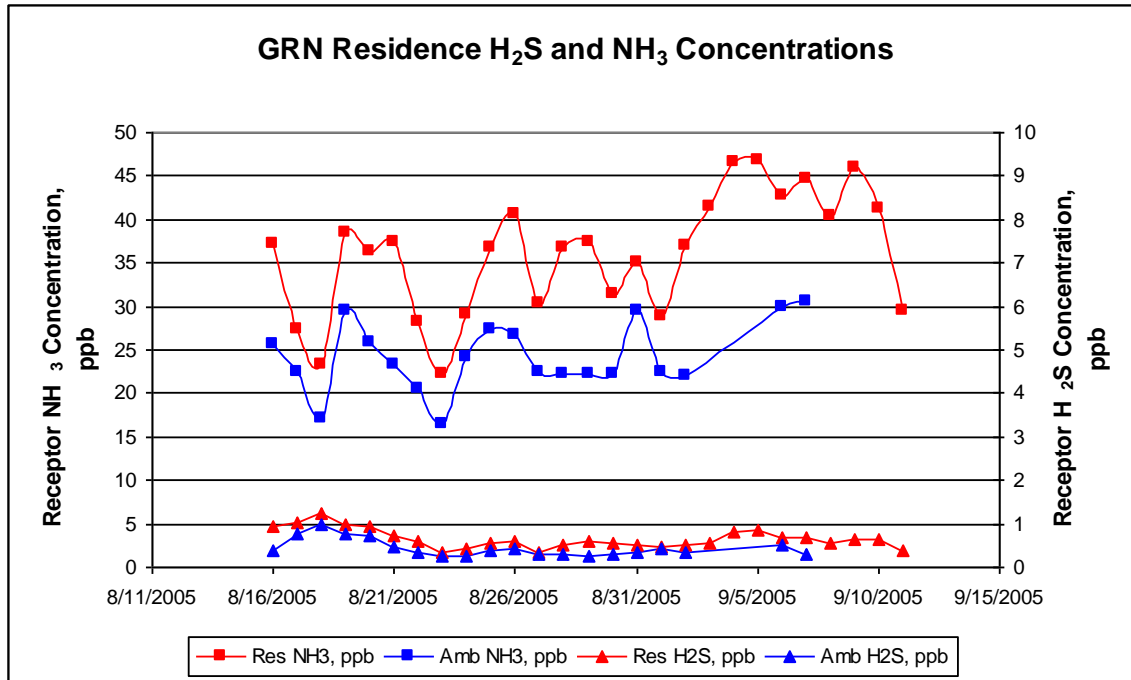
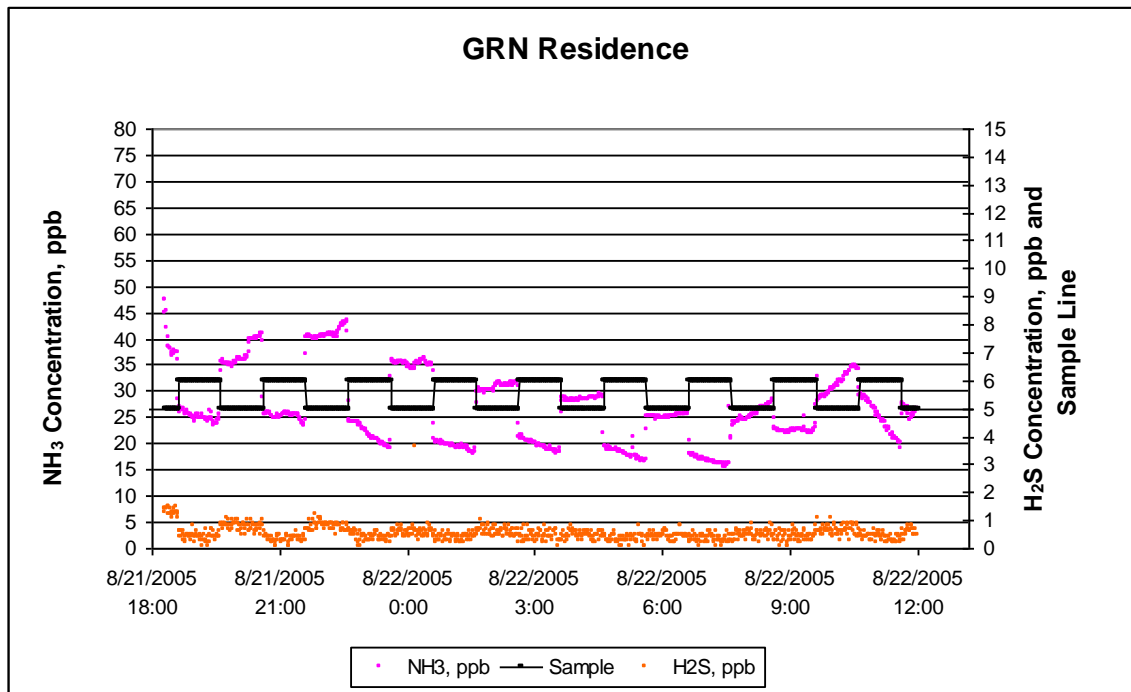


Figure 32. STC residence monitoring showing real-time data collected as the sampling system was fixed to inside home sampling for an extended period.

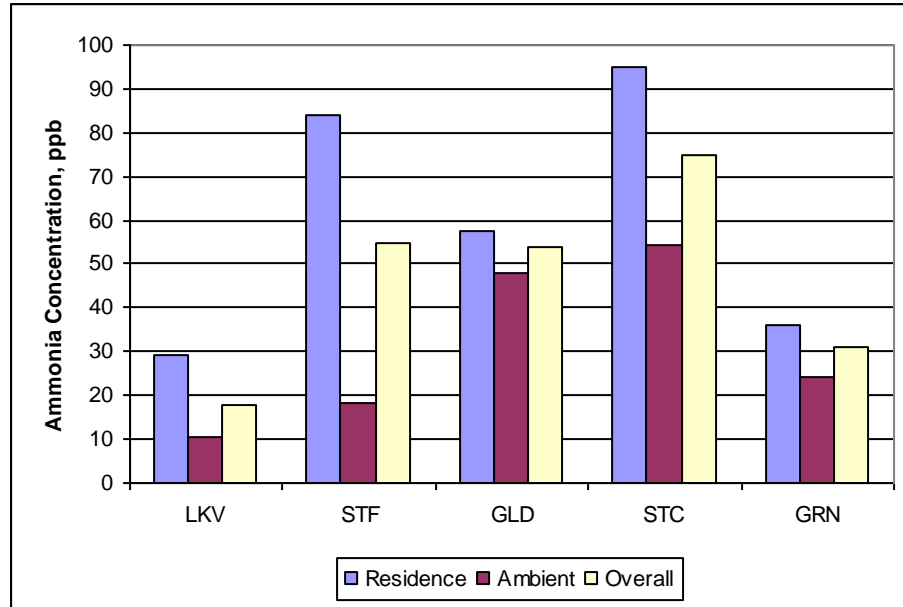


A

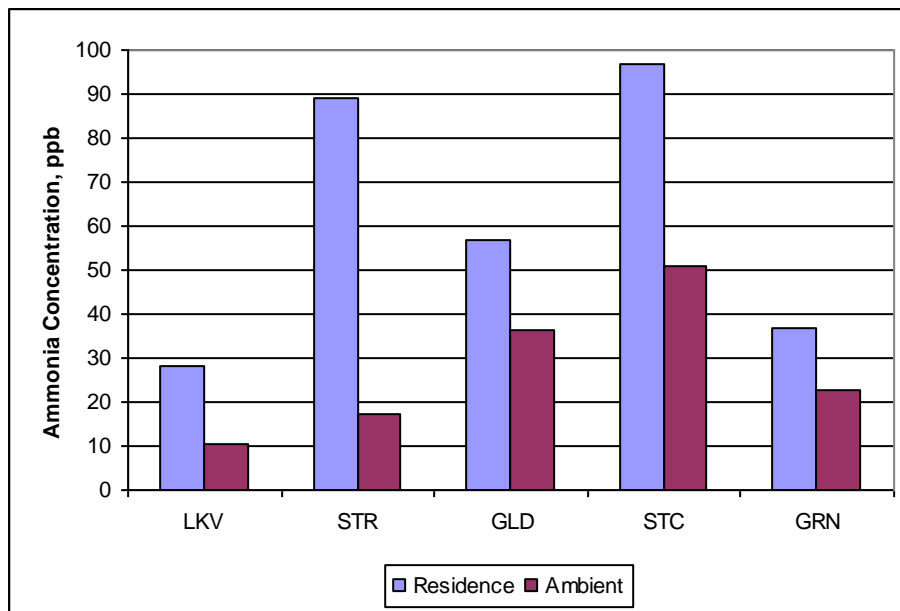


B

Figure 33. GRN residence (A) daily average hydrogen sulfide and ammonia concentration comparison between inside residence (red) and in the ambient (blue) air surrounding the residence, and, (B) a typical response in real-time showing ammonia and hydrogen sulfide concentrations for inside the residence (Sample Line=5) and in the ambient air (Sample Line=6).

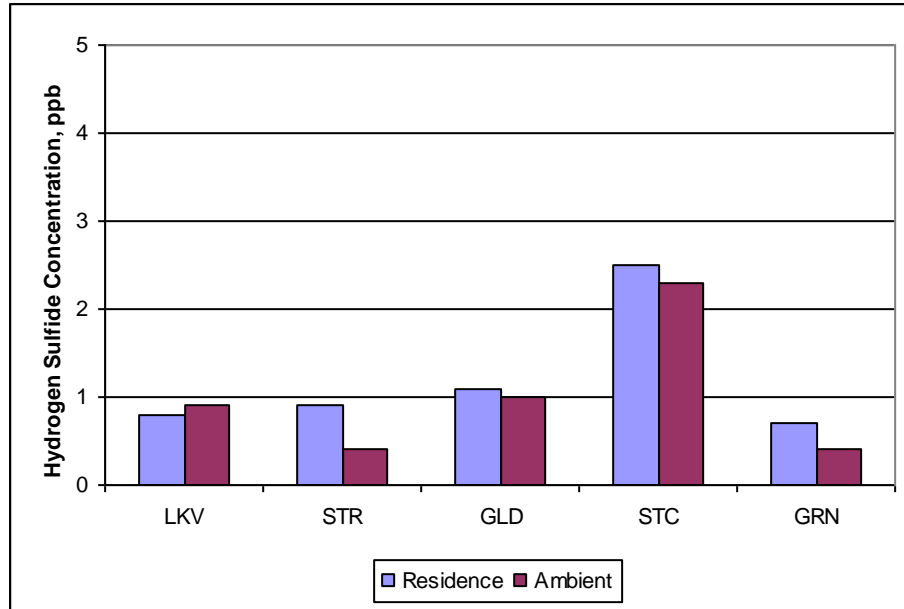


A

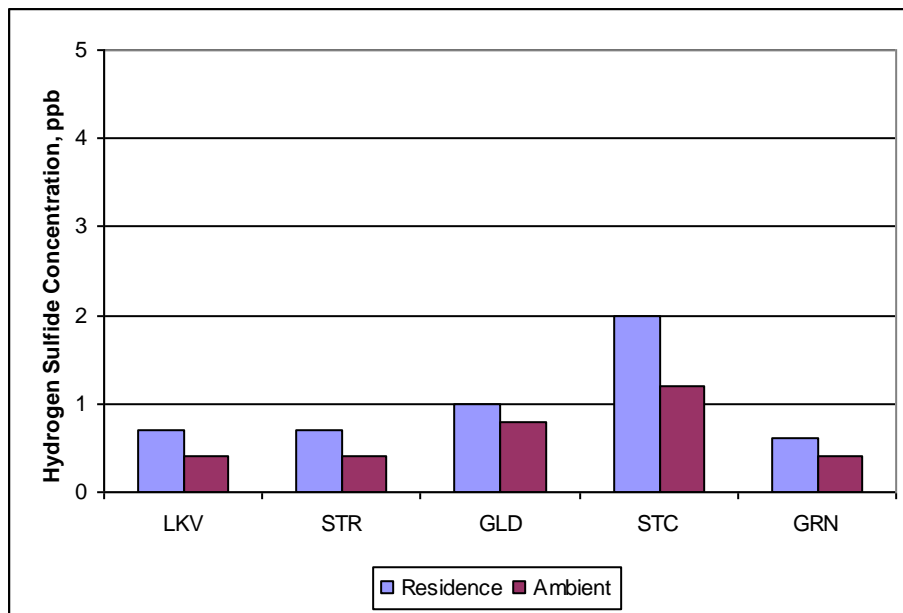


B

Figure 34. (A) Overall daily average NH₃ concentration inside, outside, and averaged across all measurements (Overall) and (B) median values for the five residences monitored.



A



B

Figure 35. (A) Overall daily average H₂S concentration inside and outside and (B) median values for each of the five residences monitored.