Picarro Surveyor™ Leak Detection Study

Sacramento Side-by-Side Study

3/22/2012 – 4/17/2012

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ABSTRACT. The Sacramento Side-by-Side Study was conducted from March 22, 2012 through April 17th, 2012 and designed to assess the capabilities and accuracy of the vehicle mounted Picarro's Surveyor™ methane detection system and P- Cubed Software which is designed to locate natural gas pipeline leaks emanating from distribution systems. The Study was conducted in Pacific Gas & Electric's Sacramento Gas Division. Its primary purpose was to compare the performance of Picarro's Leak Detection System against traditional ground based leak survey methods. This report highlights the leak survey results of 16 gas facility maps containing 4,195 gas services and 56 miles of distribution main. The report compares the survey rate, ability to locate gradable and non-hazardous gas leaks while assessing the survey coverage of both methods.

1. INTRODUCTION.

Preceding the Sacramento side-by-side study Pacific Gas & Electric conducted two controlled tests at its Livermore Training Academy[1] and a similar leak survey training facility located in Southern Nevada[2]. The controlled tests were small scale conducted in training facilities where the leaks could be operator controlled, leak locations were known (by both Picarro and test administrators in Livermore and only test administrators in Nevada), and where additional atmospheric data could be collected. These controlled tests established a "Proof of Concept" showing that the Picarro instrument could detect natural gas leaks in simulated natural gas distribution systems from a variety of leak sources both above and below ground and at various concentrations.

Analysis of the results from the control tests was utilized to further refine the Picarro leak detection algorithms and software which would be used for field testing in Pacific Gas & Electric's Diablo[3] division. Sacramento Division was selected as a second side-by-side field study to test the leak detection ability of the Picarro Surveyor™ against traditional leak detection instruments currently used by PG&E.

By comparison the proposed methods and instruments developed by Picarro make use of a vehicle mounted cavity ring down spectrometer fitted with a sonic anemometer, a GPS device to measure methane concentrations, and various atmospheric conditions relative to a fixed position to sense and locate natural gas leaks. The Picarro instrument utilizes a cavity ring down spectrometer and can detect methane in the parts per billion (ppb) range allowing the survey method to be conducted primarily in a vehicle driven at common traffic speeds (see below in FOV section for more explanation on vehicle speeds). However, the Picarro instrument samples gas every second in comparison with the traditional tools which sample continuously. Additionally, the higher sensitivity and associated P-Cubed software does not require the surveyor to have detailed knowledge of buried mains and services as Picarro's software generates a Leak Indication Search Area (LISA) once a plume of methane is detected (see *Figure 1.0)*. Moreover, the Picarro method and instrument differs from current methods as Picarro's software generates a Field Of View (FOV) plot showing which mains and services have been surveyed by the instrument, a feature not widely available with current methods and instruments. Also, the speed of the vehicle has a direct affect on the FOV. The coverage is lessened the faster the vehicle is driven.

A LISA is a shown below in *Figure 1.0* as indicated by the yellow wedge. By using a set of GPS coordinates and a corresponding LISA to investigate, the Piccaro method requires a natural gas leak be investigated by the field surveyor, field graded, and recorded or repaired, since the Picarro Surveyor™ cannot pinpoint or grade leaks. TFOV plot shown in *Figure 1.0* is illustrated by the green and tan areas and is representative of the region which the Picarro was surveying. By detecting methane plumes at distance and targeting them, the Picarro method and instrument show a shift in leak survey methodology compared to current methods and instruments.

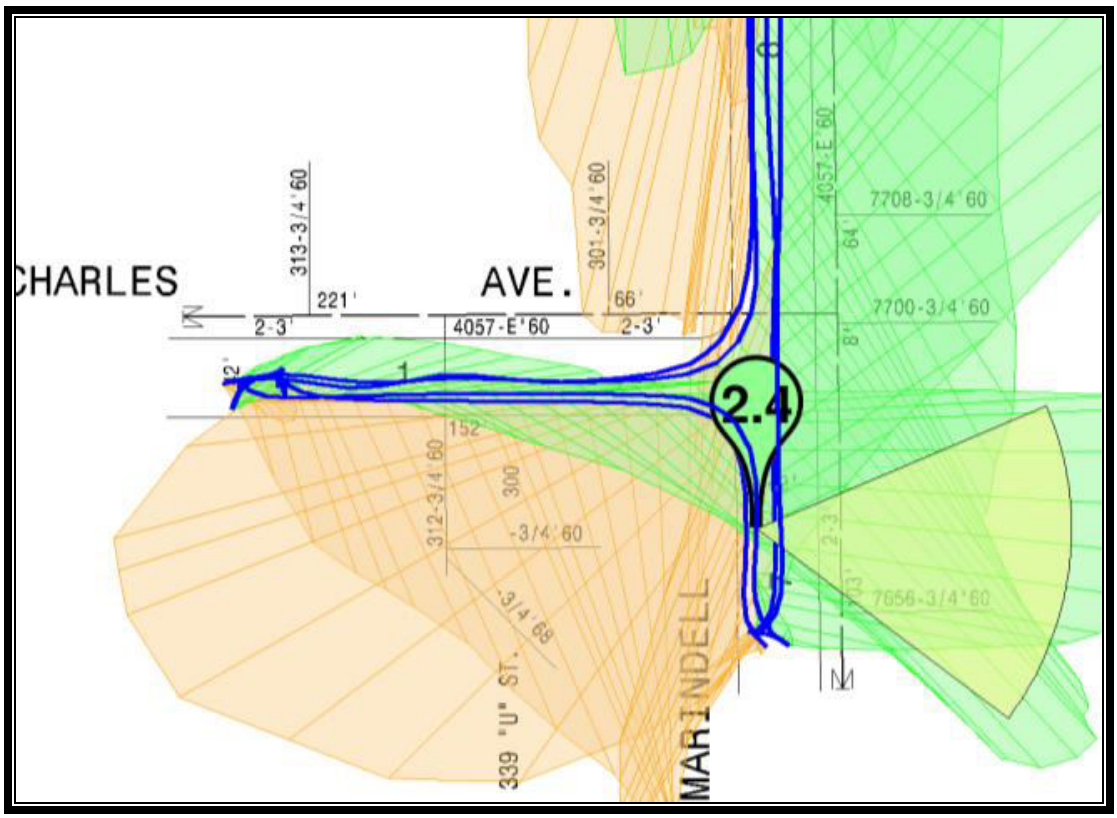


Figure 1.0 – Leak Indication Search Area (LISA)

As the Picarro Surveyor™ methods and instruments represent a new model by which gas utilities can leak survey distribution systems it is critical for Pacific Gas & Electric to fully evaluate Picarro's leak survey system while understanding the benefits and impacts of potentially adopting this technology. To further evaluate Picarro's technology, the Sacramento Side-by-Side Study was designed to utilize results and recommendations from the previous Diablo Side-by-Side Study and compare the results of traditional ground survey to the Picarro Surveyor™ and associated P-Cubed Software. The Study's primary focus will be on each method's ability to sense and locate leaks as well as the survey rates and FOV, or coverage, of traditional and Picarro leak surveys.

2. METHOD. Pacific Gas & Electric's Sacramento Gas Division is located in California's Central Valley region, a vast flat river valley situated between the coastal mountain range and Sierra Nevada mountain range. The Sacramento Division gas operation services approximately 545,000 natural gas customers, a significant portion of PG&E's total gas customer base. The Sacramento Division, specifically the 16 gas facility plat maps, were chosen due to their flat level land and variety of suburban and rural regions. Additionally, the combination of the Sacramento Division's large number of customers and variety in suburban and rural regions are representative of much of PG&E's service territory.

The Sacramento valley in the Sacramento Division has an elevation ranging from 30 to 150 feet and is surrounded by rolling grassland, farmland, and urban sprawl in the form of housing and light commercial. The small farms in the vicinity of the area surveyed vary from small livestock operations to mixed produce production while the suburban areas represent common subdivisions for the region. *Figure 2.0* is an aerial view of the operating Division, specifically the 16 plat maps which were surveyed during the side-by-side test.

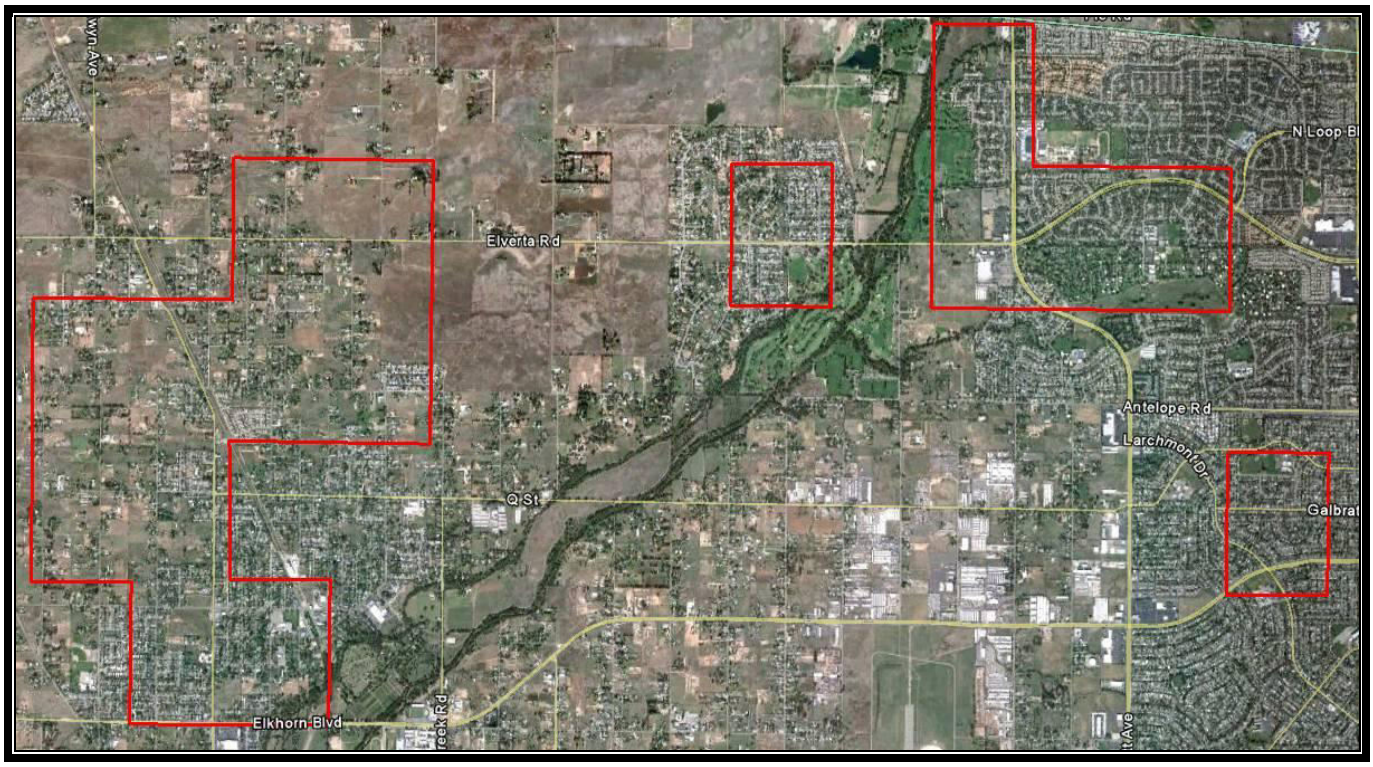


Figure 2.0 – Sacramento Valley (area surveyed in red)

The side-by-side testing method took measurements of three key metrics to evaluate the effectiveness of current survey methods and instruments to the Picarro Surveyor™ and P-Cubed software. These three metrics were:

1. Total leaks found.
2. System survey coverage.
3. Time to complete leak survey.

To ensure the Local Leak Survey Technicians remained unbiased in their survey methods and techniques as each surveyed the 16 plat maps in a routine 5-year leak survey cycle, they were not aware that the 16 plats surveyed would be part of a side-by-side study. The traditional leak survey of the 16 plats occurred from 1/12/2012 - 2/21/2012 and recorded all findings in accordance with PG&E Standard Operating Procedures. Additionally, as part of the traditional leak survey process the local Mapping Office provided an "Open Leaks Report" and plotted all known existing leaks on the corresponding 16 plat maps prior to local operations conducting the traditional leak survey while Picarro drivers were not provided the same plat maps with existing leak information shown.

Following the traditional leak survey the Picarro Surveyor™ (installed in a Chevrolet Sierra Hybrid pickup truck) drivers were provided with unmarked versions of the 16 plats to be leak surveyed and were instructed to survey (drive) the maps from 3/22/2012 - 4/17/2012 (start of Picarro survey began approximately a month after the traditional survey was completed). Drivers were instructed to

record their time driving and note any large leak indications. Upon completion of the Picarro field surveys Picarro LISA plots were generated to allow Local Leak Survey Technicians to investigate and grade leaks found. Leak results were recorded and repaired according to PG&E Standard Operating Procedures.

Figure 3.0 – Chevrolet Sierra Hybrid used for the Picarro survey

Atmospheric weather conditions affect the Picarro Surveyor's™ performance significantly and wind speeds greater than zero are required. During the weeks of testing the weather, as measured from the nearby airport, was reported to be generally calm with very little precipitation and temperatures and winds averaging 54 °F and 5 mph.

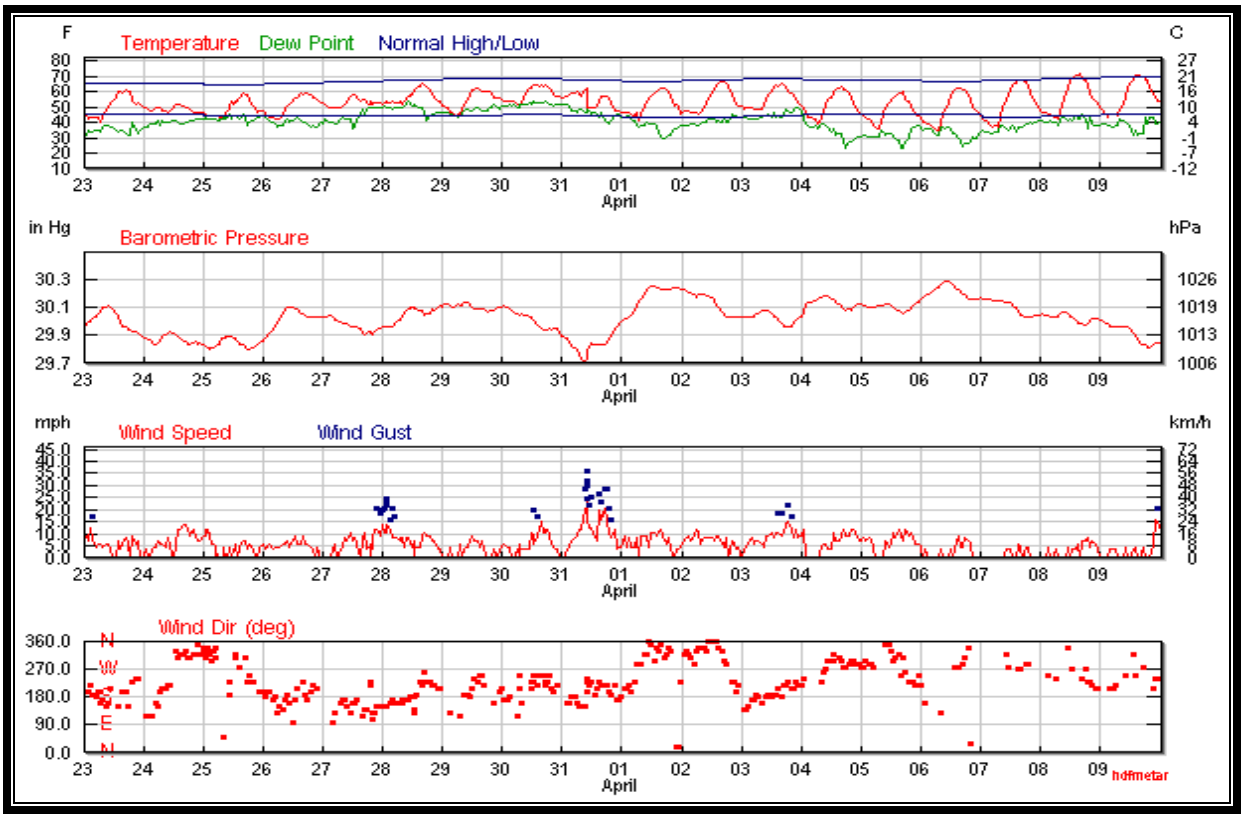


Figure 3.1 - KSAC Weather Station data (3/23/2012 – 4/9/2012) from Weather Underground

The Sacramento side-by-side study benefited and implemented Picarro methods gleaned during the Diablo side-by-side study which increased the effectiveness of the Sacramento Picarro survey. For the Sacramento Picarro survey drivers were instructed to conduct a drive in the early morning from 3:00 am - 10:00 am and a second late evening drive from 7:00 pm - 3:00 am. Additionally, to maximize the use of street space and to ensure complete coverage, drivers were instructed to drive both sides of all streets.

3. RESULTS. *SURVEY COVERAGE.* The traditional ground survey was conducted first and traditional leak survey coverage was confirmed to be 100% of mains and services with all leaks found, graded, or repaired. Following the completion of both (the early morning and late evening) Picarro field surveys, analysis of Picarro's leak survey data was conducted by reviewing FOV plots generated by Picarro's software.

As learned from the Diablo side-by-side study both the night and daytime FOV plots were displayed on a single plot in order to determine the coverage by the Picarro Surveyor™. Shown in *Figure 4.0,* are the Picarro Survey results from the daytime and nighttime runs for Sacramento Plat "G".

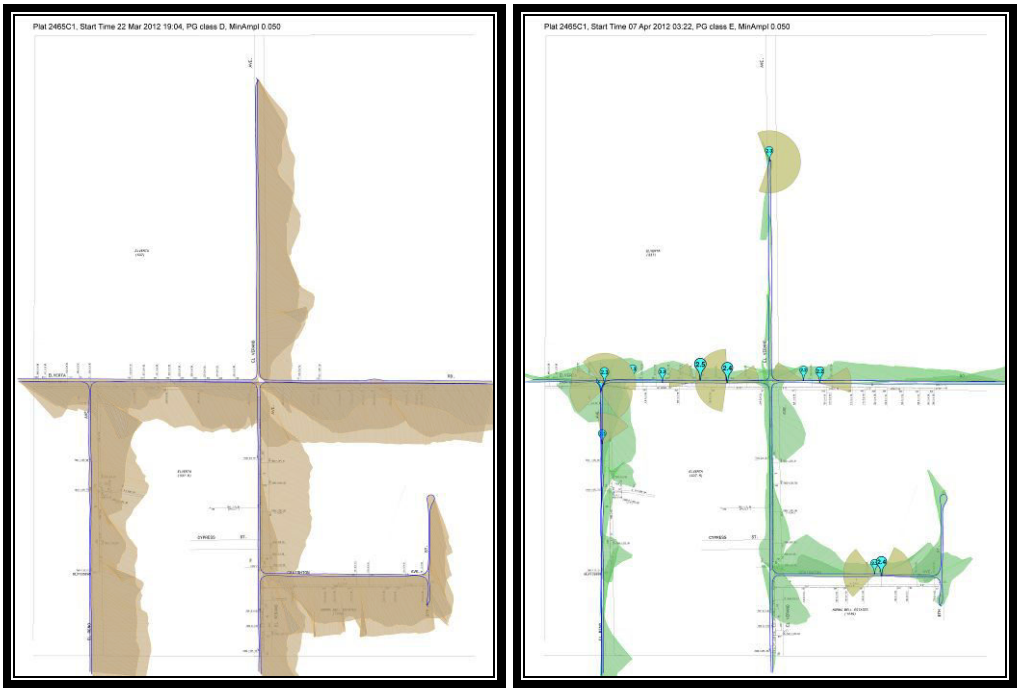


Figure 4.0 – Sacramento plat maps G Evening & Morning Picarro Runs

A combination of the evening and morning Picarro runs shown in *Figure 4.1* illustrate the full coverage potential of the Picarro Surveyor during this study. There is a very distinct change in direction of the wind in these plots as shown by the evening FOV (tan) which provided coverage to the south as compared to the morning FOV (green) which gave coverage to the north. By combining an evening and morning Picarro Surveyor™ run, the leak survey can take advantage of the natural shifts in wind directions.

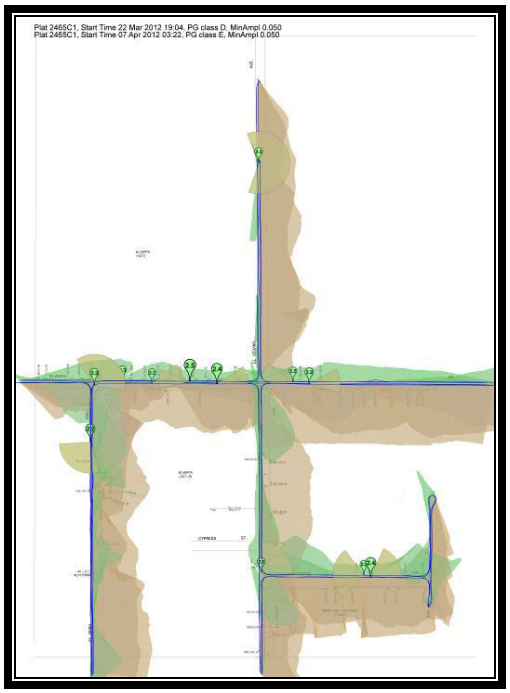


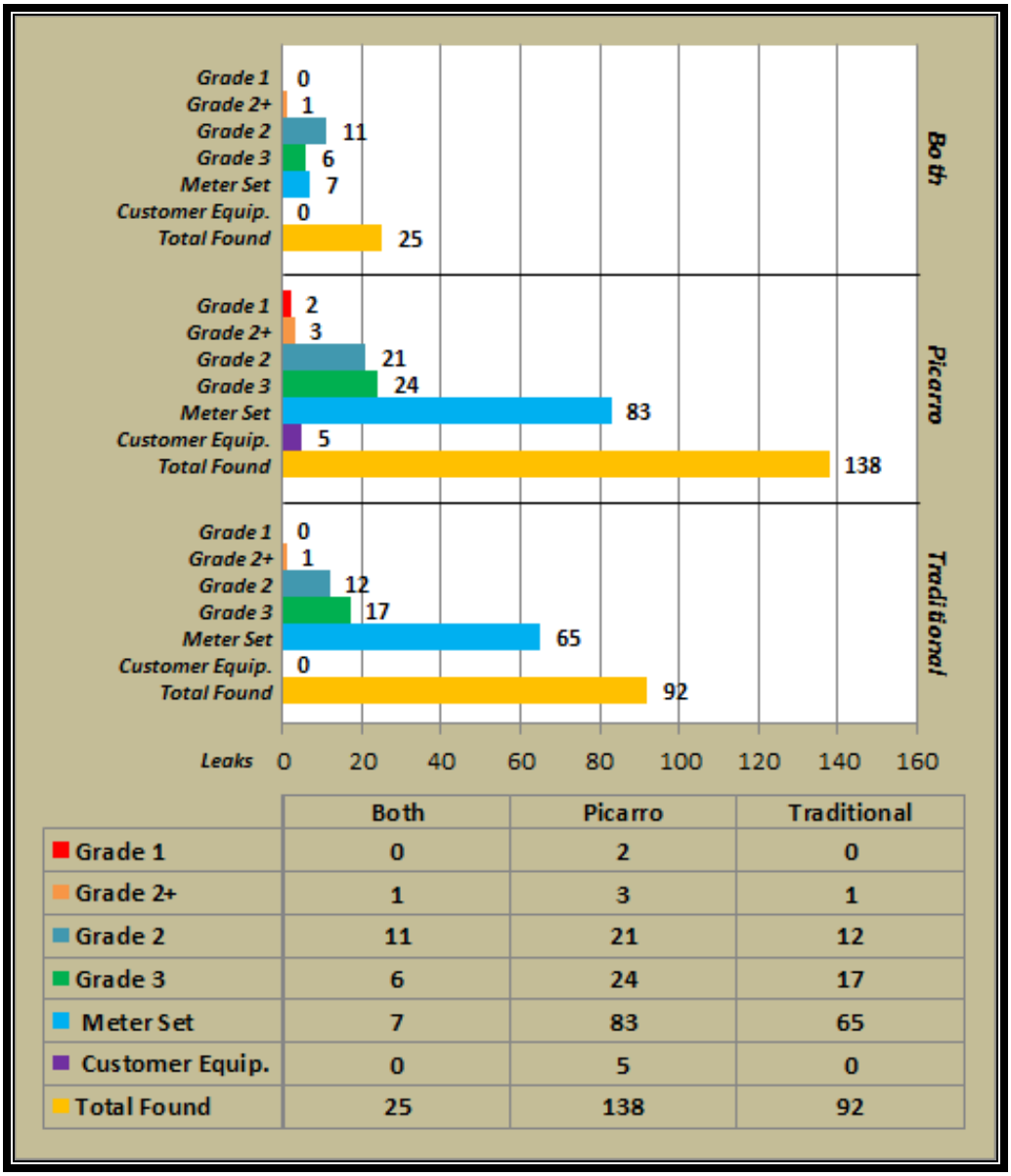
Figure 4.1 – Sacramento Plat Map G Evening & Morning Run Combined

A summary of survey coverage for all 16 Sacramento plat maps is shown in *Table 1.0.* After combining Picarro's evening and morning runs, the overall service count and miles-of-main coverage were found to be 88% coverage of services and 97% of mains. The percentage of mains and services not covered by Picarro's FOV plot would need to be leak surveyed by traditional leak survey technicians in order to obtain 100% coverage of all gas facilities and fulfill regulatory requirements.

PG&E Plat Map Data			Picarro - 1st Run				Picarro - 2nd Run				Picarro Combined Runs			
Plat	Services	Miles of Main	Services	% Service	Miles of Main	% Miles of Main	Services	% Service	Miles of Main	% Miles of Main	Services	% Service	Miles of Main	% Miles of Main
A	48.0	0.849	27.0	56%	0.770	91%	31.0	65%	0.849	100%	37.0	77%	0.849	100%
B	126.0	3.030	84.0	67%	3.030	100%	103.0	82%	3.030	100%	107.0	85%	3.030	100%
C	42.0	1.154	24.0	57%	1.154	100%	17.0	40%	1.154	100%	28.0	67%	1.154	100%
D	302.0	4.046	206.0	68%	3.888	96%	216.0	72%	3.987	99%	266.0	88%	3.998	99%
E	511.0	8.286	452.0	88%	7.975	96%	433.0	85%	7.955	96%	502.0	98%	8.244	99%
F	353.0	3.475	237	67%	3.098	89%	211.0	60%	3.019	87%	284.0	80%	3.337	96%
G	64.0	1.110	37.0	58%	1.110	100%	41.0	64%	1.084	98%	56.0	88%	1.110	100%
H	4.0	0.106	3.0	75%	0.106	100%	2.0	50%	0.106	100%	3.0	75%	0.106	100%
I	197.0	3.152	146.0	74%	3.147	100%	124.0	63%	2.642	84%	172.0	87%	2.983	95%
J	191.0	2.759	142.0	74%	2.757	100%	142.0	74%	2.386	86%	165.0	86%	2.575	93%
K	181.0	2.203	110.0	61%	2.201	100%	142.0	78%	2.186	99%	158.0	87%	2.197	100%
L	116.0	1.895	92.0	79%	1.894	100%	95.0	82%	1.895	100%	108.0	93%	1.895	100%
M	298.0	5.407	242.0	81%	5.405	100%	206.0	69%	5.377	99%	280.0	94%	5.364	99%
N	633.0	7.582	492.0	78%	7.573	100%	433.0	68%	6.739	89%	543.0	86%	7.139	94%
O	482.0	4.930	271.0	56%	3.898	79%	336.0	70%	4.195	85%	404.0	84%	4.557	92%
P	647.0	6.011	406.0	63%	5.163	86%	388.0	60%	5.403	90%	576.0	89%	5.886	98%
Totals	4,195	56.0	2,971	71%	53.2	95%	2,920	70%	52.0	93%	**3,689**	**88%**	**54.4**	**97%**

Table 1.0 - Sacramento Study Survey Coverage

LEAK INDICATIONS. Following standard operating procedures for leak survey and using traditional handheld instruments, PG&E's Division Leak Surveyors found and graded 117 (92 traditional + 25 found by both) natural gas leaks within the 16 Plat Maps. Picarro's survey results, minus the confirmed 75 false positives ("ghosts LISAs"), were investigated by Division and Quality Control Surveyors who located and graded 138 leaks.



	Both	Picarro	Traditional
Grade 1	0	2	0
Grade 2+	1	3	1
Grade 2	11	21	12
Grade 3	6	24	17
Meter Set	7	83	65
Customer Equip.	0	5	0
Total Found	25	138	92

Figure 3.0 – Sacramento Both, Picarro, Traditional leaks found by Grade

Figure 3.0 shows leaks found by both the traditional and Picarro methods, by Picarro only, and by traditional only. These results illustrate that both methods of survey identified the same leaks, however Picarro was able to locate 138 leaks which traditional survey did not. Conversely, the traditional leak survey method was able to identify 92 leaks (65 were meter set leaks) which Picarro did not identify.

A total of 230 (138 + 92) leaks were found during the side-by-side study. By including leaks found by "both" methods of leak survey the results show that the Picarro method found 2 hazardous leaks and 2 more *Grade 2+* leaks than the traditional survey. It is impossible to determine whether these leaks existed when the traditional survey was conducted because of the time delay between each survey

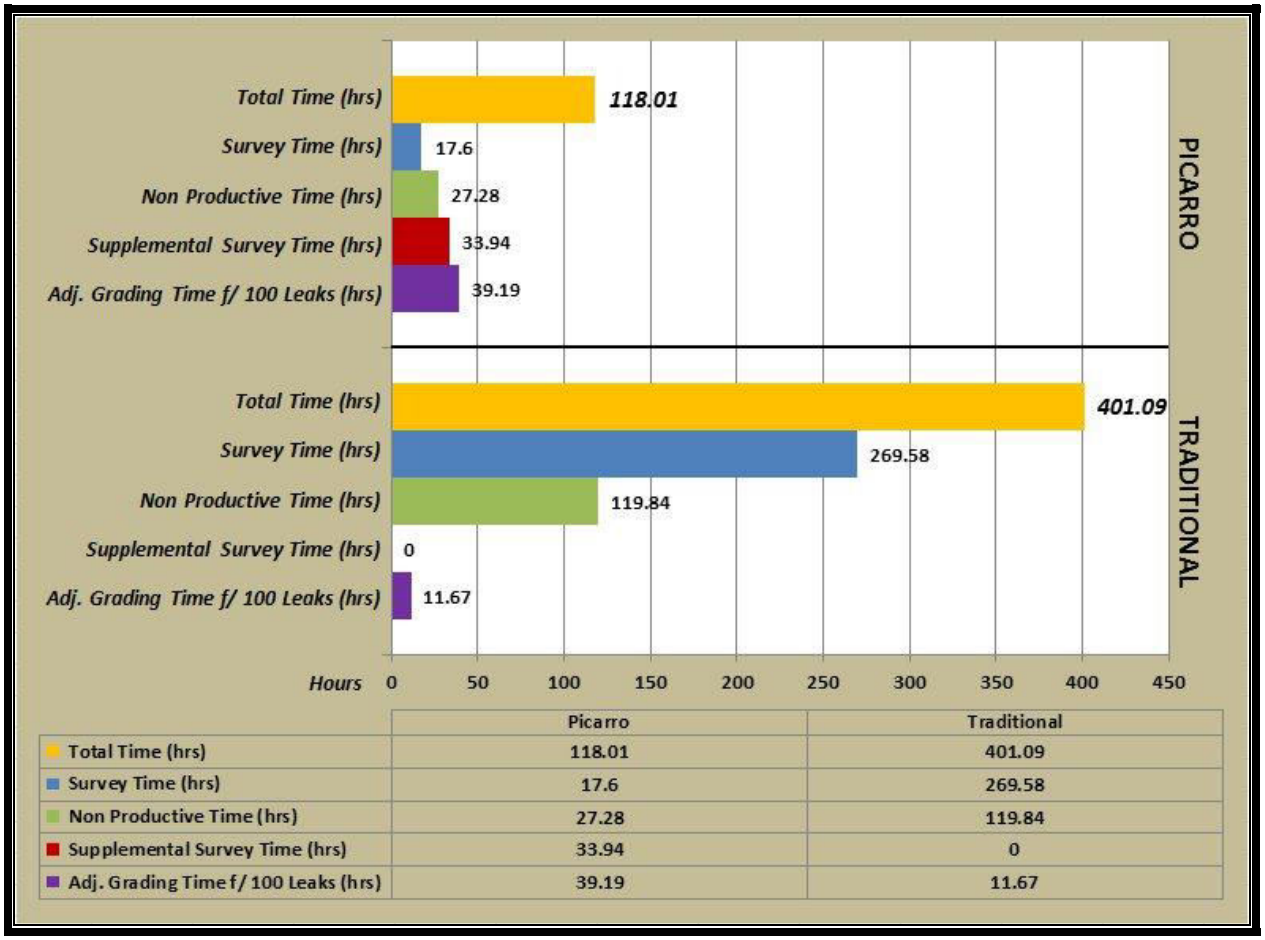
(2.5 months), and it is impossible to determine if Picarro would have detected the hazardous and *Grade 2+* leaks that had already been repaired as a result of the traditional leak survey. Although Picarro identified more, it missed a substantial amount of leaks found by the traditional. In addition, Picarro provided 75 false leak indications where a leak surveyor was dispatched to investigate and determined that no leak was present.

Referring to *Figure 3.0*, a leak "missed" by Picarro is defined as a leak originally found by traditional methods (92) which was within the Survey Coverage (FOV) of Picarro, but was not detected by Picarro. For leaks outside of the FOV of Picarro that were found by traditional, these were not counted as misses and the leak was not counted towards traditional either, as that would not be a true side by side comparison. In addition, leaks found by Picarro include all leaks found within a LISA, and any leak found 150 feet outside of a LISA.

TIME COMPARISON. Total time was segmented into four categories:

1. Survey Time.
2. Non-Productive Survey Time (includes administrative time associated with leak survey).
3. Supplemental Survey Time.
4. Adjusted Grading Time (normalized for 100 leaks or LISAs).

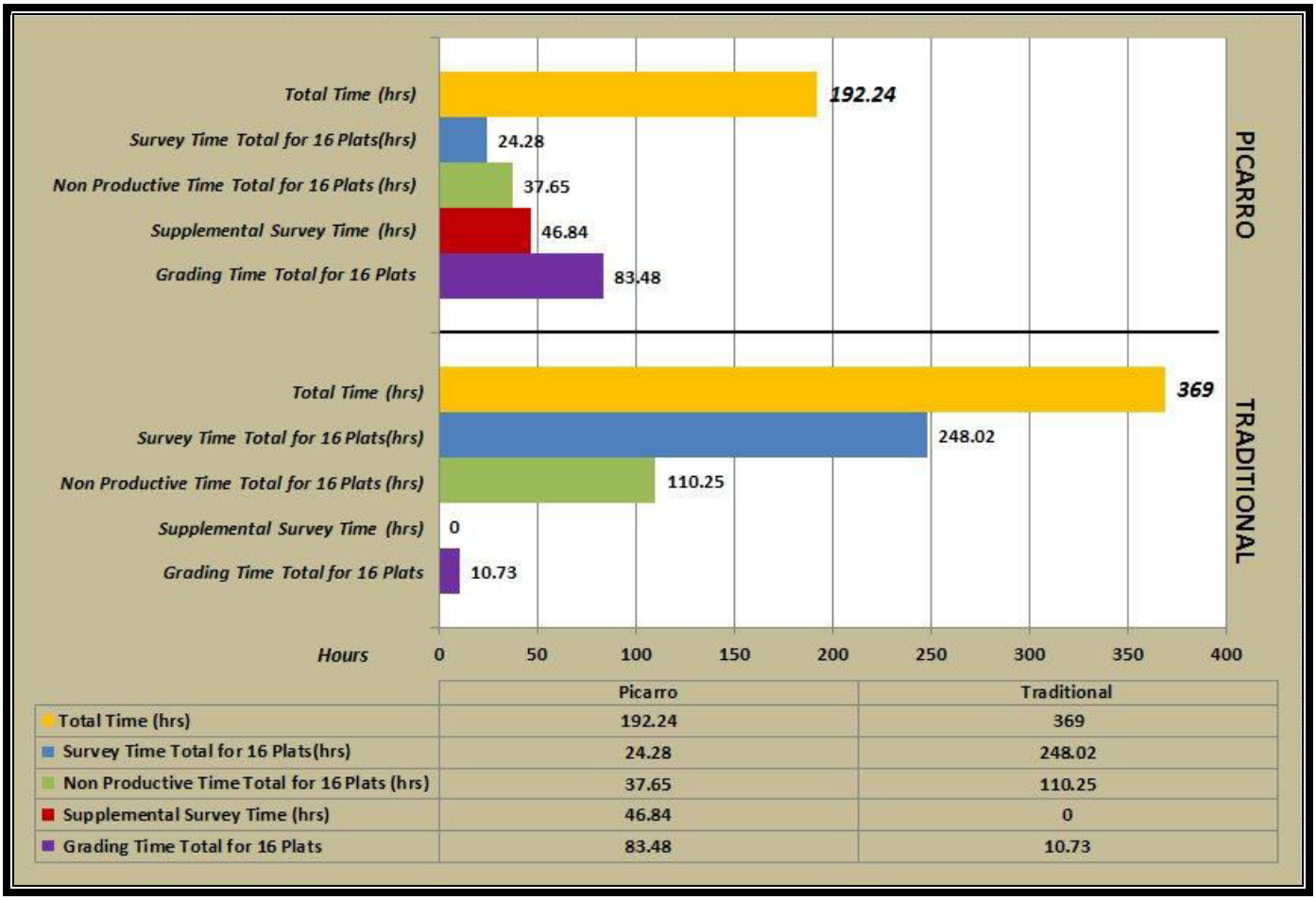
These categories were used to evaluate the production survey rate for each survey method. As shown in *Figure 4.0 (normalized),* the Picarro method completed the survey for all 16 maps in 118 hours vs. 401 hours for the Traditional ground and Picarro methods, respectively.



	Picarro	Traditional
Total Time (hrs)	118.01	401.09
Survey Time (hrs)	17.6	269.58
Non Productive Time (hrs)	27.28	119.84
Supplemental Survey Time (hrs)	33.94	0
Adj. Grading Time f/ 100 Leaks (hrs)	39.19	11.67

Figure 4.0 – Normalized Sacramento Time Comparison, Picarro vs. Traditional

Traditional leak grading time was fixed at 7 minutes per leak while Picarro's leak indication investigation time was fixed at 23.5 minutes per LISA. Additionally, standard production rates (9.9 services/hr & 2.5 mi/hr) were utilized to calculate the Supplemental Survey Time needed to foot survey the remaining "missed" services and distribution main that were not captured during the Picarro survey coverage. Non-productive survey time was taken directly from time sheets or as recorded by test administrators.



	Picarro	Traditional
Total Time (hrs)	192.24	369
Survey Time Total for 16 Plats(hrs)	24.28	248.02
Non Productive Time Total for 16 Plats (hrs)	37.65	110.25
Supplemental Survey Time (hrs)	46.84	0
Grading Time Total for 16 Plats	83.48	10.73

Figure 5.0 – Non-normalized Sacramento Time Comparison, Picarro vs. Traditional

In addition, *Figure 5.0* shows a non-normalized comparison of the time needed to Leak Survey 16 plats between Picarro and Traditional. Because Picarro found more leaks over the 16 plats than traditional, and because the pinpointing and grading of leaks takes an average of 23.5 minutes per LISA for Picarro, the time to complete a geographic region by the two methods are 192 hours for Picarro and 369 hours for traditional.

4. DISCUSSION. The Sacramento side-by-side testing was the second field study conducted to compare traditional leak survey to Picarro leak survey and was also preceded by two controlled studies in Livermore and Nevada. Throughout the testing of the Picarro Surveyor™ improvements to testing protocols were made, amplitude controls used, Leak Indication Search Algorithms (LISA) were adjusted, and the FOV methodology improved. These improvements were applied to the Sacramento side-by-side study and have contributed to enhancing three fundamental characteristics of this side-by-side study of leak survey:

1. Proficiency to Detect & Locate Leaks.
2. Rate of Survey.
3. Ability to Document Area Surveyed.

PROTOCOL ENHANCED. Several protocol enhancements were incorporated into the Sacramento study from the Diablo side-by-side study which were utilized to increase Picarro survey coverage. These improvements included a shift in the time of day for the Picarro Survey and a requirement to drive both sides of the street.

The Sacramento study took lessons learned from the Diablo study and instructed drivers to drive in two shifts, an evening and early morning time period. This change in protocol was due to atmospheric conditions are best for leak survey when the atmosphere is stable. Atmospheric stability is largely a function of surface wind speeds, solar radiation, and cloud cover which tend to be more favorable during the periods selected to run the Picarro Surveyor. Additionally, since the Picarro Survey requires wind speeds greater than 0 mph to conduct a leak survey, the second early morning drive was required. The early morning drive time was selected as coverage area is directly related to wind direction, which tends to shift direction during different times of the day and night. By adding a second Picarro leak survey shift it was found that coverage was greatly increased over a single daytime leak survey.

To further increase coverage and to ensure a thorough leak survey, drivers were instructed to drive both sides of all streets within the plat maps, an example is shown in *Figure 6.0*. By driving both sides of all streets, incremental increases in coverage were gained while allowing for further coverage by the Picarro Surveyor™ along services and up to meter sets. It was noticed that coverage did not appear to increase dramatically, however this method does increase coverage of mains buried in roadways as surveying both sides of the streets allowed for a wider field of view.

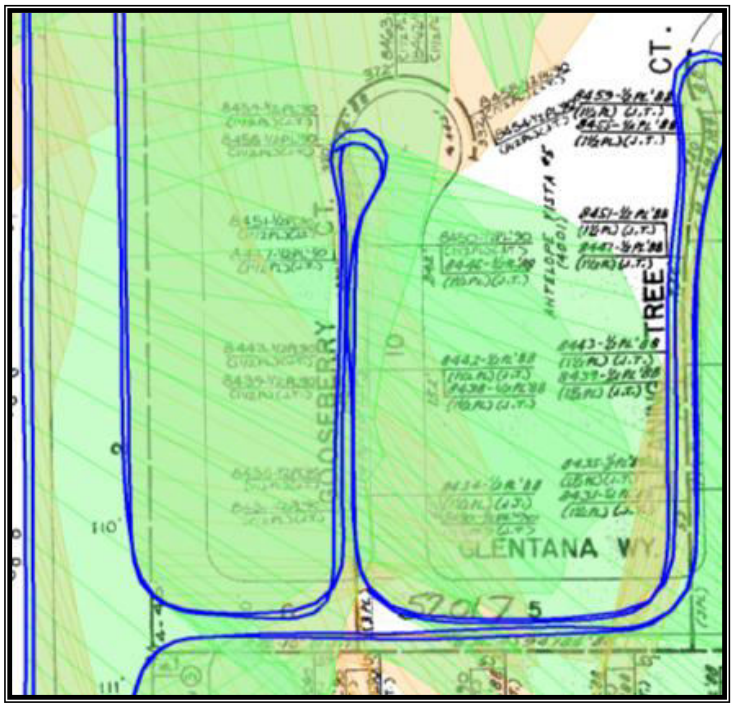


Figure 6.0 – Driving Path (blue) & Coverage (green & tan).

AMPLITUDE SETTINGS & LEAK INDICATIONS. Testing of the Picarro Surveyor™ during the Nevada Control Test at a leak training facility (where leaks could be simulated and controlled) was conducted in part to determine if Picarro's Amplitude settings could be used to adjust the volume of Leak Indication Search Areas. To explain this further it should be noted that a peak in the methane concentration is reported as a leak indication provided that it may be approximated by a Gaussian whose width lies within a certain range. The *Figure 7.0* illustrates how the measured methane concentration (blue line) is approximated by a Gaussian. The amplitude of the peak (at position 20m along the path) is defined as the height of the green curve (approximately 2.47) above the background concentration (shown as 2.0). The concentration reported in the leak indication is defined as the measured concentration at the position of the peak of the Gaussian. In the figure, the reported concentration in the leak indication would be 2.53. Note that because of the way the quantities are defined, it is possible that the concentration in the leak indication may not in fact be the maximum measured concentration in the peak.

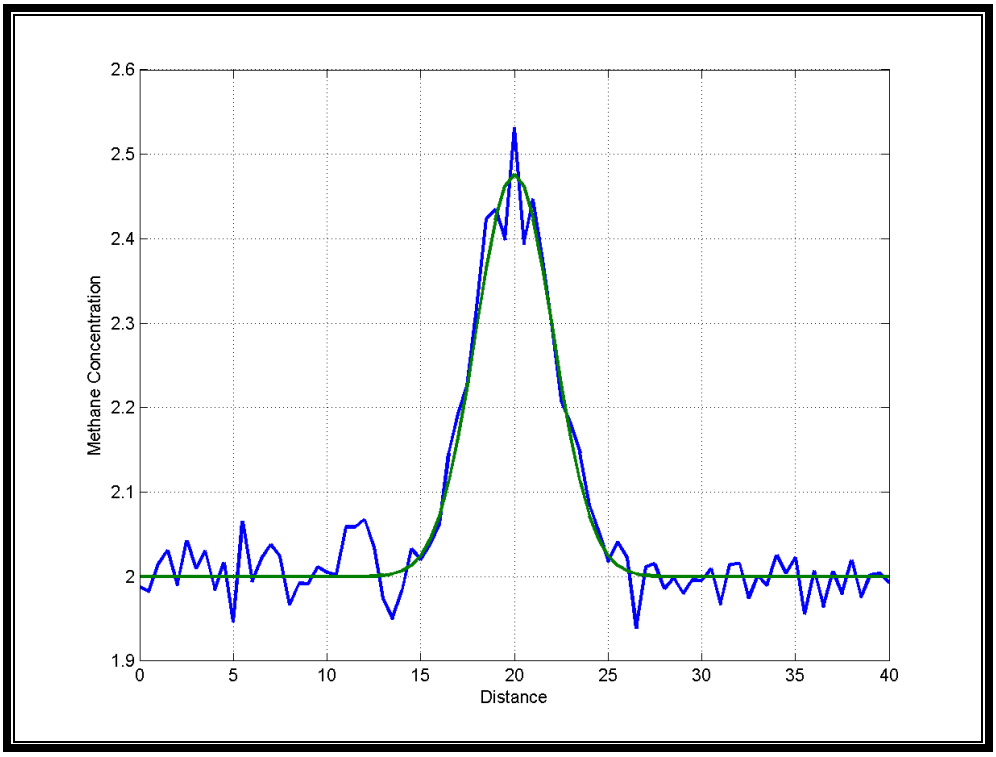


Figure 7.0 – Example of Leak Indication and Gaussian Approximation

A peak in methane is recorded through the P-Cubed software, and by adjusting the amplitude settings the user can effectively adjust the level at which they desire to see leak indications above background methane concentrations as was shown during the Nevada Control Study. It was determined that although the user could use amplitude adjustments to reduce excess leak indications, this was undesired during the Sacramento side-by-side testing as all indications needed investigation to fully compare traditional leak survey to Picarro leak survey. Additionally should Picarro's Surveyor be utilized for gas distribution leak survey it is recommend to leave amplitude at it's lowest setting to allow for the identification and investigation of all leak indications.

FIELD OF VIEW (FOV) DEFINITION. The FOVis a representation of the area surveyed as a result of driving the vehicle past the location of potential leaks. More precisely, points within the FOV are such that the probability of missing a leak located within the FOV is less than a certain value, given the motion of the vehicle, the measured wind velocity and the prevailing atmospheric conditions. If the wind direction is constant and blowing directly from the source to the analyzer (and not blocked by high walls, dense trees, etc), the distance at which a source can be detected is greatest. Under favorable (stable) atmospheric conditions, this distance can approach 100 meters. When the wind is variable, or cannot be determined precisely due to the motion of the vehicle, the distance is correspondingly reduced.

FOV plots generated by Picarro for the Sacramento side-by-side study were generated on electronic plat maps which were in the form of Tiff files. These Tiff files have geographic coordinates associated with the corners of the plat map and are geographically referenced to their physical locations in a GIS or Google Earth mapping system. The P-Cubed software integrates the GPS path which the Picarro vehicle drove and generates a path in blue and a FOV swath in green or tan.

5. CONCLUSION. Studies of the Picarro Surveyor™ and its P-Cubed software have proved the initial concept that Picarro's expertise in gas sampling can be specifically engineered for use by natural gas distribution company's leak survey programs to indicate, target, and confirm the presence of gas pipeline leaks. Furthermore, the P-Cubed software working in unison with Picarro's highly sensitive cavity ring down spectrometer technology allows for data acquisition of leaking distribution systems and an auditable leak survey record unparalleled by current leak survey methods and instruments.

In addition, use of Picarro was shown to reduce the time needed to complete a leak survey by 175 hours, or a savings of 4.4 weeks for a full time employee in the study area. The time savings is a result of being able to drive most or all sections of the distribution system as opposed to walking, however a portion of this time savings can be attributed to the P-cubed software which generated auditable FOV plots showing coverage of the leak survey.

This study confirmed information collected during the Diablo study that Picarro is able to cover 97% of the miles of main and 88% of services by driving the Picarro System early in the morning and late evening on both sides of the street.

The results of this study confirm there is not one leak survey method can identify 100% of all leaks in a single survey. However, this study also indicates that, when used in concert and coordination, traditional and Picarro leak survey methods can be combined to maximize the effectiveness and efficiency of leak detection programs. The delay between the Traditional and the Picarro survey during this test may have led to additional leaks which were not detected during the first survey. Ideally, designating the Picarro Surveyor™ as the leading leak survey method while the traditional leak survey provides support in small targeted areas where Picarro cannot survey as readily.

Additional enhancements to the Picarro Surveyor™, software, and protocols continue to be refined at this time and will further improve its ability to detect and target leaks in natural gas piping systems.

[1] *PG&E Picarro Surveyor™ Leak Detection Study: Livermore Leak Test Facility, 1/13/2012 – 1/19/2012*

[2] *PG&E Picarro Surveyor™ Leak Detection Study: Southern Nevada Leak Test Facility, 3/19/2012 – 3/22/2012*

[3] *PG&E Picarro Surveyor™ Leak Detection Study: Diablo Leak Detection Study 2/21/2012 – 4/11/2012*