STATE OF NEW YORK
PUBLIC SERVICE COMMISSION

Proceeding on Motion of the Commission as to the Rates, Charges, Rules and Regulations of Consolidated Edison Company for Electric Service	)))	**Case 19-E-0065**
Proceeding on Motion of the Commission as to the Rates, Charges, Rules and Regulations of Consolidated Edison Company for Gas Service	)))	**Case 19-G-0066**

DIRECT TESTIMONY
OF
VIRGINIA PALACIOS
ON BEHALF OF
ENVIRONMENTAL DEFENSE FUND

Dated: May 24, 2019

I. Introduction and Qualifications

Q. Please state your name, title, and business address.

A. My name is Virginia Palacios. I am a Principal at VP Environmental, LLC, and my business address is P.O. Box 27, Encinal, Texas 78019.

Q. On whose behalf are you submitting this testimony in this proceeding?

A. I am submitting this testimony on behalf of the Environmental Defense Fund ("EDF"), an intervenor in this proceeding.

Q. Please provide a summary of your education and experience.

A. I hold a Master of Environmental Management from Duke University and a B.S. in Aeronautical Science from Embry-Riddle Aeronautical University. I am currently a Principal at VP Environmental, LLC, and work part-time as Senior Environmental Scientist with Glenrose Engineering in Austin, Texas. From 2017-2018, I was the State and Local Policy Manager at South-central Partnership for Energy Efficiency as a Resource, where I managed a collaborative effort between investor-owned electric utilities and stakeholders interested in improving the achievements of energy efficiency programs in Texas.

In all, I have eight years of experience working on issues relating to the natural gas sector. In my role as Principal of VP Environmental, LLC, I lead the development of policy solutions to mitigate methane emissions in the natural gas distribution sector in various states through the U.S. Previously, as a Senior Research Analyst at EDF, I provided technical expertise on scientific and regulatory concepts related to local distribution pipeline safety, lost and unaccounted for gas, and quantification of methane emissions from local distribution system pipelines. I also analyzed quantitative and geospatial data related to methane leakage in the natural gas sector. In my prior position as a Research Analyst at EDF, I investigated local, state, and federal rules related to local distribution pipeline safety and lost and unaccounted for gas, and developed an understanding of how methane emissions from local distribution system pipelines can be quantified. Some of my work, which involved geospatial attribution of methane emissions data, was published in two peer-reviewed articles.[1]

When I began working for EDF as a Research Associate, I conducted regulatory comparisons and data analysis related to the oil and gas industry, with a particular focus on federal and state regulations on distribution system integrity management, SCADA leak detection systems, cost recovery mechanisms, lost and unaccounted for gas, and pipeline mileage and leakage data provided in Pipeline and Hazardous Materials Safety Administration ("PHMSA") Annual Distribution System reports. I co-authored a paper titled "Integrating Leak Quantification into Natural Gas Utility Operations," which was published in Public Utilities Fortnightly in May 2017, provided as Exhibit __ (VP-3) to this testimony. Additionally, I have had the opportunity to participate in field research comparing several leak quantification

[1] Lyon, D., et al. (2015). Constructing a Spatially Resolved Methane Emission Inventory for the Barnett Shale Region. Environmental Science and Technology (http://doi.org/10.1021/es506359c); and Zavala-Araiza, D., et al. (2015). Towards a Functional Definition of Methane Super-Emitters: Application to Natural Gas Production Sites. Environmental Science and Technology (http://doi.org/10.1021/acs.est.5b00133).

methodologies. I have also met with advanced leak detection technology service providers and reviewed information supporting the technical basis for the services they offer. As part of numerous regulatory proceedings, I have reviewed and analyzed several utilities' gas infrastructure programs. Please refer to Exhibit __ (VP-1) for my complete resume.

Q. Have you previously filed testimony before regulatory or legislative bodies?

A. Yes. I submitted testimony to the New Jersey Board of Public Utilities ("BPU") in Docket No. GR17070776 and the New York Public Service Commission ("Commission") in Case 16-G-0061. In Illinois Commerce Commission Docket No. 16-0376 I submitted, on behalf of the Citizens Utility Board, Direct Testimony in 2016, Direct Testimony on Reopening in 2017, and Rebuttal Testimony on Reopening. I also submitted an affidavit on behalf of the Office of the People's Counsel in Formal Case No. 1154 before the Public Service Commission of the District of Columbia. Please refer to Exhibit __ (VP-2) for a detailed listing of my testimonies.

II. Purpose of Testimony and Recommendations

Q. What is the purpose of your testimony?

A. The purpose of my testimony is to present information and recommendations relating to the use of advanced leak detection technology and leak quantification methods to assist Consolidated Edison Company of New York, Inc. ("Con Edison" or "Company") in its proposed leak repair and pipe replacement activities, in order to advance New York policy to reduce natural gas leaks and methane emissions. In particular, my testimony describes the current status of advanced leak detection technology, leak quantification, and associated analytics. Next, I explain the benefits of advanced leak detection technology and using its resulting data to prioritize leak abatement and pipeline replacement decisions. My testimony recommends Con Edison incorporate leak flow rate data derived from advanced leak detection technology into the Company's existing prioritization methods as a cost effective and superior means to advance New York methane reduction and climate policies. I also recommend revisions to the Company's proposed leak incentive mechanism to align its structure with the capabilities of advanced leak detection technology.

Q. Please provide a summary of your testimony and recommendations.

A. I first comment on the Company's proposed accelerated pipe replacement efforts and the potential benefits to the Company, customers and the environment associated with the use of advanced leak detection technology and leak quantification methods in designing and implementing leak repair and pipe replacement activities.[2, 3] I recommend that Con Edison utilize the advanced leak detection technology it has already purchased and employ leak quantification

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[2] By advanced leak detection technology, I am referring to high sensitivity (i.e. measuring methane concentrations in parts per billion and collecting data points at a rate of at least twice per second) methane detectors mounted on vehicles equipped with Global Positioning Systems ("GPS") that collect latitude and longitude coordinates at the same time as methane concentration data is being collected.

[3] "Leak quantification methods" refers to the advanced analytics or algorithms that utilize data acquired from advanced leak detection technology to estimate the methane flow rate (e.g. in liters per minute) that can be attributed to a leak indication.

methodologies and associated analytics to prioritize pipeline replacements and leak repairs based on leak flow rate data, after considering safety factors in order to increase the cost effectiveness and leak reductions resulting from its ongoing efforts. I assert that the Company's evaluation and assessment of the technology should not stand in the way of its use, as advanced leak detection technology and leak quantification have already been evaluated at length in terms of the number of leaks found compared to using traditional leak detection technologies, source attribution, and usefulness of the leak size estimate.

In addition, I recommend that the Commission require Con Edison to submit annual reports, detailing the Company's progress in implementing advanced leak detection technology and leak quantification to improve its leak abatement programs. The reports should include a metric that measures annual methane leak flow rate reduction based on the mileage of retired pipe and the leak flow rates estimated for those miles using advanced leak detection technology and leak quantification methods, as further detailed below.

Finally, I propose certain revisions to the Company's leak incentive mechanism. Before the Company can better achieve New York State methane reduction policy and capitalize on the benefits that advanced leak technology and analytics can provide, certain barriers embedded within the current incentive structure need to be removed. Specifically, while advanced leak detection technology can find many more leaks than traditional measures (which will consequently add to a utility's backlog), utilities may be reluctant to adopt such technology if they are rewarded solely for reducing the number of leaks in their non-hazardous leak backlog, rather than reducing leak flow volumes. Instead, utilities should be incentivized to find more leaks, identify larger leaks (as measured by volume of methane) and reduce those leaks. For these reasons, I propose that Con Edison's incentive mechanism be structured to reduce methane volumetrically (i.e., leak flow volume) and be designed via a leak distribution curve.

Q. Are you providing any exhibits to your testimony?

A. Yes. I am attaching the following exhibits to my testimony:

- Exhibit __ (VP-1): Resume
- Exhibit __(VP-2): List of Expert Testimony of Virginia Palacios
- Exhibit __(VP-3): "Integrating Leak Quantification into Natural Gas Utility Operations," Public Utilities Fortnightly (May 2017)
- Exhibit __(VP-4): Con Edison Response to EDF-1-3; Case No. 19-G-0066 *et al.*
- Exhibit __(VP-5): Con Edison Response to EDF-1-13; Case No. 19-G-0066 *et al.*
- Exhibit __(VP-6): Con Edison Response to EDF-1-7; Case No. 19-G-0066 *et al.*
- Exhibit __(VP-7): Response of ABB Inc. ("ABB") – Los Gatos Research to Letter of Inquiry Dated May 9, 2017 from the Citizen's Utility Board submitted in Illinois Commerce Commission Docket No. 16-0376

- Exhibit __(VP-8): Response of Picarro, Inc. ("Picarro") to Letter of Inquiry Dated May 9, 2017 from the Citizen's Utility Board submitted in Illinois Commerce Commission Docket No. 16-0376
- Exhibit __(VP-9): Picarro Emissions Quantification Results Final Report in Support of the Methane Leak Surveying Report for the Public Service Electric and Gas Company ("PSE&G") Gas System Modernization Program ("GSMP") II Program
- Exhibit __ (VP-10): PSE&G Presentation "Replacement Main Prioritization: A Practical Application of Using Risk and Methane Emissions" (May 2, 2019)

III. Con Edison's Leak Prone Pipe Replacement Efforts

Q. Please summarize your understanding of the Company's proposed leak prone pipe replacement efforts.

A. Under the Company's Main Replacement Program, the Company proposes to replace 256 miles of leak prone pipe over the next three rate years (i.e. 2020-2022) at a total cost of approximately $1 billion.[4, 5] The annual rate of pipeline replacement in this proposal (85 miles) is lower than the 95-100 mile annual target proposed in Case No. 16-G-0061, which the Company attributes to a changing

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[4] Gas Infrastructure, Operations and Supply Panel Testimony at page 39, lines 7-14 and page 41, lines 20-23.

[5] Under the Main Replacement Program, the company targets 12-inch-and-under cast iron, wrought iron, and unprotected steel pipe. Gas Infrastructure, Operations and Supply Panel Testimony at page 38, line 22 and page 39, lines 1-2.

portfolio and "the need to balance improvements with the bottom line in mind."[6] Nonetheless, the Company states that the proposed goals for 2020-2022 are consistent with the Company's 20-year replacement strategy.[7]

Q. Please explain your understanding of the various grades of leaks.

A. PHMSA's website offers non-binding guidance resources produced by industry trade groups to operators on how to grade leaks based on safety risk,[8] thereby establishing leak repair priority, and assisting operators in complying with federal safety rules that require them to "evaluate and rank risk" posed by their distribution pipeline systems.[9] The guidance suggests metrics by which leak grades may be established based on readings of the percent of gas in air compared to the lower explosive limit, and the location of the leak relative to a building or substructure.

New York regulations have built upon this guidance, including specific definitions of leak grades, using the following categories: Type 1, Type 2A, Type 2, and Type 3.[10]

The regulations define Type 1 leaks as leaks that are hazardous and require immediate attention. Type 2A, 2 and 3 leaks are not immediately hazardous. Type

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6 Gas Infrastructure, Operations and Supply Panel Testimony at page 39, lines 17-23 and page 40, line 1.

7 Gas Infrastructure, Operations and Supply Panel Testimony at page 39, lines 14-16.

8 Gas Piping Technology Committee. Guide for Gas Transmission, Distribution and Gathering Piping Systems. Appendix G-192-11, Gas Leakage Control Guidelines for Natural Gas Systems.

9 49 CFR § 192.1007 (2009).

10 NYCRR 16 Part 255.811 to 255.817.

2A leaks require frequent surveillance and scheduled repair. Type 2 leaks require scheduled repair. Type 3 leaks are to be reevaluated during the next required leakage survey or annually, whichever is less.

Q. Does the Company propose to consider leak flow rate in its project area prioritization for pipeline replacements?

A. No, although the Company cites the benefits of "protecting the environment by reducing emissions of methane" through enhanced leak detection,[11] the Company has indicated that they are not proposing to track or report actual methane reductions associated with their main replacement program, distribution integrity enhancement program, or any other program.[12] While the Company seeks to identify and prioritize the highest emitting Type 3 leaks, it is not currently nor is it planning to track or report actual methane emission reductions from these efforts, nor has it indicated that it is proposing to prioritize pipeline replacement project areas using leak flow rate data.

Rather than using leak flow rate data based on field measurements, the Company considers Volume Pressure Factor as a leak consequence factor.[13] Volume Pressure Factor uses information on pipe diameter and pressure, and assumptions about leak volume based on the type of failure to rank the relative volume of the leak. This

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[11] Gas Policy Panel Testimony at page 16, lines 13 to 16.

[12] Exhibit __(VP-4).

[13] Exhibit __(VP-5).

consequence factor is then incorporated into the Optimain DS risk model which is used to prioritize mains for replacement.

Q. Please explain the difference between leak flow rate and volume pressure factor.

A. Leak flow rate estimates that are derived using data from advanced leak detection technology are representative of quantitative methane emissions data taken in real time, whereas the Volume Pressure Factor is derived using knowledge about the physical characteristics of the pipe and an assumed relative ranking of the severity of gas loss based on failure type. A leak flow rate estimate derived using data from advanced leak detection technology would be capable of providing empirical data on the severity of gas loss, rather than a ranking based on qualitative assumptions.

IV. Status of Advanced Leak Detection Technology and Recent Technological Advancements

Q. Please summarize how available advanced leak detection technologies work to identify and quantify natural gas leaks, as compared to traditional methods.

A. Utility estimates of leak size have typically been made using best available estimates of pipeline type, diameter, pressure, and historical leak data. However, this method has limitations; traditional leak surveys can miss up to 66% of leaks, rely on dated and sometimes incomplete records, and may not provide spatially-attributed information that can be easily linked to infrastructure asset maps.[14]

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[14] Picarro. 2016. "Pipeline Replacement and Emissions Reduction." Santa Clara, CA. http://naturalgas.picarro.com/support/library/documents/pipeline-replacement-and-emissions-reduction-using-picarro-emissions.

Advanced leak detection technologies, leak quantification methodologies, and the analytics and visualizations that can be developed using these methods can provide more accurate and useful tools in the Company's leak prioritization efforts. Advanced leak detection technology involves the use of sensitive sensors (e.g. methane sensors with detection limits on the order of parts per billion) installed on vehicles to collect emissions data such as methane and ethane while driving selected survey routes. The emissions data are then analyzed using algorithms (typically proprietary) to draw out key leak information such as estimated leak flow rate (e.g. liters per minute), leak density (e.g. leaks per mile), and probable grade (e.g. Type 1, 2, 2A, or 3).[15]

Q. Is advanced leak detection technology typically able to find many more leaks than traditional technologies? If so, please explain the significance of finding more leaks using advanced leak detection technology.

A. Yes. The ability of advanced leak detection technology to find many more leaks than traditional technologies was discussed in the direct testimony of Joseph Von Fisher, filed in Case 16-G-0061 on May 27, 2016. Building on the observations presented in the 2016 testimony, a peer reviewed 2018 Colorado State University ("CSU") study reported data suggesting that utility crews locate only 35% of the

[15] For a publicly available description of an algorithm for developing leak indications using data from mobile methane surveys, see Weller, Z. D., Yang, D. K., & von Fischer, J. C. (2019). An open source algorithm to detect natural gas leaks from mobile methane survey data. Plos One, 14(2), e0212287. https://doi.org/10.1371/journal.pone.0212287.

pipeline leaks found using traditional technologies in comparison to using advanced leak detection methods.[16]

Combining advanced leak detection technology with traditional leak surveys offers utilities unique insight into their systems that is not possible using only traditional leak survey methods. While studies have shown that advanced leak detection technology is capable of finding many more existing leaks than traditional leak survey methods, it should be noted that the two methods are often finding different subsets of leaks.[17] This suggests that advanced leak detection technology should not replace traditional survey methods, but can support a company's existing datasets by providing up to date information about otherwise undiscovered leaks in a system. Moreover, it is important to highlight that advanced leak detection technology is helping utilities to find more gradable and hazardous leaks (e.g., requiring abatement due to safety) than they were able to detect using traditional technologies.[18]

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[16] Weller, Zachary *et al.*, Vehicle Based Methane Surveys for Finding Natural Gas Leaks and Estimating their Size: Validation and Uncertainty, Environmental Science and Technology (2018). If this detection rate is applied at the national scale, then the national inventory for the number of pipeline leaks in natural gas distribution infrastructure would increase by a factor of 2.4. *Id.* at 11925.

[17] Weller, Z. D., Roscioli, J. R., Daube, W. C., Lamb, B. K., Ferrara, T. W., Brewer, P. E., & Von Fischer, J. C. (2018). Vehicle-Based Methane Surveys for Finding Natural Gas Leaks and Estimating Their Size: Validation and Uncertainty. Environmental Science and Technology, 52, 11922–11930. research-article. https://doi.org/10.1021/acs.est.8b03135.

[18] Redding Sr., Stephen M., and Brenda Glaze. 2015. "Revolutionising Leak Management." In World Gas Conference. 2015. Paris, France.

Advanced leak detection technology not only offers a better understanding of leak density (leaks per mile), but also can be used to estimate leak flow rate. Both leak density and leak flow rate are valuable parameters to be considered in pipeline replacement prioritization, particularly to cost-effectively reduce the volume of leaked and emitted methane.

Q. Please describe any recent improvements in technology or analytics that enhance the utility of data collected by advanced leak detection technology.

A. Materials submitted in Illinois Commerce Commission Docket No. 16-0376 by ABB and Picarro, two companies that provide advanced leak detection technology, describe modern leak quantification and associated analytics. The materials are presented as attachments to my testimony, Exhibit __(VP-7) and Exhibit __(VP-8). Additionally, in a publicly available publication, Weller, Yang, and Fischer (2019) of CSU describe improvements made to their leak location and quantification algorithm that relies on data from advanced leak detection technologies based on advanced statistical analysis of over 6,100 leak indications collected from 15 cities.[19] These improvements include better source attribution, leak flow rate quantification software, leak locating and survey completeness features, leak grade probability software, and depiction of "flute" maps.

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[19] Weller, Z. D., Yang, D. K., & von Fischer, J. C. (2019). An open source algorithm to detect natural gas leaks from mobile methane survey data. *Plos One*, *14*(2), e0212287. https://doi.org/10.1371/journal.pone.0212287.

Q. What is a flute map, and how is the information provided in a flute map beneficial?

A. Flute maps depict areas where multiple leak indications are observed in close proximity along a pipeline path.[20] Information about the locations of flute areas can help utilities to prioritize segments of pipeline for replacement, rather than pursuing individual leak repair. Flute maps offer yet another application of advanced leak detection technology that can assist utilities in improving the cost-effectiveness of pipeline replacement and leak repair projects, while also maximizing volumetric leak reductions.

Q. Please describe what is meant by source attribution.

A. ABB, Picarro, and CSU researchers each employ sensors capable of reporting both methane and ethane at very low detection levels. Dual deployment of methane and ethane sensors allows for the separation of thermogenic methane (typically associated with natural gas leaks) and biogenic methane (typically associated with sewer or landfill methane emissions). Excluding readings of biogenic methane from the population of leak indications results in fewer "false positives" during leak surveys.

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[20] Weller, Z. D., Yang, D. K., & von Fischer, J. C. (2019). An open source algorithm to detect natural gas leaks from mobile methane survey data. *Plos One*, *14*(2), e0212287. https://doi.org/10.1371/journal.pone.0212287.

Q. Please further describe the usefulness of leak flow rate quantification software.

A. Technology service providers ABB and Picarro provide leak quantification analytics as a part of their software packages. In addition, Picarro has made a white paper available describing their emissions quantification ("EQ") analytics services.[21] Picarro's EQ analytics feature offers a report that attributes leak indications to the utility's infrastructure (if the utility provides this data), and summarizes the results of a leak quantification survey in a way that does not trigger the responsibility to investigate each leak indication. A utility can use the leak flow rate data derived from advanced leak detection technology to prioritize pipeline replacements or measure progress in reducing gas lost from leaks, without having to spend resources investigating individual leaks. Picarro's EQ reports contain the following information:

- Segment ID
- Segment Rank (based on aggregated leak flow rate of the segment)
- Emissions Rate in standard cubic feet per hour (SCFH)
- Emissions Range (confidence)
- Segment Length in feet (ft.)
- Emissions Factor (SCFH/ft.)
- Estimated Number of Leaks

[21] Picarro. (2016). Pipeline Replacement and Emissions Reduction. Santa Clara, CA. Retrieved from http://naturalgas.picarro.com/support/library/documents/pipeline-replacement-and-emissions-reduction-using-picarro-emissions.

- Number of Leaks per ft.
- Emissions Rate per Leak

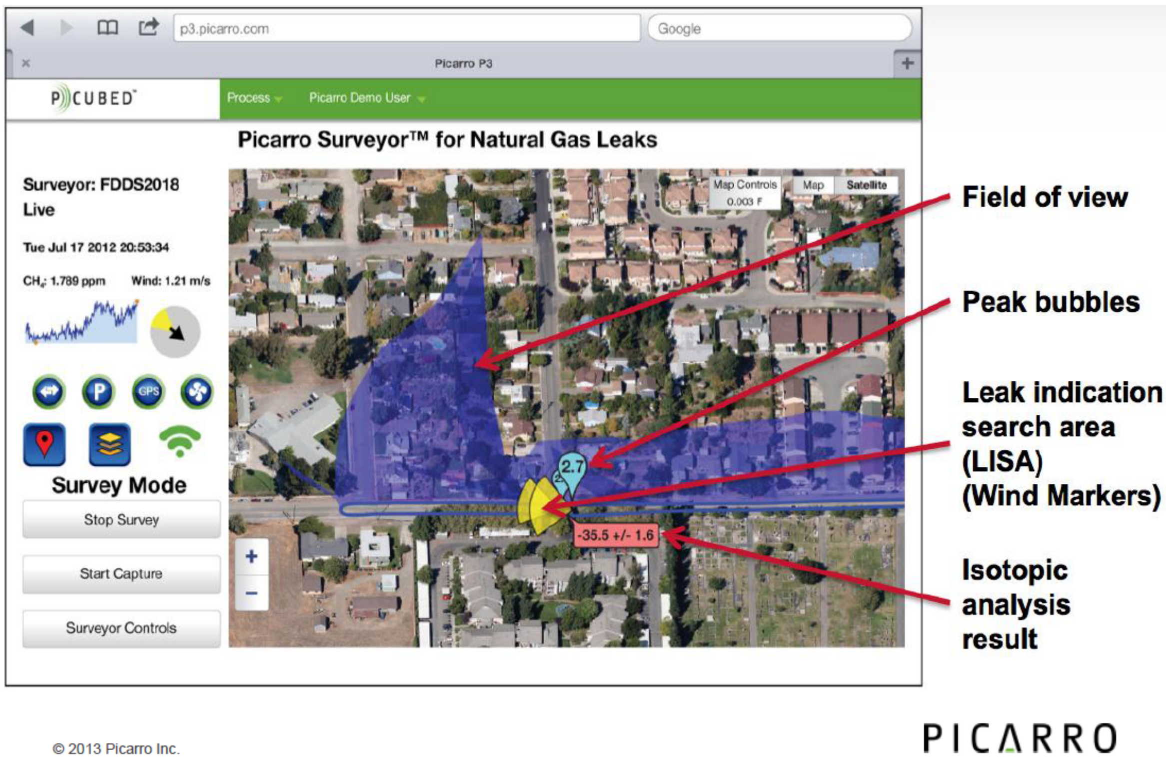
Q. Please further describe leak locating and survey completeness features.

A. ABB and Picarro collect wind data during mobile surveying. Wind data allows utilities to assess which search areas have already been surveyed, and to predict where leaks are located relative to the vehicle's position. The wind information is used to estimate the direction the elevated methane readings may have been coming from; combined with specialized algorithms, ABB and Picarro are able to calculate statistics that indicate the probable location of the leak. In addition to locating leaks, the wind data can be used to estimate areas where the equipment's field of view was likely to have covered—that is, the distance and direction from the vehicle where the methane sensors are likely to detect a leak, if one exists. Conversely, this also helps to identify geographic areas that the advanced leak detection technology is not able to reach.

An example of the "field of view" from Picarro's user interface is provided in the figure below:[22]

[22] Picarro, and PG&E. 2013. "Picarro Surveyor for Natural Gas Leaks." In Distribution Technology Transfer Workshop. Orlando, FL: U.S. Environmental Protection Agency. https://www.epa.gov/natural-gas-star-program/pacific-gas-and-electric-experience-picarro-technology.

Figure 1



Those areas that are not reached by the advanced leak detection technology's field of view can then be prioritized for foot surveys, if the utility determines a need to do so.[23]

Traditional technologies for surveying typically do not allow for an extended field of view the way that advanced leak detection technology does, because the advanced technology uses more sensitive equipment and wind information.

[23] Picarro. 2016. "PG&E Routine Regulatory Compliance Leak Survey of Distribution Pipelines." Santa Clara, CA. http://naturalgas.picarro.com/support/library/documents/routine-regulatory-compliance-leak-survey-distribution-pipelines.

Because of this hindrance in sensitivity and field of view, use of only traditional technologies may result in a utility being unaware of leaks that exist on their system.

Q. Please further describe grading probability software.

A. In its white paper "The Transition to Smart Gas Distribution," Picarro writes that analytics utilizing advanced leak detection technology can be used to "prioritize each leak indication by the likelihood that it corresponds to a hazardous leak"[24] With information about the probability of a leak being hazardous, utilities can prioritize leak investigations in a way that maximizes the number of hazardous leaks found per effort spent investigating leaks. Such a strategy would ultimately improve the performance of the utility at reducing the greatest number of hazardous leaks per dollar spent on investigations.

In summary, these technology improvements, source attribution, leak flow rate quantification software, leak locating and survey completeness features, and grading probability software, allow utilities to maximize the return on investment when using advanced leak detection technology, from both a financial and safety perspective.

[24] Picarro. 2016. "The Transition to Smart Gas Distribution." Santa Clara, CA. http://naturalgas.picarro.com/sites/default/files/2017-04/Picarro%20Analytics.pdf.

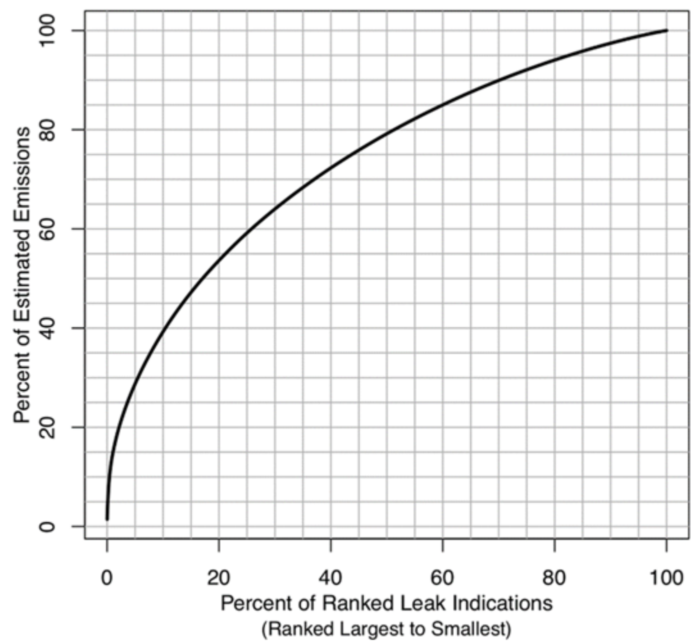
V. Benefits of Advanced Leak Detection, Data Analytics and Quantification

Q. How can the use of advanced leak detection technology and leak quantification methodologies in leak prioritization ensure that ratepayer funding is deployed efficiently?

A. Fischer et al. (2017) aggregated leak flow rate data collected in several locations in the northeast and Midwest, and estimated that on average "cutting emissions in half could be accomplished by repairing the largest 20% of leaks."[25] This is further demonstrated by the following leak distribution curve,[26] which shows that, among the leaks studied, using advanced leak detection and data analytics to prioritize the repair the top 20% of leaks could reduce distribution system emissions by 54%:

[25] Fischer, J. von, Cooley, D., Chamberlain, S., Gaylord, A., Griebenow, C., Hamburg, S., Ham, J. (2017). Rapid, Vehicle-Based Identification of Location and Magnitude of Urban Natural Gas Pipeline Leaks. *Environmental Science & Technology*, *51*(7), 4091–4099. https://doi.org/10.1021/acs.est.6b06095.

[26] Weller, Z. D., Yang, D. K., & von Fischer, J. C. (2019). "Cumulative emissions curve from the estimated sizes of 6125 leak indications. The cumulative emissions curve indicates that largest 20% of leaks account for approximately 54% of total emissions."



Based on extensive analysis of utility system leaks, including within the Company's service territory, a similar level of leak reduction can be achieved by Con Edison. Integrating advanced leak detection technology into regular leak survey operations and using leak flow rate data to inform decisions relating to gas utility infrastructure investments provides several benefits including cost savings, improved risk mitigation, current and accurate data to improve prioritization evaluations, improved scheduling of replacement programs, relevant metrics with which the Company and others can objectively assess replacement programs, and forward-looking modeling. Specifically, prioritizing pipelines for replacement using leak flow rate data allows utilities to improve the efficiency and efficacy of pipeline replacement expenditures, for the benefit of ratepayers.

Q. What are the cost savings that advanced leak detection technology and leak quantification potentially offer?

A. Advanced leak detection technology service providers describe a wide variety of use cases for advanced leak detection technology and leak quantification.[27] Prioritizing pipe replacement is only one potential use of the technology and methodology. Considering all these other use cases, benefits are significantly greater when using advanced leak detection holistically in comparison to what can be realized through only applying advanced leak detection technology and leak quantification to the management of a pipe replacement program.

Potential cost savings can be found through:

- Capturing gas through identification and remediation of high volume leaks
- Reducing risk through replacement of pipe segments with high leak density (leaks per mile)
- Reducing risk through auditing a walking survey[28]
- Responding to fewer odor calls
- More quickly locating hard-to-find leaks
- Conducting rapid post-emergency survey
- Finding leaks during post-construction quality control

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27 *See* Exhibit __(VP-7) and Exhibit __(VP-8).

28 Advanced leak detection technology can be used to survey an area after a walking survey has taken place, identifying leak indications that may not have been detected in a walking survey. Using leak grade probability software in conjunction with advanced leak detection technology can help to identify priority leak indications that deserve to be revisited.

- Real-time source attribution, if using methane/ethane sampling
- Verifying quality of a system prior to asset acquisition

Q. Please explain how advanced leak detection technology and leak quantification methodologies can lead to improved risk mitigation.

A. Advanced leak detection technology and leak quantification methodologies can improve risk assessments by providing direct metrics of leak size, and other detailed information about leak expression and density—such as leak flow rate—in formats that are easy to compile and analyze. Advanced leak detection technology is essential for capturing leak flow rate data because it automatically provides spatially-attributed data about potential leak expressions and it is more sensitive than traditional leak detection technologies. Compared to other quantification methods, data can be captured in a more timely manner and can be easily analyzed with Geographic Information Systems ("GIS") and/or in a comma separated value (.csv) format.

Advanced leak detection technology collects leak concentration data, the same data that is collected in traditional foot surveys and that is used to estimate % lower explosive limit. The GIS capabilities of advanced leak detection technology may be used to estimate proximity to buildings or substructures; datapoints that must be considered when grading leaks. Leak flow rate estimates from data that is collected using advanced leak detection technology is an additional meaningful data point that can be used in risk assessments, to give a clear indication of the potential for leak expressions to migrate into an enclosed area. That is, by studying plume characteristics, advanced leak detection technology software can estimate the probability of a leak indication representing an immediate hazard. Using probable leak grade information, utilities can prioritize a list of leak indications to investigate for the purposes of grading. By considering leak grade probability first, utilities can increase the rate at which they find and respond to hazardous leaks out of every hour spent investigating leak indications.

As I mentioned earlier, I am not suggesting that advanced leak detection technology surveys be used to replace traditional foot surveys. Rather, advanced leak detection technology and associated analytics can make utilities aware of many more leaks than would otherwise be possible, can aid utilities in reducing system risk by providing more actionable information than they currently have available for making leak abatement decisions, and aid in prioritizing leak investigations for leaks that are likely to be hazardous.

Q. Please explain how data from advanced leak detection technology can lead to more current and actionable data to improve prioritization evaluations.

A. Data from advanced leak detection technology, such as leak flow rate and leak density, also increases the accuracy of prioritization evaluations, which can lead to more effective and impactful replacement decisions. Relying on historical datasets that use only traditional leak detection methods is very likely to result in less accurate pipeline replacement prioritization. Supplementing historical leak data with more robust and up to date leak data provided by advanced leak detection technology, leak quantification methodologies, and associated analytics can improve utility decision-making for spending customer funds in comparison to reliance on historical data, and ensure that replacement activities prioritize the pipelines with the greatest need for replacement.

Q. Can the metrics associated with advanced leak detection technology and analytics provide useful information for the Commission, Staff, the Company, and ratepayers?

A. Data collected using advanced leak detection technology and analytics can also provide useful input to assist the Company, ratepayers, Staff and the Commission in evaluating the efficacy of the Company's pipeline replacement program. Having data on leak flow rates that is spatially attributed results in metrics that can be verified, as advanced leak detection technology can provide insightful performance analysis. By supplying spatially attributed data that can be used to report on meaningful evaluation metrics, advanced leak detection technology and leak quantification can improve the information stakeholders, Staff and the Commission use to evaluate the Company's pipeline replacement program. Specifically, information including leak flow rate data and leak frequency can be used to evaluate the pace at which risk is mitigated, and whether the scheduling of each grid for replacement has been prioritized in a way that optimizes risk mitigation, and allows for replacement program progress to be tracked and assessed frequently and easily.

Q. Please explain how the use of advanced leak detection technology and analytics can enhance forward looking modeling.

A. Use of the best available data, gathered from advanced leak detection technology and leak quantification methodologies, can enhance forward-looking models of risk by including direct data on the current state of the system. These data, when considered as a part of the Company's prioritization strategy, allow for predictions about pipeline integrity in the future, and can be updated on a regular basis as new data is made available. Predictive capabilities can improve the efficiency of replacement plans and help optimize the expenditure of ratepayer funds.

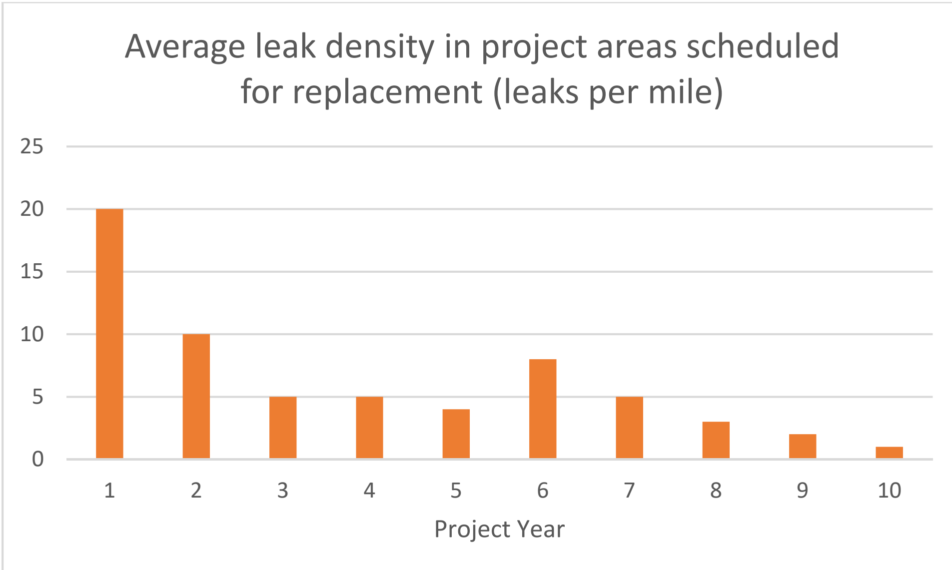
Q. How can advanced leak detection technology and leak quantification provide meaningful information for enhancing forward looking modeling that will allow Con Edison to make appropriate adjustments in prioritizing pipeline replacements?

A. Advanced leak detection technology and leak quantification can provide data that is relevant to predictive risk models, which would integrate well with the Company's rankings identified through the Company's DIMP. Through capturing the current state of the system in each project area with advanced leak detection technology and leak quantification, the Company can determine a more accurate number of active leaks per mile in each project area and the leak flow rate per mile in each project area. Incorporating these two data points into the Company's existing databases will allow the Company to make prioritization decisions based on up-to-date data on system threats, rather than relying primarily on historical leak repair data.

When considered along with traditional metrics, leak flow rates per mile can be a valuable factor in risk assessment. While leak flow rates are not always correlated with risk ranking, it is readily apparent that a larger leak has a greater ability to release more flammable natural gas into an enclosed space and present a potential hazard. In this testimony, I propose that the Company include another metric in their reporting, the percent of total leak flow rate reduced per year over the percent of pipeline miles replaced per year.

The benefits of such a metric are evident in the following example. Consider a hypothetical situation where the Company is replacing pipes in several project areas per year, and the leak density (leaks per mile) distribution for each planned project year is as follows:

Figure 2:



Depending on the replacement strategy, project areas with the highest leaks per mile might be scheduled first, but this may not necessarily be the case, because of other factors that may influence prioritization.

In figure 2, project areas are not prioritized solely based on leak density. Empirical research has shown that leak flow rates per mile are not necessarily correlated to leak densities.[29, 30, 31] Consider, for example, that the leak flow rates per mile for the hypothetical project areas in figure 2 could be as follows:

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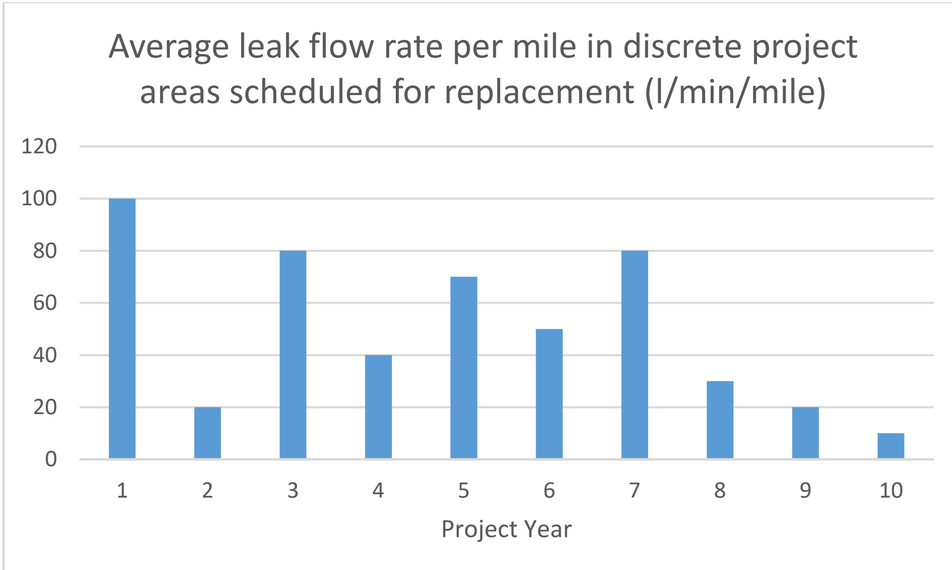
[29] Fischer et al. (2017).

[30] Brandt, A. R., Heath, G. A., & Cooley, D. (2016). Methane leaks from natural gas systems follow extreme distributions. *Environmental Science & Technology*, acs.est.6b04303. https://doi.org/10.1021/acs.est.6b04303

[31] Hendrick, M. F., Ackley, R., Sanaie-Movahed, B., Tang, X., & Phillips, N. G. (2016). Fugitive methane emissions from leak-prone natural gas distribution infrastructure in

Figure 3:



In the hypothetical example above, project year 2 has the second highest average leak density (Figure 2) out of all the project years, but one of the lowest average leak flow rates per mile (Figure 3). The lack of correlation between leak density and leak flow rates indicates that a utility could achieve reductions in large numbers of leaks without also achieving comparable reductions in overall leak flow rates. This is further evidenced by considering project years one and two. In Figure 3, project year one demonstrates the highest average leak flow rate per mile for the project areas scheduled for replacement in project year one. This is ideal, because it shows that greater volumes of potentially lost gas will be captured earlier on in the program. However, in project year two, the average leak flow rate is much lower, even though the average leak densities are relatively high compared to other

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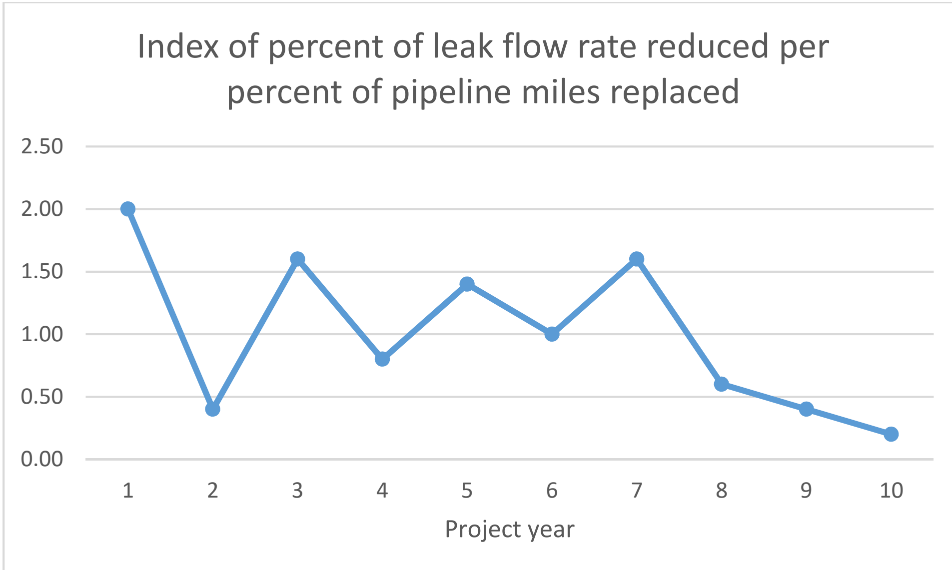
urban environments. *Environmental Pollution*, *213*, 710–716. https://doi.org/10.1016/j.envpol.2016.01.094.

project years. This means that a replacement program that only prioritizes leak density will not optimize replacements based on overall volume of leakage.

Considering leak flow rate in pipeline replacement scheduling can help the Company capture greater volumes of gas earlier in their replacement program, improving efficiency and benefiting ratepayers. Because leak flow rate is an indicator of the overall volume of gas lost from a system, a prioritization ranking that includes leak flow rate, after taking safety into consideration, will result in a replacement program that addresses the leakiest pipes sooner.

In addition to simply having a forward-looking metric that will predict changes in risk level with replacement, the metric I am proposing, percent of total leak flow rate reduced per year over the percent of pipeline miles replaced per year, will directly relate costs expended to risk mitigation accomplished. In a scenario like those above, where project areas are not prioritized solely based on leak flow rate (and therefore some project years in the future have higher leak flow rates than earlier years), the index of leak flow rate reduced to pipeline miles replaced would appear as follows, if the pipeline miles replaced remained at 10% each year for ten years:

Figure 4:



Using this metric, in years three, five, and seven, higher leak flow rate reductions could be achieved per expenditure than in the other years. Leaving high-emitting leaks flowing for longer periods of time results in increased risk and lost gas over time, which results in avoidable costs and inefficiencies. With respect to leak flow rate reductions and lost gas, it makes more sense to prioritize greater reductions in leak flow rate for earlier years, to maximize the cost savings of the program. Therefore, the Company's next step in assessing the index presented above could be to reprioritize some project areas to earlier years in the project forecast in order to capture more savings earlier on in the project.

Using the best available data, gathered from advanced leak detection technology and leak quantification methodologies, can enhance forward-looking models of risk by including direct data on the current state of the system. These data, when considered as a part of the Company's risk ranking models, allow for predictions about pipeline integrity in the future, and can be updated on a regular basis as new data is made available.

Q. Please explain relevant aspects of the prevailing regulatory and utility context as it relates to the use of advanced leak detection technology and data analytics by utilities.

A. Utilities are employing such data to supplement existing information on asset risks, and thereby design and target system modernization and maintenance efforts more effectively. Gas utilities are now moving beyond regulatory compliance towards proactive asset risk and integrity management in response to a number of factors, including regulatory advancements, and an increased focus on pipeline safety.[32] Advanced leak detection and quantification methods have significant ratepayer, environmental and system-wide benefits, as I detail below. A number of major utilities including PSE&G, New Jersey's oldest and largest utility, National Grid in New York, and Peoples' Gas Light and Coke Company ("PGL") in Chicago have recognized the benefits of these methods and created pathways for the adoption of such advanced technologies.

Q. Please elaborate on these utilities' efforts to integrate advanced leak detection, data analytics and quantification into their operations.

A. In November 2015, the New Jersey BPU approved a settlement agreement among New Jersey's largest utility, PSE&G, and other stakeholders on the Company's

[32] PricewaterhouseCoopers (2016).

accelerated pipe replacement program.[33] As part of this settlement, PSE&G received BPU approval to implement a $905 million pipe replacement program over a three-year time period. Under the terms of this settlement, after taking into account safety considerations, PSE&G was required to consider data on the volume of methane emissions leaked from its pipes, in conjunction with other relevant factors, to identify those that are most in need of replacement.[34] By using leak flow rates for prioritization, PSE&G achieved an 83% reduction of methane emissions early on by replacing one-third fewer miles of gas lines than that needed to achieve the same result under a business as usual scenario.[35] This difference is noteworthy considering that the typical cost to replace one mile of gas line on PSE&G's system is $1.5 to $2.0 million.

PSE&G built upon these efforts in the second phase of its gas system modernization program. As part of a settlement agreed to in BPU Docket No. GR17070776, PSE&G committed to contract with a third party vendor to conduct a leak survey

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[33] *Decision and Order of the New Jersey Board of Public Utilities In The Matter Of Public Service Electric And Gas Company for Approval of a Gas System Modernization Program and Associated Cost Recovery Mechanism*, Docket No. GR15030272, November 16, 2015, retrieved from http://www.nj.gov/bpu/pdf/boardorders/2015/20151120/11-16-15-2F.pdf.

[34] Further information about this analysis can be accessed at https://www.edf.org/climate/methanemaps/pseg-collaboration. The methodology used by PSE&G to integrate leak flow rate data into its pipe replacement prioritization scheme is described in Exhibit __(VP-3).

[35] *Id.*

in 2018 on 280 miles of leak prone pipeline grids.[36] Leak survey data will be used to generate an "Estimated Flow Rate per Mile (Liter/min/mile)."[37] PSE&G will then develop a ranking threshold which will be used to prioritize grids for replacement in subsequent program years.[38]

Q. Has PSE&G acknowledged the accuracy and benefits that advanced leak detection and data analytics provide?

A. Yes. The Methane Leak Surveying Report on PSE&G's Gas System Modernization Program II explains that "[w]ith methane maps and their aggregated emissions data…it is possible to make accurate, surgical construction decisions at the grid or individual pipeline section level as desired."[39] The report concludes:

> This variability shows the power of the methane mapping technique for providing additional granularity that can be used to maximize methane emissions reductions and/or maximize remediation of the maximum number of belowground leaks through changes to construction priorities based on these methane maps and associated data.[40]

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[36] *In the Matter of the Petition of Public Service Electric and Gas Company for Approval of the Next Phase of the Gas System Modernization Program and Associated Cost Recovery Mechanism*, BPU Docket No. GR17070776, Stipulation of Settlement and Agreement at P 24 (April 18, 2018). The BPU approved this settlement in a June 1, 2018 order.

[37] *Id*.

[38] *Id.*

[39] Exhibit __(VP-9) at page 8.

[40] *Id.* at page 11.

In addition, PSE&G also concludes that its use of advanced leak detection technology is "better for the environment, [provides] less chance of non-hazardous leaks getting worse, and [results in] fewer potential customer calls/complaints."[41]

Q. Please detail other utilities' efforts to integrate advanced leak detection and data analytics into their operations.

A. Recognizing the value of leak quantification methods in terms of enhancing operational safety, reducing methane emissions, and advancing ratepayer interests, KeySpan Gas East Corporation d/b/a National Grid ("KEDLI") and the Brooklyn Union Gas Company d/b/a National Grid ("KEDNY"), both subsidiaries of National Grid, are working on a suite of pilot projects in National Grid's service territory in Long Island, New York, leveraging these new technological capabilities, as envisioned in settlement agreements approved by the Commission in the 2016 KEDNY and KEDLI Rate Cases. The Joint Proposal states that "KEDNY will utilize internal personnel or a qualified contractor to develop the means to quantify emission flow rate data on an ongoing basis."[42] The settlement agreement provides that leak flow rate data gathered as part of these projects will be used by National Grid to enhance leak repair and pipe replacement efforts in its Long Island service territory, and that the companies shall develop the means to quantify leak flow rate from their systems in order to better prioritize their leak

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[41] Exhibit __(VP-10) at slide 26.

[42] *Proceeding on Motion of the Commission as to the Rates, Charges, Rules and Regulations of KeySpan Gas East Corporation d/b/a National Grid for Gas Service*, Case No. 16-G-0058 *et al.*, page 51, section 8.2.2 (Sep. 7, 2016).

repair and LPP replacement projects on an ongoing basis. Niagara Mohawk, National Grid's upstate New York utility, built upon these efforts in a January 19, 2018 Joint Proposal. That settlement obligates Niagara Mohawk to continue to "develop a methodology for assessing leak size and volume using leak quantification methods" and consider "best practices for identifying and abating high volume leaks."[43]

The Peoples' Gas Light and Coke Company ("PGL") in Chicago, Illinois agreed to conduct a pilot program in which "leak flow rate data, collected by a contracted service provider or PGL using advanced leak detection and quantification technology, will be considered in prioritizing leak-prone pipe ("LPP") replacement under the [System Modernization Program]."[44] The Illinois Commerce Commission approved the pilot, and directed PGL to report the following metrics on an annual basis:

- A metric that reports a list of the neighborhoods that are re-prioritized based on the result of leak flow rate data; and
- A metric that measures annual methane leak flow rate reduction based on the mileage of retired pipe and the leak flow rates estimated for those miles

[43] *Proceeding on Motion of the Commission as to the Rates, Charges, Rules and Regulations of Niagara Mohawk Power Corporation d/b/a National Grid for Gas Service*, Case No. 17-G-0239 *et al.*, Joint Proposal at page 42, Section 7.6 (January 19, 2018).

[44] *Illinois Commerce Commission On its Own Motion v. The Peoples Gas Light and Coke Company*, ICC No. Docket 16-0376 at page 77 (January 10, 2018 Final Order).

using advanced leak detection technology and leak quantification methods.[45]

Most recently, Peoples Gas of Pittsburgh committed to using advanced leak detection and data analytics to cut methane emissions from its distribution system by 50%.[46] After mapping and measuring the leaks from its underground pipes, Peoples will use the data to prioritize upgrades to achieve the greatest climate benefits. This pledge to reduce emissions by a specified percentage is the first of its kind by a U.S. utility.

Q. Please describe the pilot project that EDF conducted in collaboration with Con Edison in order to characterize the Company's Type 3 leak backlog.

A. Con Edison, EDF, and EDF's collaborators at CSU conducted a pilot program in 2016 to survey Con Edison's backlog of Type 3 leaks and characterize the leaks by size (i.e. flow rate). In order to facilitate this survey exercise, the Company provided EDF with location information for its Type 3 leak backlog, including information on underground infrastructure locations, under the terms of a non-disclosure agreement. Using cutting-edge spatial analytics algorithms developed by scientists at CSU, combined with methane sensors specially fitted to Google Street View mapping cars, EDF gathered data on leak locations, calculated leak sizes, and

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45 *Id.* at page 81.

46 Environmental Defense Fund. January 8, 2019. Peoples Gas, EDF Unveil New Commitment to Help Protect the Climate by Cutting Methane Emissions From Pittsburgh Utility System in Half. Retrieved from: https://www.edf.org/media/peoples-gas-edf-unveil-new-commitment-help-protect-climate-cutting-methane-emissions.

ranked them from largest to smallest. The Company used these data to prioritize the repair of the Type 3 leaks with the highest leak flow rates. That is, the Company considered leak size as a factor when selecting backlog leaks for rapid repair.

Q. What were the results of the pilot project?

A. The leak flow rate data provided by EDF allowed Con Edison to repair the largest emitting non-hazardous leaks, representing an estimated reduction in nearly twice the amount of methane emissions compared to a business-as-usual scenario. EDF estimated that Con Edison reduced about 30% of the total emissions from surveyed areas. If Con Edison had used a random prioritization method, they would have reduced just 15% of the total emissions, or only half as much as using EDF's ranking information. To establish a baseline "business as usual" scenario, CSU researchers performed a Monte Carlo analysis. This analysis allowed them to estimate the percentage of emissions the utility would have reduced in many scenarios where the leaks would have been prioritized randomly. Our analysis indicated that if Con Edison repaired the leaks in a random order, without EDF's leak flow rate information it would have reduced only 15% of the total estimated emissions (95% confidence interval: 11.1%-23.2%).[47] As a result of using leak flow rate information, the average improvement in emissions mitigation by doubled,

[47] This indicates that the average emissions reduction percentage for a randomly ordered leak repair prioritization is likely to fall between 11.1% and 23.2% in 95% of the scenarios.

going from 15% to 31%. These results and an interactive map showing the leak locations are available on EDF's website.[48]

VI. Integrating Advanced Leak Detection Technology and Data Analytics

Q. Has the Company already invested in advanced leak detection technology?

A. Yes. The Company has purchased a Picarro Surveyor, and is renting a similar cavity ring-down spectrometry ("CRDS") system from a different supplier.[49] The Company is planning to purchase new leak detection equipment from an alternative supplier after the technology's performance has been assessed.

Q. Does the Company acknowledge the benefits that advanced leak detection technology provides?

A. Yes, the Company has acknowledged the use of state of the art leak detection technology as critical to risk management, and notes "through enhanced leak detection, we can identify, respond and remediate leaks more rapidly, reducing risk, keeping the public safe, and protecting the environment by reducing emissions of methane, a greenhouse gas."[50] Using advanced leak detection technology, the Company has stated that they found leaks that were not identified by traditional technologies, and that nearly half of these leaks were classified as Type 1 or 2/2A.[51]

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[48] Environmental Defense Fund. Innovative collaboration fixes non-hazardous leaks faster. Retrieved from: https://www.edf.org/climate/methanemaps/con-edison Accessed on: May 20, 2019.

[49] Gas Infrastructure, Operations and Supply Panel at page 99, lines 4-5 and 18-21 and page 100, lines 8-11.

[50] Gas Policy Panel Testimony at page 16, lines 13-16.

[51] Exhibit __(VP-6).

The Company acknowledges this as evidence of the safety benefit provided by using advanced leak detection technology.

Q. Has the Company committed to integrating the technology it has already purchased?

A. The Company has explained that plans for integrating the technology into Company operations will be developed once all field trials have concluded and leak detection results have been assessed, and has noted that "additional field trials are scheduled for 2019, and further leaks are expected to be identified and mitigated."[52]

Q. What factors are important to consider when evaluating advanced leak detection technology and leak quantification?

A. Important evaluation considerations for advanced leak detection technology and leak quantification include:

- The number of leaks found compared to using traditional leak detection technologies
- Source attribution
- Usefulness of the leak size estimate

Q. Have these aspects of advanced leak detection technology and leak quantification been adequately evaluated to date?

A. Yes, as I discussed earlier in my testimony in the section titled "Status of Advanced Leak Detection Technology and Recent Technological Advancements," advanced

[52] *Id.*

leak detection technology and leak quantification have already been evaluated at length in terms of the number of leaks found compared to using traditional leak detection technologies, source attribution, and usefulness of the leak size estimate.

Q. Do you have any observations regarding the Company's evaluation?

A. Yes. The Company's evaluation and assessment of the technology should not stand in the way of its use. The Company has already acknowledged the benefits that advanced leak detection technology provides and should integrate this technology into its operations so that customers can benefit from its purchase, as are numerous utilities around the country.

Q. You stated above that the Company should integrate advanced leak detection technology into its operations. Can you provide more details regarding this recommendation?

A. I recommend that Con Edison integrate advanced leak detection technology and leak quantification methods into its operations, and that the Company incorporate leak flow rate data derived using these technologies into their pipeline replacement prioritization on an ongoing basis. I also recommend that the Commission adopt a metric that uses leak flow rate data gathered by advanced leak detection technology to track the efficiency of the pipeline replacement program.

Q. Please further describe your suggestion that the Commission adopt a proposed metric to track the efficiency of the pipeline replacement program.

A. I recommend that the Commission adopt a metric on annual methane leak flow rate reduction based on the mileage of retired pipe and the leak flow rates estimated for those miles using advanced leak detection technology and leak quantification methods.

Furthermore, I recommend that the Company submit a Methane Leak Surveying Report to the Commission. The Report should contain:

- An explanation of the advanced leak detection and leak quantification technology used, including description of equipment and software, sensitivity and capabilities relative to equipment and technology traditionally used by Con Edison for these purposes.
- A description of methodology used to integrate leak flow rate data into the Company's prioritization scheme, as an additional factor to supplement hazard ranking.
- Depiction of results, *i.e.*, tabular representation of aggregate leak flow rate for each project area targeted, ranking of each grid using leak flow rate relative to risk ranking based on existing algorithm, and final prioritization rank after considering leak flow rate data.
- A table with the project area IDs, and associated information, including:
    - Miles of leak prone pipe in the project area,[53]
    - Total estimated flow rate (liters/minute),
    - Estimated flow rate per mile (liters/minute/mile),
    - Total risk score per mile,

[53] Defined as aging 12-inch-and-under cast iron, wrought iron, and unprotected steel pipe.

- Main risk score per mile,
- Service risk score per mile,
- Project area priority rank,
- Rank by estimated flow rate per mile,
- Ranked year of construction using methane flow rate data
- Planned year of construction description of factors contributing to prioritization bypass decisions (if planned year of construction does not match ranked year of construction)

VII. Leak Incentive

Q. Please explain the current incentives the Company receives for eliminating the highest volume Type 3 leaks.

A. Governor Cuomo's May 2017 Methane Reduction Plan directs state agencies, including the Department of Public Service ("DPS"), to develop proposals and policies to inventory emissions and identify strategies for methane capture and elimination. The Plan directs the DPS to "utilize rate cases to incentivize utilities to maintain a low backlog of leaks and replace leak-prone pipe for State jurisdictional pipeline operators."[54] Consistent with this directive, various New York gas utilities have adopted incentives in order to reduce their leak backlogs. Con Edison's 2016 rate case established an incentive, the Gas Performance Mechanism, for reducing their leak backlog and eliminating the highest volume

[54] Methane Reduction Plan at 6 (May 2017), https://www.dec.ny.gov/docs/administration_pdf/mrpfinal.pdf.

Type 3 leaks.[55] The Gas Performance Mechanism allows for both negative and positive rate adjustments regarding the Leak Management Year-End Total Backlog. First, the negative rate adjustment was designed to incentivize the company to reduce the number of total leaks in their backlog (including all leak types: 1, 2, 2A and 3) each successive year, by penalizing the company if the leak backlog was not reduced below a certain threshold each year.

Table 1: Current leak backlog thresholds for earning negative basis points, 2017 – 2019.

Year	Leak Backlog Reduction Threshold	Negative basis points
2017	600 or less	No adjustment
	Greater than 600	12 basis points
2018	550 or less	No adjustment
	Greater than 550	12 basis points
2019	500 or less	No adjustment
	Greater than 500	12 basis points

Next, the positive rate adjustment is designed to incentivize the company to both go beyond the leak backlog reduction threshold and target the highest volume leaks. This has allowed the Company to earn a maximum of five positive basis points if the leak backlog was reduced beyond the thresholds established for each year

55 Appendix 16 – Gas Performance Mechanism of the Joint Proposal dated September 19, 2016, approved in the final order for Case 16-G-0061 on January 25, 2017.

(Table 1). After the leak backlog is reduced beyond the threshold, the Company has been able to earn positive basis points, earning a higher number of basis points when they eliminate more of the highest volume Type 3 leaks, under a system of five tiers (Table 2). The incentive also allows for the Company to count leaks as eliminated and earn positive basis points if the Type 3 leak backlog is less than 150 leaks, which is the highest tier for earning basis points.

Table 2: Current basis points earned by number of highest volume Type 3 leaks eliminated, 2017 – 2019.

Number of leaks eliminated	Basis points earned
28 of the top 30	1
56 of the top 60	2
84 of the top 90	3
112 of the top 120	4
140 of the top 150	5

Q. How is the Company proposing to change the current incentive structure for eliminating the highest volume Type 3 leaks?

A. The Company is proposing to increase the annual maximum positive incentive to six basis points, while maintaining the 2019 year-end total leak backlog target of 500 for the year 2020 using the tiers outlined in Table 3. These proposed changes would allow the Company to earn more basis points in each tier for achieving the same leak backlog target as 2019, and reducing the same number of the highest emitting leaks as in past years.

Table 3: The Company's proposed basis points earned by number of highest volume Type 3 leaks eliminated for 2020.

Number of leaks eliminated	Basis points earned
28 of the top 30	2
56 of the top 60	3
84 of the top 90	4
112 of the top 120	5
140 of the top 150	6

Q. Is there a tension between the current incentive mechanism and the Company's willingness to deploy modern technology such as advanced leak technology that would find and quantify more leaks?

A. Yes. As I explained above, advanced leak detection technology and analytics are typically able to find many more existing and ongoing leaks than traditional technologies. At the same time, Con Edison's current incentive structure rewards the utility primarily for reporting a lower <u>number</u> of leaks in their backlog at the end of the year. This reveals a tension between the capabilities of the best available technology to find more existing leaks and the incentive structures that guide utilities to demonstrate that there are fewer leaks in the backlog at the end of the year.

Q. Do you have a suggestion to resolve this identified tension?

A. Yes. Con Edison's current incentive structure should be revisited, as it ultimately serves to discourage the Company from finding more leaks on its system and is consequently an obstacle to achieving New York State methane abatement goals and policies. Rather, Con Edison should be incentivized to find more leaks using advanced leak detection, estimate their flow rate, and to reduce those leaks, prioritizing the highest volume leaks first by using a leak distribution curve.

Q. Please further explain how your recommendation would work in practice.

A. I recommend that Con Edison first complete a methane leak survey of its entire service territory using advanced leak detection technology. Using the information gathered from this initial survey, Con Edison could then establish a system-wide baseline leak flow rate. Next, a volumetric leak reduction target could be established within Con Edison's leak abatement incentive. In order to receive its annual maximum positive incentive, the Company would be required to achieve a 50% reduction over three to five years which, according to our data, would require abatement of approximately the largest 20% of leaks in its non-hazardous leak inventory. This objective could be met through a combination of pipeline replacement and Type 3 leak repairs, allowing the utility to optimize its approach to leak mitigation through pipeline replacements when necessary.

Q. Please explain why you are recommending a three to five year range for the Company to achieve a 50% reduction in emissions reductions.

A. I am recommending a range of three to five years for two reasons: first, the current, estimated rate of advanced leak detection technology surveying is such that a system-wide survey could take approximately 18 months to complete over Con Edison's 4,400 miles of gas main; and second, in recognition of the time that may be required for the Company to integrate leak flow rate information into its geospatial information systems, and prioritization systems for leak repair and pipeline replacement. I believe it is possible for the Company to achieve 50% emissions reductions within a three-year period, but also that some flexibility in the timeline is warranted to ensure that integration of the technology and information derived from its use is well thought out and positions the Company to make efficient prioritization decisions over the long term.

Q. How does the three to five year range impact your recommendations regarding the Company's incentive structure?

A. I recommend that the Company use its proposed incentive structure based on the current leak backlog until a system-wide leak survey using advanced leak detection technology has been completed, and the Company has developed a plan for prioritizing leak repairs and pipeline replacements based on leak flow rate, after taking safety into consideration. After the Company has made its prioritization plan available to the Commission, the new incentive structure based on percentage emission reductions should come into effect.

Q. Does this conclude your testimony?

A. Yes.

Exhibit __ (VP-1):

Resume of Virginia Palacios

VIRGINIA E. PALACIOS

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virginia@vpenv.com
P.O. Box 27
Encinal, Texas 78019

EDUCATION

MASTER OF ENVIRONMENTAL MANAGEMENT

Duke University – Durham, NC - May 2012

Concentration: Global Environmental Change

Relevant coursework: Energy and Ecology, Natural Resources Economics, Climate Change Economics, Human Health and Ecological Risk Assessment

BACHELOR OF SCIENCE IN AERONAUTICAL SCIENCE

Embry-Riddle Aeronautical University – Daytona Beach, FL - May 2007

Commercial pilot, airplane single- and multi-engine land, instrument-rated

Relevant coursework: Physics I and II, Calculus I, Meteorology I and II

WORK EXPERIENCE

PRINCIPAL

VP Environmental, LLC – Encinal, TX – May 2019 to present

Lead the development of policy solutions to mitigate methane emissions in the natural gas distribution pipeline sector in various states throughout the U.S.

SENIOR ENVIRONMENTAL SCIENTIST

Glenrose Engineering – Austin, TX – March 2019 to present

Conduct geospatial analysis and use modeling tools provided by the City of Austin to estimate potential pollutant loads into the Edwards Aquifer.

INDEPENDENT CONSULTANT

Self-employed – Oct. 2017 to Apr. 2019

Advise on strategic considerations for projects aimed at reducing methane leakage and risks from natural gas distribution systems.

Write testimony for regulatory proceedings explaining how to use methane leakage data to achieve cost-savings and greenhouse gas emission reductions.

STATE AND LOCAL POLICY MANAGER

South-central Partnership for Energy Efficiency as a Resource (SPEER)
Austin, TX – Oct. 2017 to Oct. 2018

Managed collaborative group of investor-owned utilities and stakeholders to discuss expanding utility energy efficiency programs in Texas.

Shared expertise on energy efficiency in buildings as a member of the Energy and Buildings Working Group for the City of San Antonio's Climate Action Plan.

SENIOR RESEARCH ANALYST

Environmental Defense Fund (EDF) - Austin, TX - Apr. 2016 to Oct. 2017

Provided technical expertise on scientific and regulatory concepts related to local distribution pipeline safety and methane emission quantification.

Compared state and federal regulations on local distribution pipeline safety.

Solved complex analytical problems using geospatial analysis.

RESEARCH ANALYST
Environmental Defense Fund (EDF) - Austin, TX – Apr. 2014 to Apr. 2016
Investigated local, state, and federal rules related to distribution pipeline safety.
Analyzed data related to environmental impacts of oil and gas development.

RESEARCH ASSOCIATE
Environmental Defense Fund (EDF) - Austin, TX – Jul. 2012 to Apr. 2014
Wrote reports on distribution system leak detection technology and regulations.
Researched distribution system integrity management and leakage.
Analyzed data on distribution system material mileage and leak frequencies.

RESEARCH AND CAMPAIGN ASSOCIATE
Rio Grande International Study Center - Laredo, TX - May 2011 to Aug. 2011
Organized expert panels to provide public opportunities to learn about potential environmental impacts of oil and gas development.
Drafted letters and other documents to establish public positions of coalition.

PUBLICATIONS

Palacios, Virginia, Simi R George, Joseph C von Fischer, and Kristina Mohlin. (2017). Integrating Leak Quantification into Natural Gas Utility Operations. *Public Utilities Fortnightly, May.*

Lyon, D., Zavala-Araiza, D., Alvarez, R., Harriss, R., Palacios, V., Lan, X., … Hamburg, S. (2015). Constructing a Spatially Resolved Methane Emission Inventory for the Barnett Shale Region. *Environmental Science and Technology.*

Zavala-Araiza, D., Lyon, D., Alvarez, R., Palacios, V., Lan, X., Talbot, R., & Hamburg, S. (2015). Towards a Functional Definition of Methane Super-Emitters: Application to Natural Gas Production Sites. *Environmental Science and Technology.*

Palacios, V. (2012). Baseline groundwater quality testing needs in the Eagle Ford Shale region. *Duke University.*

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Palacios, V. (2018). Moderator: Restructuring Investor-owned Utility Programs for Maximum Impacts Panel. *SPEER Summit.* Austin, Texas.

Palacios, V. (2014). Environmental Perspective on Methane Emissions and EDF Research Program Overview. In *Government/Industry Pipeline R&D Forum - Leak Detection/Fugitive Methane Working Group*. Rosemont, IL: U.S. Department of Transportation, Pipeline and Hazardous Materials Safety Administration. https://primis.phmsa.dot.gov/rd/mtg_080614.htm

ARTICLES

Palacios, V. (2016). PSE&G and EDF “Google It.” Energize | A PSEG Blog.

Palacios, V., and Simi Rose George. (2016). Managing Methane: New Jersey’s Largest Utility Using Better Data for Better Decisions. *EDF Energy Exchange.*

Palacios, V., and Holly Pearen. (2016). New Technologies Deliver Data That Can Make Gas Pipelines Safer. *EDF Energy Exchange.*

Exhibit __ (VP-2):

List of Expert Testimony of Virginia Palacios

Expert Testimony of Virginia E. Palacios

Name of Case	Jurisdiction	Docket Number	Date
Proceeding on Motion of the Commission as to the Rates, Charges, Rules and Regulations of Consolidated Edison Company of New York, Inc. for Gas Service	State of New York Public Service Commission	16-G-0061	May 27, 2016 (Direct Testimony)
I/M/O Public Service Electric and Gas Company For Approval Of The Next Phase of the Gas System Modernization Program And Associated Cost Recovery Mechanism	New Jersey Board of Public Utilities	GR17070776	January 19, 2018 (Direct Testimony)
Investigation of the cost, scope, schedule and other issues related to the Peoples Gas Light and Coke Company's natural gas system modernization program and the establishment of Program policies and practices pursuant to Sections 8-501	Illinois Commerce Commission	16-0376	October 11, 2016 (Direct Testimony) June 14, 2017 (Direct Testimony on Reopening) July 18, 2017 (Rebuttal Testimony on Reopening)
Application of Washington Gas Light Company for Approval of PROJECTpipes2 Plan	Public Service Commission of the District of Columbia	1154	March 22, 2018 (Affidavit)

Exhibit __ (VP-3):

“Integrating Leak Quantification into Natural Gas Utility Operations”

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Integrating Leak Quantification into Natural Gas Utility Operations

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Abstract

Natural gas utilities can incorporate leak flow rate data into existing pipeline replacement and leak repair prioritization frameworks to more rapidly and efficiently reduce leakage on their system. Leak distributions typically demonstrate a "fat-tail," where a few, large leaks are responsible for the majority of lost gas volumes. Through ranking and ordering leak flow rate data, utilities can identify a subset of the largest leaks to repair or the leakiest pipelines to replace, and capture more gas per dollar spent on leak repair or pipeline replacement. This benefits ratepayers, who pay for the cost of lost gas, and also carries broader environmental and societal benefits.

1. Introduction

Studies of natural gas distribution pipeline leaks indicate that a relatively small subset of leaks is responsible for a disproportionate share of total observed emissions (Brandt et al., 2016; Lamb et al., 2015; Hendrick et al., 2016; von Fischer et al., 2017). Even though natural gas distribution utilities must expeditiously repair hazardous leaks, many large leaks can persist for months or years prior to repair because the standard used to grade a leak's risk generally places greater weight on the proximity to structures than to leak size. Recently, mobile monitoring has been used to detect the presence of underground pipeline leaks and estimate their size (von Fischer et al., 2017). If utilities used such leak quantification systems to prioritize abatement of the largest non-hazardous leaks, after taking safety into account, the climate benefits of leak repair and pipe replacement programs could be enhanced. By eliminating more natural gas losses per dollar spent on leak repair and pipeline replacement, leak quantification also helps constrain ratepayer costs.

Information on the size of leaks can also help utilities to verify and validate the need for leak repair and pipe replacement programs and allow regulatory agencies responsible for authorizing utility leak abatement projects to better assess the need for such efforts. In addition, leak quantification can improve project management by allowing utilities and public utility commissions to evaluate the progress of leak repair and pipeline replacement programs by considering the reduction in volumes of leaked gas achieved through implementation of such programs. This paper describes the implications of integrating leak quantification into utilities' regular leak operations and explores potential frameworks for implementation based on currently employed utility practices.

2. Leak Repair and Pipeline Replacement Programs: Current Regulatory Framework and Utility Practice

Natural gas leaks and leak-prone infrastructure impose costs and pose safety risks to society. Natural gas leaks are also harmful to the climate and environment because they consist primarily of methane, a potent short-lived climate pollutant and an ozone smog precursor. Traditionally, local gas distribution utilities focus their repair programs on finding, assessing, and repairing leaks in their infrastructure to prevent explosions. The occurrence of pipeline leaks is influenced by the following factors (U.S. Department of Transportation, 2011; American Gas Foundation and Yardley Associates, 2012):

- Exposure to extreme weather (e.g. temperature, moisture),
- Corrodible or brittle pipeline materials (cast iron, bare steel, copper, and certain vintage plastic pipes),
- Age,
- High occurrence of joints,
- Material or weld failures,
- Location of pipeline in the vicinity of excavation, or
- Areas where soil is unstable (e.g. earthquake-prone areas, karst-prone systems or in shrink/swell soils).

The Pipeline and Hazardous Materials Safety Administration (PHMSA) rules require operators to annually report data on the number of leaks repaired and the number of known leaks remaining on their system at the end of each year, but do not require operators to quantify leak volume (49 C.F.R. §191.11 and Form PHMSA F 7100.1-1).

PHMSA also offers non-binding guidance to operators on how to grade leaks based on safety risk, thereby establishing leak repair priority, and assisting operators in complying with federal safety rules that require them to “evaluate and rank risk” posed by their distribution pipeline systems (49 C.F.R. § 192.1007). Some states have incorporated or adapted PHMSA’s leak grading guidance into their rules and statutes (NAPSR, 2013). The grading categories are based solely on an evaluation of the risk to persons or property and primarily considers proximity to building envelopes (PHMSA, 2000). Moreover, some researchers have observed the size, or leak flow rate, of grade one (i.e. “immediately” hazardous) leaks to be no different from other grades of leaks (Hendrick et al., 2016). Under the existing regulatory framework, utilities are generally not required to repair non-hazardous leaks (i.e. leaks that are not immediately hazardous) within a specific timeframe. As a result, non-hazardous leaks may continue unabated for long periods, in some cases decades,[1] thereby wasting a valuable resource and hurting the economic interests of ratepayers, who bear the costs of leaked gas.

[1] Two jurisdictions in the U.S., California and Massachusetts, require gas distribution utilities to report leak inventories with relevant characteristics. Leak data made available through the California Public Utilities Commission R. 15-01-008 – Natural Gas Leakage Abatement Rulemaking indicates that as of May 22, 2015, there were some leaks discovered in the 1990s that still had not been scheduled for repair.

PHMSA guidance on leak grading suggests comparing the concentration of gas in air around the leak to the lower explosive limit (LEL) of natural gas. [2] However, methane concentrations in air (e.g. parts per million) in and around a leak are not necessarily proportional to the rate at which gas is being lost (i.e. flow rate, typically measured in standard cubic feet per hour). Current utility practices, therefore, are insufficient for: (1) prioritizing leak repair using flow rate, or (2) verifying the effectiveness of leak repair and pipeline replacement initiatives at reducing system-wide losses of methane from natural gas.

It is important to distinguish between leak repairs, which occur on a regular basis and are paid for through operation and maintenance budgets, and pipeline replacements. On average leak repairs cost from $2,000 to $7,000 per leak (Aubuchon and Hibbard, 2013; Pacific Gas and Electric Company, 2015a). Considering that utilities are required to repair hazardous leaks immediately while non-hazardous leaks can persist for longer periods of time, leak quantification can be used to prioritize non-hazardous leaks for repair, thus improving cost-effectiveness by capturing the highest volumes of gas per dollar spent on leak repair without negatively impacting safety.

Similarly, leak quantification can be used to prioritize pipelines for replacement. Pipeline replacement can cost between $900,000 and $3 million per mile of pipe depending on a variety of factors (Aubuchon and Hibbard, 2013; Anderson et al., 2014). Utilities across the country are looking to replace many, if not most, of the 70,000 miles of leak-prone distribution pipes still in operation in the U.S. over the next two decades at an estimated cost of $270 billion (U.S. Department of Energy, 2015).[3]

The size of these investments underscores the need to thoughtfully design and execute these programs. In order to prioritize leak repair and pipe replacement programs, many utilities use hazard assessment algorithms to estimate the relative safety risk posed by leaks on their system, considering factors such as pipe material, environmental conditions, leak history, etc. After hazard assessment data is considered, leak flow rate data provides additional information that can be considered in prioritizing leak repair and pipeline replacement activities, and by so doing optimize the benefits of both operating and capital expenses.[4] Typical utility practices do not include leak flow rate assessments and therefore do not allow for this kind of improved prioritization.

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[2] The PHMSA guidance document, "Gas Leakage Control Guidelines for Petroleum Gas Systems," gives several examples of a Grade 1 leak:

- *Any leak which, in the judgment of operating personnel at the scene, is regarded as an immediate hazard*
- *Escaping gas that has ignited*
- *Any reading of 80% LEL or greater in a confined space*
- *Any reading of 80% LEL or greater in small substructures (other than gas associated substructures) from which gas would likely migrate to the outside wall of a building*

[3] The estimated 70,000 miles of leak-prone pipe includes cast iron, unprotected bare steel, copper, ductile iron, and "other," as listed in PHMSA 2015 Annual Distribution Data. Cost estimates provided from the U.S. Department of Energy (2015) may be based on older mileage values, and it is unclear which materials are included in the U.S. Department of Energy's estimate.

[4] The availability of additional data points indicating the character of pipeline infrastructure is naturally useful for the purposes of integrity management as well. Utilities may find that it is beneficial to integrate leak flow rate values into hazard assessments.

3. Benefits of Using Leak Quantification

In 2011, PHMSA issued a "Call to Action" to state pipeline regulatory agencies, pipeline operators, and technical and subject matter experts after a series of natural gas distribution pipeline explosions. Recognizing the safety risks associated with cast iron gas mains, PHMSA urged state agencies to facilitate accelerated pipeline replacement programs for cast iron and other high-risk pipeline segments (U.S. Department of Transportation, 2011). Accelerated pipeline replacement programs are necessary from a safety standpoint, but also carry significant ratepayer and environmental implications.

With advanced leak detection technology and leak quantification, a utility can quickly and comprehensively assess the leakiness of its infrastructure with geospatial awareness. Using leak flow volume to further prioritize leak repair and pipeline replacement programs, once safety considerations have been taken into account, offers benefits to both ratepayers and society as a whole. First, the larger reductions in lost gas that leak prioritization can achieve translates into savings for ratepayers who generally pay both for gas delivered as well as gas lost on the pipeline system, which is considered an accepted cost of service (Webb, 2015). Second, there are societal benefits from reducing the amount of gas leaked because natural gas is composed primarily of methane,[5] a powerful short-lived climate forcer 84 times more potent than carbon dioxide over a 20-year time horizon (IPCC, 2013).

Researchers have estimated the social costs of greenhouse gas emissions by considering their effect on the climate and subsequent impacts such as changes in agricultural productivity, heat-related illness, and property damages from increased flood risk. The social cost of methane is a monetized value of the damages occurring as the result of an additional unit of methane emissions. Specifically, it represents society's aggregate willingness to pay to avoid the future impacts of one additional unit of methane emitted into the atmosphere in a particular year (Martens et al., 2014). Estimates of the social cost of methane can be used in a cost-benefit analysis of proposed regulations or projects with an impact on methane emissions. That is, the social cost of methane can be used to assess the benefits to society of a leak repair or a pipeline replacement program. The estimate for the social cost of methane used by federal agencies to value the climate impacts of new rulemakings is $1000/ton of methane (Interagency Working Group on Social Cost of Greenhouse Gases, 2016).[6] This estimate translates into social damages of $17 per thousand cubic feet (Mcf) of natural gas leaked and hence each reduced Mcf of gas leaked to the atmosphere spares society as much in climate change-related damages.[7]

4. Using Leak Quantification to Prioritize Pipe Replacement and Leak Repair

Studies show that distributions of leaks often exhibit a "fat-tail," where a small number of large leaks, often referred to as superemitters, account for the majority of measured gas losses in a sample (Brandt et al., 2016; Lamb et al., 2015; von Fischer et al., 2017). Leak quantification can help utilities facilitate cost-effective design and implementation of leak repair and pipe replacement programs by allowing for

[5] On average, pipeline-quality natural gas is composed of over 90% methane by volume (Demirbas, 2010).
[6] This specific estimate refers to the damages associated with a ton of methane emitted in 2015 monetized in 2007 dollars. The current value therefore would be higher when adjusted for inflation. The value is also higher for emissions in later years because future emissions are expected to produce larger incremental damages (see Interagency Working Group on Social Cost of Greenhouse Gases, 2016).
[7] Assuming a mass of 19,200 g/Mcf natural gas, and a methane share of 78.8% per mass unit of natural gas. This estimate is in $2007 for one Mcf of natural gas leaked in 2015.

prioritization of the highest-emitting leaks or pipe segments, as the case may be. The methodology also allows public utility commissions to consider the need for, and progress of, the planned program.

4.1 Information that improves efficiency

Utilities are starting to adopt the use of advanced leak detection equipment capable of finding more leaks more rapidly. For example, the California Public Utilities Commission reports that utilities experienced a 21% increase in the number of leaks detected from 2013 to 2014, due partly to the use of advanced leak detection technologies (Mrowka et al., 2016). Additionally, the use of advanced leak detection technology has been shown to reduce the time needed to complete a leak survey, have a longer-distance field of view for detecting leaks, and can be used overnight when atmospheric conditions are more stable (Clark et al., 2012).

Applied efficiently, advanced leak detection technology can be used to obtain (on a continuous basis) leak information sufficient for determining the most hazardous and/or largest emitting leaks that in turn can be prioritized for remediation. Rather than continuing the paradigm that leaks are found and remediated one at a time, industry and regulators can foster innovative strategies that involve obtaining leak survey information as the first step, and application of advanced analytics as a second step, in order to prioritize remediation of the most hazardous and largest leaks.

4.2 Leak repair and pipe replacement prioritization methodology

One key consideration in employing leak quantification methodologies to leak repair programs is how to systematically translate a database of measured leak flow rates into a prioritized list. This consideration is equally applicable to pipe replacement programs, where the corresponding challenge is to prioritize pipeline segments for replacement. In providing the data necessary, the primary emphasis should not be on the accuracy of individual leak measurements, but rather on the precision of the characterization of the leaks, the ability to provide a prioritized list and a cost-effective path to reducing leak volumes.

A cumulative distribution, ordering leaks by size, is a useful tool to determine the relative priority of leaks for repair, which is made possible with the use of sufficiently precise leak quantification methodologies. A cumulative distribution can both help identify the largest leaks, and determine their relative contribution to overall leakage.

As shown in Figure 1 (A), the flow rate of leaks can vary significantly. When ranked from largest to smallest as shown in Figure 1 (B), the relative importance of different leaks is transparent and the relative contribution of each leak to overall leak flow rate is easily quantified (Figure 1 [C]). The cumulative distribution is created by integrating the ranked distribution in Figure 1 (B) from left to right. The first data point from the left on the X-axis in the CD plot is the leak determined to have the largest leak volume, the second point is the cumulative leak flow rate of the top two leaks, the third point is the sum of leak flow rates of the top three leaks, and so on. Thus, the last data point is the sum of leak flow rates of all known leaks. This distribution is then normalized to 1 (or 100% in Figure 1 [C]) so that we can readily consider the relative contribution of a certain number of leaks to the total system-wide leakage.

While this discussion focuses on the particular context of leak repair, a similar analytical approach can be applied to prioritize pipeline segments for replacement (see Appendix).

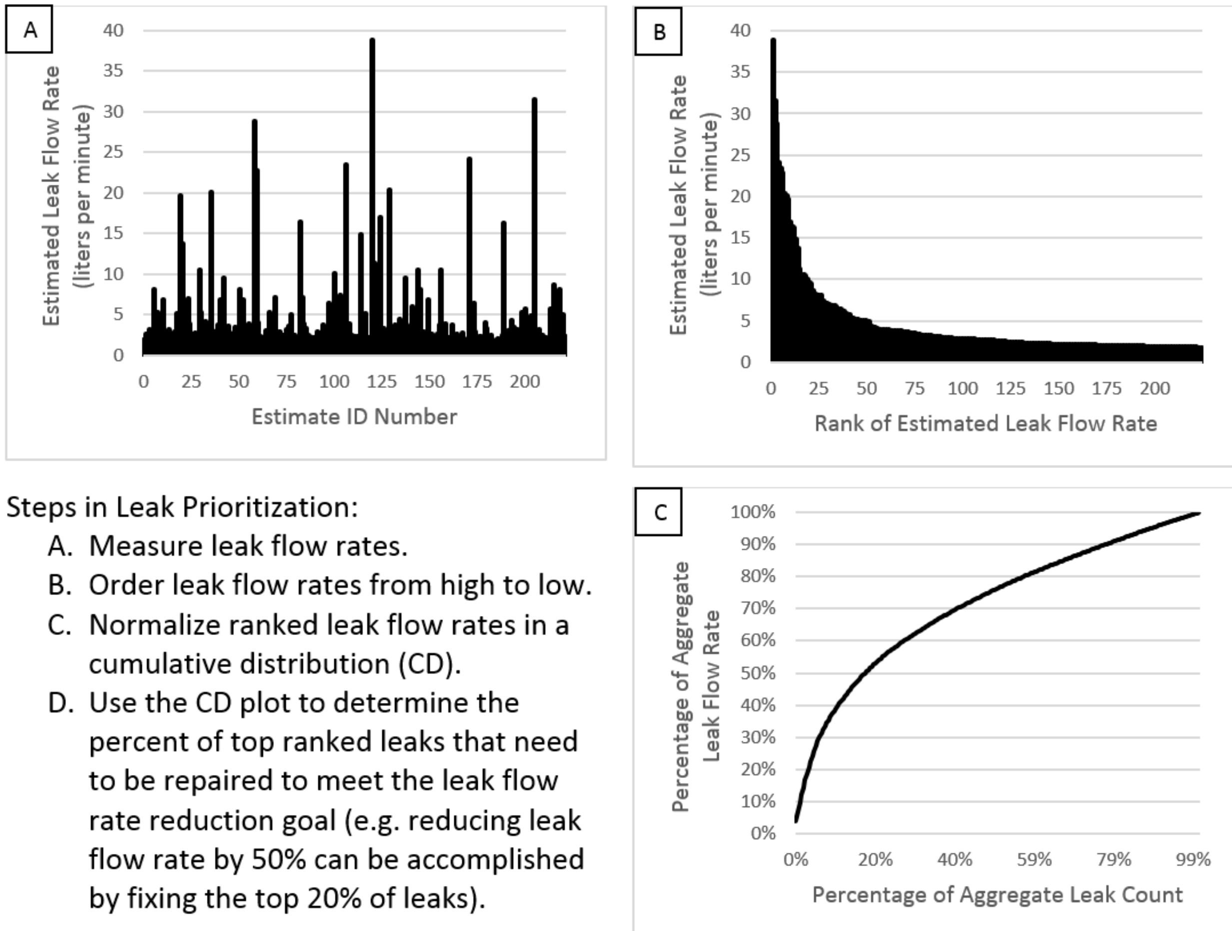

Figure 1 An example step-by-step model depicts how to construct a cumulative distribution curve for the purpose of leak prioritization, using data collected by EDF in Syracuse, NY.

In the near term, leak quantification can help utilities reduce the volumes of gas lost through leakage, and thereby save ratepayers money and reduce methane emissions, by enabling the prioritization of both leak repair and leak-prone pipeline replacement projects based on leak flow rate. In the longer term, as leak quantification methodologies become more sophisticated, utilities will be able to easily quantify leak rates for their entire system, measuring progress in reducing emissions.

In the context of leak repair programs, leak volume may be considered to prioritize the repair of non-hazardous leaks, with the utility addressing larger leaks first. Similarly, in the context of leak-prone pipe replacement, a utility may prioritize the leakiest pipeline segments on its system for replacement first. In either case, as discussed below, utilities are starting to recognize the benefits of a “bundling” or “grid-based” approach whereby leaks or pipeline segments in a given geographic area are bundled together for repair or replacement, as the case may be, in order to allow for efficient use of time and resources (Clark et al., 2012).

5. Case Studies: Applying Leak Quantification Data to Utility Operations

Using leak data collected by Environmental Defense Fund (EDF), Public Service Gas & Electric (PSE&G), New Jersey’s largest utility, is applying a spatially-attributed grid-based method to prioritize pipe segments for replacement. This effort is part of a large-scale $905 million pipe replacement program that was recently approved by the New Jersey Board of Public Utilities (Public Service Electric and Gas, 2012). The methodology developed by EDF in collaboration with PSE&G is discussed below.

First, PSE&G's distribution system was plotted using geographic information systems (GIS) divided into roughly equally sized polygons of one square mile. Using its Hazard Risk Index Model, PSE&G ranked grids for pipeline replacement based on the hazard index per mile of cast iron pipes in each grid, which is calculated based on an assessment of safety risk factors.[8] The hazard index per mile for each grid for which EDF quantified leak flow rate is depicted in Table 1 of the Appendix.

Next, using a Google Street View car equipped with methane detection equipment and geographic positioning systems (GPS), EDF surveyed 30 grids targeted for pipe replacement based on their ranking by the Hazard Risk Index Model. A leak quantification algorithm developed by Colorado State University was applied to the resulting data such that the leak flow rate for each leak observed was calculated (von Fischer et al., 2017). Flow rates for all leaks detected in a given grid were then summed and averaged over the number of miles of pipe in each grid to arrive at the estimated leak flow rate per mile of pipe in each grid. The resulting normalized metric resulted in a ranking of grids by their leak flow rate per mile of pipe (Table 1 of the Appendix).

This methodology was used to develop spatially attributed leak data for each grid cell (Figure 2),[9] presenting a visual depiction of the relative size, frequency, and location of leaks in each grid cell, and attributing each leak to particular segments of utility infrastructure. This information when sorted by comparable Hazard Risk Index results, used in making the initial prioritization of the grids, allowed PSE&G to prioritize grids for pipeline replacement. Specifically, for grids with comparable hazard ranks, the overall leak flow rate/mile of pipe was considered to identify and prioritize the leakier grids for replacement.

PSE&G's approach allowed it to focus its expenditures and resources on the leakiest pipeline segments and also recover the largest volume of usable natural gas per section of pipeline replaced. An analysis of emission reductions from PSE&G's final prioritized grid replacement strategy indicated that PSE&G was able to control 83% of the measured leak flow rate by replacing 58% of the pipeline mileage in measured grids (Appendix, Table 1 at grid 2B-42). In the business-as-usual case, PSE&G would have needed to replace 99% of the pipeline mileage in the surveyed grids to reach the same level of emission reductions (Appendix, Table 2 at grid 2C-43). Therefore, PSE&G achieved an 83% reduction in leak flow rate by replacing approximately one-third fewer miles of pipe than would have been necessary to achieve the same level of emission reductions if they had not used leak flow rate data. All of the pipes

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[8] PSE&G conducts an annual study using this model to evaluate each cast iron main segment that has had a break, to rank each segment for replacement based on a combination of break history and environmental factors. Each geographic grid is ranked by adding the hazard indexes for individual pipe segments within the geographic grid and dividing them by the total miles of utilization pressure cast iron (UPCI) in the grid, arriving at a hazard index per mile for each geographic grid. Using the hazard index per mile results, grids were ranked by highest to lowest and then placed into A, B, C, and D priority grid categories.

[9] PSE&G's infrastructure data is protected under a non-disclosure agreement, and is not shown here. However, an example of the grid method, using fictitious data, is provided in Figure 2.

targeted for replacement will eventually be replaced, but emission reductions were achieved sooner than they would have been in a business-as-usual scenario.

Cast iron pipelines make up roughly 4% of pipelines nationwide. The avoided leak rates assumed here are based on roughly 9% of cast iron pipeline mileage having been prioritized for replacement out of the PSE&G miles where leak flow rates were quantified. In the case of PSE&G, those 9% of cast iron pipeline miles were equivalent to 37% of the estimated leak flow rate. Let us assume that utilities across the nation find and replace superemitting pipeline segments in a similar proportion to PSE&G — that is, where the prioritized grids represent 37% of the measured emissions and 9% of the pipeline miles. If this is possible, then 37% of emissions would be reduced by prioritizing 9% of nationwide cast iron pipeline miles, or roughly 2,500 miles. Reducing 37% of national cast iron pipeline emissions would be equal to reductions of 600,000 Mcf/year (+/- 70,000 Mcf/year).[10] This would have the same climate impact as taking 200,000 passenger vehicles off the road each year (+/-24,000 passenger vehicles).[11]

There are of course, uncertainties in the proportional presence of superemitting pipeline segments, the actual leak flow rates of those segments, and whether superemitting pipeline segments would be coincidentally classified as hazardous, regardless of leak flow rate. Even in PSE&G's system, the frequency of superemitters is unknown on a system-wide basis, because only some areas were surveyed, and because little is known about the "birth rate" of superemitters on a system. Nonetheless, these results from PSE&G indicate that there are likely to be sizeable benefits of leak quantification and prioritization for the climate and ratepayers.

PSE&G is already beginning to capture the benefits of prioritizing high-emitting (or "superemitting") grids for replacement. If other utilities find and prioritize superemitting pipeline segments or leaks at a similar rate nationwide, significant climate benefits could be achieved earlier than might otherwise be possible under a business as usual efforts.

As mentioned above, the grid approach can also be used to prioritize geographic zones not only for pipeline replacement, but also for leak repair. In 2015, Consolidated Edison of New York (CECONY) had the highest percentage of leak prone pipeline mains out of any utility in New York.[12] Just as PSE&G is using leak quantification to prioritize pipeline segments for replacement, CECONY recently completed a pilot program in collaboration with EDF to prioritize the utility's non-hazardous leaks for repair (Environmental Defense Fund and Consolidated Edison Company of New York, 2016). CECONY provided EDF with location and infrastructure information for its non-hazardous leak backlog. EDF surveyed the areas indicated by CECONY and quantified these leaks. CECONY will rank and prioritize leaks for repair based on the emissions flow volume. Preliminary results show that more than half of the emissions identified through our survey efforts could be eliminated by addressing the largest 18% of the leaks.

[10] This estimate only includes the removal of cast iron pipelines. The calculation of potential reductions of national cast iron pipeline emissions is derived by multiplying the average emission factor of 60.1 Mcf/mile/year for cast iron by the total miles of cast iron in the nation and multiplying that product by 37%. The estimate does not account for the added potential emissions of plastic mains — the most likely replacement material — which have an estimated average emission factor of 0.5 Mcf/mile/year (Lamb et al., 2015; U.S. Environmental Protection Agency, 2016).

[11] Assuming a 20-year Global Warming Potential of 84 for methane.

[12] "Leak prone pipeline mains" includes miles of unprotected bare steel mains and cast iron mains.

By enabling the ranking of the leakiest pipeline segments and individual leaks, leak quantification can help utilities decide where to repair leaks or replace pipelines when comparing sections of infrastructure with comparable risk rankings, thereby balancing safety and efficiency considerations. This approach, now pioneered by two major utilities, presents significant safety, capital efficiency, ratepayer, and environmental benefits, and is ready for adoption by other utilities.

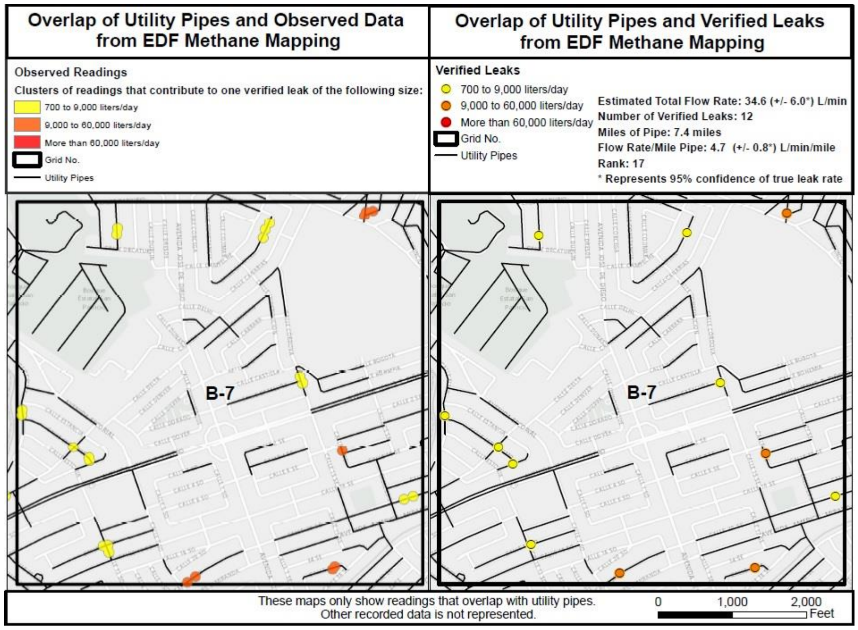

Figure 2 This simulated depiction of leaks in one grid cell of a utility's pipeline system demonstrates how overlapping observed readings are treated as individual "verified leaks," attributable to pipeline infrastructure. The result of such spatial attribution is a visual depiction of the relative size, frequency, and location of leaks in each grid cell.

6. Opportunities for Further Methodological Improvements

Leak quantification methodologies offers utilities an opportunity to use leak quantification to establish a baseline system-wide leak flow rate for their entire distribution system and measure progress in reducing emissions over time. Applied in this manner, quantification would be informative when considering major pipeline repair or replacement initiatives, allowing regulators and other stakeholders to assess the effectiveness of leak repair and pipe replacement programs in a transparent, measurable way.

Currently, utilities are building out and integrating advanced leak detection technology and spatial analysis into their routine pipeline safety and inspection programs. The federal rules establishing integrity management requirements for gas distribution pipeline systems ("Distribution Integrity Management Program for Natural Gas Distribution Sector") came into effect in 2011 (49 C.F.R. §192 [2009]). Under those rules, operators are required to develop and implement a distribution integrity management program. While the rules do not explicitly require utilities to quantify leaks, they state that: (1) pipeline operators must consider all reasonably available information to identify threats to pipeline integrity, and (2) the number and severity of leaks can be important information in evaluating the risk posed by a pipeline in a given location (49 C.F.R. §192.1007 [2009]). Under the rules, operators are required to consider the following categories of threats to each gas distribution pipeline: corrosion, natural forces, excavation damage, other outside force damage, material or welds, equipment failure, incorrect operations, and other concerns that could threaten the integrity of its pipeline. Sources of data may include, but importantly, are not limited to: incident and leak history, corrosion control records, continuing surveillance records, patrolling records, maintenance history, and excavation damage experience.

With technology available that makes leak quantification methods commercially available and viable, and PHMSA rules requiring operators to consider all relevant data in identifying threats to pipeline integrity, it is clear that the prevailing regulatory framework not only allows for leak flow rate to be considered in evaluating threats to pipeline integrity, but in fact, underscores the need to do so.

Some utilities, in addition to those described above, are already making use of leak quantification technology for this purpose. In California, Pacific Gas & Electric Co. (PG&E) is exploring how to integrate leak quantification technology into its leak management efforts (Pacific Gas and Electric Company, 2015b; Pacific Gas and Electric Company, 2012). This includes collecting leak data in a format that supports predictive analytics for assessing and mitigating risks to PG&E's infrastructure. CenterPoint Energy has also begun pilot testing advanced leak detection technology in Houston, Texas, and Minneapolis, Minnesota (Centers and Coppedge, 2015). The company has implemented a phased deployment strategy to evaluate and use advanced leak detection technology for leak surveys, and integrated the resulting data into leak prediction models that rely on spatial analytics. A collaborative, utility-led effort exploring leak quantification methods is also underway.[13]

A recent report by researchers at PricewaterhouseCoopers discusses the benefits of using spatial analytics to predict when and where pipeline leaks will occur (Wei et al., 2016). The authors describe how using quantitative failure history data, customer calls, and condition assessments can enable utilities to transparently manage their system, reduce human error, and cost-effectively improve decision-making (Wei et al., 2016). Traditional risk assessment has relied heavily on subject-matter experts who may use subjective data to make decisions about prioritizing risk mitigation actions. The report proposes that integrating spatial analytics with condition assessment data can allow operators to obtain a quantitative snapshot of asset risks in near real-time to inform investment planning and pipeline replacement project prioritization. The report further indicates that advanced leak detection technology can be used to provide data on leak density that can be integrated into a predictive model of leaks, further enabling capital prioritization. Such an approach can lead to efficiency and cost savings. For example, a case study presented in the report found that the client's quantitative spatial analytics model "delivered an estimated 3.9 times more leaks avoided, 3.6 times greater leaks/mile replaced, and 4.1 times more O&M (operations and maintenance) expense cost savings for the same capital investment" (Wei et al., 2016).

7. Conclusion

Quantifying and ranking leak flow rates for prioritization of leak repair and pipe replacement programs makes it possible to achieve larger reductions in gas lost for the same amount of time and resources, resulting in more cost-effective leak repair and pipeline replacement programs. As demonstrated by PSE&G's successful use of new practices to prioritize a large-scale pipe replacement program, leak

[13] i.e. NYSEARCH. 2014. "Technology Evaluation and Test Program For Quantifying Methane Emissions Related to Non-Hazardous Leaks." https://www.nysearch.org/tech_briefs/TechBrief_Methane-Emissions-Quantification.pdf

quantification technologies and methodologies can currently be deployed to prioritize leak repair and pipeline replacement programs. Using leak quantification allows for more robust leak prioritization, which helps to improve safety, minimize waste of natural gas, and reduce greenhouse gas emissions. Moving forward leak quantification will allow utilities to establish a baseline of system leaks that can provide an improved mechanism for comparing pre- and post-repair/pipe replacement outcomes to evaluate the success of such programs.

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Appendix A: Emission Reduction Analysis

EDF quantified leak flow rates in 30 grids that PSE&G had designated as needing pipeline replacement. PSE&G replaced pipes in the most hazardous grids first, then used leak flow rate as an additional layer for prioritizing pipes for replacement in grids with lower, but comparable hazard indexes. This appendix describes the estimated emissions impact of this prioritization scheme.

The goal of this analysis was to quantify the amount of avoided methane emissions resulting from EDF's methane mapping activities in PSE&G's system, particularly with respect to pipeline grids that were prioritized for replacement as a result of having leak flow rate data available.

To determine this impact, leak flow rate reduced per replacement effort was considered. This includes an analysis of the percent of leak flow rate avoided under each scenario (i.e. business as usual or prioritized based on leak flow rate) and a comparison to the percent of mileage replaced under each scenario. This would give a comparison of the relative leak flow rate reduced per mile of expenditures, rather than a direct estimate of the leak flow rate reduced over time. Calculating the leak flow rate reduced over time was not possible, because we did not have data demonstrating when each grid would have undergone replacement in a business-as-usual scenario.

A.1 Procedures

PSE&G indicated that any grid with a hazard index per mile (HI/mi) greater than 25 would hold the highest priority for replacement (Table 1; grids shaded in orange). Where HI/mi was comparable (between 25 and 10 HI/mi), leak flow rate data was used to help sub-prioritize the grids by leak flow rate normalized by the number of miles in each grid. This parameter was expressed as liters per minute per mile (L/min/mi). In the datasheet, grids that met the above criteria and were prioritized based on leak flow rate were shaded in green. Three grids were prioritized this way.

The first step in determining the amount of avoided methane emissions was to sort all of the grids in order of final ranking (Table 1). Next, the cumulative percent of leak flow rate (L/min) and the cumulative percent of mileage for each successive grid was calculated (see far right columns). Finally, the same calculations were made ordering the grids by "GSMP UPCI Grid Rank" to represent the business-as-usual case (Table 2).[14] These calculations allow a demonstration of the leak flow rate avoided for each successive replacement effort, and allow a comparison between the business-as-usual case and the final ranking that includes leak flow rate.

A.2 Calculating uncertainty

Researchers at Colorado State University calculated a measure of uncertainty for the flow rate (L/min) and flow rate per mile (L/min/mi) in each grid. The measure of uncertainty, or confidence interval, was based on two times the standard deviation, which was calculated as 60% of the flow rate divided by the square root of the number of verified leaks found in each grid. Within this confidence interval, the flow rate range is expected to be true 95% of the time. In calculating a confidence interval for a select number of grids, the measure of uncertainty was summed for the total estimated flow rate (L/min) in the selected grids.

[14] GSMP stands for "Gas System Modernization Program." UPCI stands for "Utilization Pressure Cast Iron."

A.3 Avoided leak flow rate by mileage replaced

Three grids (2B-42, 2L-43, and 2C-43) met PSE&G's criteria for prioritization based on leak flow rate, and had not already been prioritized based on the hazard index. Three other grids (2A-48, 2K-44, and 2A-45) had a flow rate of greater than 10 L/min/mi, but were already prioritized based on hazard index. The green shaded grids that were prioritized based on leak flow rate, rather than hazard index, add up to a flow rate (L/min) of 37% of the total flow rate. Table 1 shows the grids in order of final ranking and demonstrates the leak reductions that could be achieved through prioritization of each successive grid, as well as the corresponding percentage of pipeline miles that had to be replaced to reach each successive leak flow rate reduction.

The grids were replaced in order of final ranking, with the orange-shaded grids having been replaced first. The total emissions reduced are calculated as a cumulative percentage from the time that the first grid (2A-48) undergoes pipeline replacement, until the last-ranked green-shaded grid (2B-42) undergoes pipeline replacement. By the time pipeline replacement takes place in all three green-shaded grids with an HI/mi less than 25, the total flow rate reduced is 83% (Table 1 at grid 2B-42). This flow rate reduction was achieved through replacing less than 60% of the surveyed pipeline mileage (Table 1 at grid 2B-42).

In this prioritization, 11 grids out of 30 (Table 1, grids 1Y-48 to 2D-53) were ranked as a lower priority than the three non-hazardous, green-shaded grids. If the business-as-usual ranking based only on hazard is considered (Table 2), the three green-shaded grids would have been prioritized lower, and all but three grids out of 30 (Table 2, grids 2B-42 to 2D-53) would need to be replaced to reach the same level of avoided emissions (83%) that came as a result of prioritization based on leak flow rate. In the business-as-usual prioritization, by the time a flow rate reduction of at least 83% would have been achieved, 99% of the pipeline miles would have to have been replaced (Table 2 at grid 2C-43).

Grid	Miles of UPCI Pipe in Grid	Total Estimated Flow Rate (L/min)	Estimated Flow Rate per Mile (L/min/mi)	Hazard Index per Mile (HI/mi)	GSMP UPCI Grid Rank	Rank by Estimated Flow Rate per Mile	Final Ranking	Cumulative Percent of Miles	Cumulative Percent of Total Estimated Flow rate (L/Min)
2A-48	1.07	16.08	15.03	54.9381	1	19	1	1%	1%
1Z-47	7.49	52.46	7.00	25.9084	15	10	2	5%	4%
2L-57	4.21	9.15	2.18	45.3544	2	24	3	7%	5%
2K-57	4.23	2.33	0.55	27.8521	11	25	4	10%	5%
2L-58	1.77	1.93	1.09	27.7219	12	27	5	11%	5%
2K-45	5.49	51.03	9.30	37.2695	3	9	6	14%	8%
2K-44	3.43	119.20	34.75	36.7325	5	5	7	16%	15%
2B-46	2.54	10.19	4.01	36.1869	6	23	8	17%	15%
2A-45	2.25	329.34	146.37	28.0060	10	1	9	19%	34%
2K-55	12.89	24.85	1.93	32.5147	7	17	10	26%	36%
2L-55	10.64	20.65	1.94	20.8300	28	14	11	32%	37%
2J-51	9.34	36.13	3.87	29.1177	8	11	12	37%	39%
2H-50	5.75	34.58	6.01	24.7551	17	12	13	41%	41%
2D-58	2.87	9.94	3.46	28.1752	9	20	14	42%	42%
2C-43	6.91	426.80	61.77	19.6449	39	2	15	46%	66%
2L-43	7.41	189.20	25.53	23.6801	20	3	16	50%	77%
2L-51	8.05	68.93	8.56	24.1780	18	4	17	55%	81%
2H-45	4.28	11.95	2.79	24.1516	19	22	18	57%	82%
2B-42	1.09	15.81	14.50	20.6577	32	16	19	58%	83%
1Y-48	4.14	23.29	5.63	23.3831	22	18	20	60%	84%
1V-50	8.2	58.26	7.10	22.2527	23	6	21	65%	88%
1V-49	2.52	1.98	0.79	20.6865	29	26	22	67%	88%
2P-53	1	0.00	0.00	22.0075	24	28	23	67%	88%
2J-52	8.95	50.98	5.70	20.6443	33	8	24	72%	91%
2G-51	10.38	28.43	2.74	20.4184	34	15	25	78%	92%
1T-60	1.97	0.00	0.00	20.3291	35	29	26	79%	92%
2 E-43	4.18	22.97	5.50	20.1753	36	13	27	82%	94%
2N-44	14.21	94.22	6.63	19.8060	37	7	28	90%	99%
2J-53	12.49	14.88	1.19	19.0926	42	21	29	97%	100%
2D-53	4.88	0.00	0.00	19.0639	44	30	30	100%	100%

Table 1 Grids in order of final ranking. Grids with flow rates shaded in green were prioritized based on leak rate. Grids with hazard index shaded in orange were replaced based on hazard index. Final ranking incorporates both hazard and flow rate. An additional 22 grids scheduled for replacement where leak flow rates were not quantified are not included in this table.

Grid	Miles of UPCI Pipe in Grid	Total Estimated Flow Rate (L/min)	Estimated Flow Rate per Mile (L/min/mi)	Hazard Index per Mile (HI/mi)	GSMP UPCI Grid Rank	Rank by Estimated Flow Rate per Mile	Final Ranking	Cumulative Percent of Miles	Cumulative Percent of Total Estimated Flow Rate (L/min)
2A-48	1.07	16.08	15.03	54.9381	1	5	1	1%	1%
2L-57	4.21	9.15	2.18	45.3544	2	21	3	3%	1%
2K-45	5.49	51.03	9.30	37.2695	3	7	6	6%	4%
2K-44	3.43	119.2	34.75	36.7325	5	3	7	8%	11%
2B-46	2.54	10.19	4.01	36.1869	6	16	8	10%	12%
2K-55	12.89	24.85	1.93	32.5147	7	23	10	17%	13%
2J-51	9.34	36.13	3.87	29.1177	8	17	12	22%	15%
2D-58	2.87	9.94	3.46	28.1752	9	18	14	24%	16%
2A-45	2.25	329.34	146.37	28.0060	10	1	9	25%	35%
2K-57	4.23	2.33	0.55	27.8521	11	27	4	28%	35%
2L-58	1.77	1.93	1.09	27.7219	12	25	5	29%	35%
1Z-47	7.49	52.46	7.00	25.9084	15	10	2	33%	38%
2H-50	5.75	34.58	6.01	24.7551	17	12	13	36%	40%
2L-51	8.05	68.93	8.56	24.1780	18	8	17	41%	44%
2H-45	4.28	11.95	2.79	24.1516	19	19	18	43%	45%
2L-43	7.41	189.2	25.53	23.6801	20	4	16	47%	56%
1Y-48	4.14	23.29	5.63	23.3831	22	14	20	50%	57%
1V-50	8.2	58.26	7.10	22.2527	23	9	21	55%	61%
2P-53	1	0	0.00	22.0075	24	28	23	55%	61%
2L-55	10.64	20.65	1.94	20.8300	28	22	11	61%	62%
1V-49	2.52	1.98	0.79	20.6865	29	26	22	63%	62%
2B-42	1.09	15.81	14.50	20.6577	32	6	19	63%	63%
2J-52	8.95	50.98	5.7	20.6443	33	13	24	68%	66%
2G-51	10.38	28.43	2.74	20.4184	34	20	25	74%	68%
1T-60	1.97	0	0	20.3291	35	29	26	75%	68%
2 E-43	4.18	22.97	5.50	20.1753	36	15	27	78%	69%
2N-44	14.21	94.22	6.63	19.8060	37	11	28	86%	74%
2C-43	6.91	426.8	61.77	19.6449	39	2	15	90%	99%
2J-53	12.49	14.88	1.19	19.0926	42	24	29	97%	100%
2D-53	4.88	0	0	19.0639	44	30	30	100%	100%

Table 2 The business-as-usual ranking, with grids in order of hazard index per mile (GSMP UPCI Grid Rank).

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Exhibit __ (VP-4):

Con Edison Response to EDF-1-3;

Case No. 19-G-0066 *et al.*

Company Name: Con Edison
Case Description: 2019 Con Ed Electric & Gas Rate Filings
Case: 19-E-0065, 19-G-0066

Response to EDF Interrogatories – Set EDF-1
Date of Response: 5/7/2019
Responding Witness: Gas Infrastructure Operations & Supply Panel

Question No. : 3

Refer to the Gas Policy Panel Testimony at page 16, which states that "[t]hrough enhanced leak detection, we can identify, respond and remediate leaks more rapidly, reducing risk, keeping the public safe, and protecting the environment by reducing emissions of methane, a greenhouse gas."

a) Does the Company intend to track or report actual methane reductions associated with its main replacement program, distribution integrity enhancement program, or any other program?

b) If yes, please provide a list of all programs where the Company intends to track or report actual methane reductions and the timeline for such tracking and/or reporting.

Response

a. The Company's primary focus on leaks is reducing risk and keeping the public safe. The environmental benefit is leaks are being identified and addressed more quickly. Currently, Con Edison identifies and prioritizes the highest emitting Type 3 leaks, but does not plan to track or report actual methane reductions associated with this effort. However, as required by 40 C.F.R. Part 98, on an annual basis, Con Edison calculates the methane emissions from the Con Edison gas distribution system.

b. See the response to a.

Exhibit __ (VP-5):

Con Edison Response to EDF-1-13;

Case No. 19-G-0066 *et al.*

Company Name: Con Edison
Case Description: 2019 Con Ed Electric & Gas Rate Filings
Case: 19-E-0065, 19-G-0066

Response to EDF Interrogatories – Set EDF-1
Date of Response: 5/6/2019
Responding Witness: Gas Infrastructure Operations & Supply Panel

Question No. : 13

Refer to the Gas Infrastructure, Operations, and Supply Panel at page 36, which explains that the DIMP risk model also calculates a separate risk profile for various consequence factors.

a) Does Con Edison consider leak flow rate as a consequence factor? If no, please explain why not.

b) Does the Company measure or estimate leak flow rate (volume over time)?

c) Does the Company calculate the relative leakiness of segments of high risk assets to inform prioritization? If not, why not?

Response

a) Con Edison uses a Volume Pressure Factor as a consequence factor. This factor considers pipe size, pressure, and failure type to identify and rank the relative volume of escaping gas when a failure occurs. For example, cast iron pipe can fail by having a break or a joint leak, but for the same pipe size and pressure, the volume of escaping gas is assumed to be greater from a break than from a joint leak.

b) No, the Company considers how the pipe might fail to estimate the severity of a leak. See a) above for an example.

c) Yes, the Optimain DS risk model considers previous history of leaks to calculate an expected value of future pipe leaks and combines this with the consequence factors, such as the volume pressure factor, to assign a risk to each individual pipe segment. The highest risk assets are than prioritized for replacement or other mitigation processes.

Exhibit __ (VP-6):

Con Edison Response to EDF-1-7;

Case No. 19-G-0066 *et al.*

Company Name: Con Edison
Case Description: 2019 Con Ed Electric & Gas Rate Filings
Case: 19-E-0065, 19-G-0066

Response to EDF Interrogatories – Set EDF-1
Date of Response: 5/7/2019
Responding Witness: Gas Infrastructure Operations & Supply Panel

Question No. : 7

Refer to the Gas Volume and Revenue Forecasting Testimony at page 99, which explains that Con Edison purchased a Picarro Surveyor and has "developed use cases for future applications."

a) Please explain in detail all use cases Con Edison considered for future applications.

b) Please explain how Con Edison currently utilizes the Picarro Surveyor.

c) Please detail Con Edison's plans for integrating use of the Picarro Surveyor into its leak management operations.

If Con Edison does not have plans for integrating use of the Picarro Surveyor into its leak management operations, please explain how purchase of this technology benefits customers

Response

a) **NBD Gas Leakage Compliance Survey**: using the existing three year frequency, the Company would utilize the Cavity Ring Down Spectroscopy technology to assess all services within the sampled area and use a risked based approach to investigate and classify gradable leaks.
Pre-pave Surveys: proactively identify and repair gas leaks on streets scheduled for re-pavement.
DIMP: Reference EDF-1-1 response.

b) The Company remains focused on ensuring the new technology provides enhanced leak detection results when compared to existing technology. With that, the Company continues to perform field trials in 2019 and work closely with the manufacturer.

c) Plans for integrating this technology into Company operations will be developed once all field trials have concluded and leak detection results have been assessed. The information from the field trials will significantly influence the integration plan.

Since the purchase of the Picarro Surveyor and through the field trial process, the Company identified 64 gradable leaks with the Picarro Surveyor that were not identified by traditional leak surveys, 29 of which were classified as a Type 1 or 2/2A, ultimately reducing risk and increasing public safety. Additional field trials are scheduled for 2019, and further leaks are expected to be identified and mitigated.

Exhibit __ (VP-7):

Response of ABB Inc. (“ABB”) – Los Gatos Research to Letter of Inquiry Dated May 9, 2017 from the Citizen’s Utility Board submitted in Illinois Commerce Commission Docket No. 16-0376

RESPONSE OF ABB INC. - LOS GATOS RESEARCH TO LETTER OF INQUIRY DATED MAY 9, 2017 FROM THE CITIZEN'S UTILITY BOARD

12 June 2017

1. Introduction to ABB-LGR

ABB, a global leader in electric power and automation with over 135,000 employees and offices in over 100 countries, acquired Los Gatos Research (LGR) in October 2013 to fill a technology gap in its portfolio of analyzers. LGR provides analyzers and services to a wide range of customers needing real-time measurement of trace gases and isotopes for research and environmental monitoring, industrial processes and gas leak detection. LGR's instruments have been deployed by scientists for acquiring the most accurate measurements possible on all seven continents, in unmanned aerial vehicles, in mobile laboratories, on research and commercial aircraft, and in undersea vehicles.

ABB-LGR's novel, innovative and patented laser-based analyzer technology is based on Off-Axis Integrated Cavity Output Spectroscopy (OA-ICOS) that has a substantially higher sensitivity, precision and accuracy than other traditional sampling and laser-based technologies.

2. Leak Detection Capabilities

2.1 Type of Sensors

- **Methane only**
- **Methane and Ethane**

ABB sells (laser-based) analyzers capable of simultaneously reporting methane and ethane while driving. Unlike older technology, these new analyzers report methane and ethane with single-digit ppb sensitivity every second. ABB also sells man-portable, battery-powered analyzers for reporting methane with single-digit ppb (part-per-billion) sensitivity while walking. These portable units bridge the gap that exists between advanced mobile leak detection (ppb detection) and conventional handheld detection (ppm or part-per-million detection).

2.2 Sensitivity (lowest/highest detection level)

Our Mobile Gas Leak Detection system is capable of reporting methane with a precision below 1 ppb and ethane concentrations below 10 ppb. While these levels are more than sufficient to detect gas pipeline leaks 100 meters (or further) away, we are developing next-generation analyzers that will be 100x more sensitive.

The highest detection levels for these two different analyzers can be as high as several percent methane. ABB's analyzers are unique in advanced leak detection solutions because of the large measurement dynamic range.

However, please note that ABB also produces other laser analyzers for measuring natural gas purity than allows quantification of levels to 100% methane.

2.3 Underlying technology

ABB's underlying technology is patented and based on a laser absorption spectroscopy technique called Off-axis ICOS, the latest generation of the cavity enhanced absorption spectroscopy methods.

LGR, which was acquired in 2013 by ABB, invented cavity ringdown spectroscopy (CRDS) and all the major cavity enhanced spectroscopy techniques, including off-axis ICOS, the fourth-generation of these techniques, which LGR patented. This unique perspective gives us the ability to discuss various laser-based techniques with authority and experience.

Off-axis ICOS is superior to conventional cavity ringdown spectroscopy in several ways, including, but not limited to, the following:

1. highest reliability
2. most robust to harsh environments (vibration, extreme temperature, etc.)
3. simplest to service
4. widest dynamic range
5. unsurpassed sensitivity
6. fastest time response

Details regarding each of these attributes is provided below.

2.4 Type of survey using sensor technology

ABB sells a comprehensive solution for Mobile (Gas Leak Detection) surveys that measure, quantify and locate leak locations on Google Earth maps in real time. This technology can be attached to and installed in a wide variety of new or used vehicles including automobiles, SUVs, trucks and UTVs that the customer presently owns, and consists of:

1. Patented gas analyzer (19" wide, 7" height, 24" deep) and proprietary computational software

platform for measuring methane and ethane simultaneously and displaying likely leak locations on Google Earth maps or other GIS platform.

2. GPS antenna (on the roof) and GPS receiver (included inside the analyzer)

3. sonic anemometer (located on the roof) for measuring wind velocity while the vehicle is either stationery or moving

4. vacuum pump for pulling the sampled air from an inlet located below the front bumper to and through the analyzer which is typically located in the trunk.

Installation and full commissioning of the entire system (in the customer's vehicle) takes less than one day.

To compliment the vehicle-based system, which provides the likely areas in which the leak originates, ABB also sells a lightweight, battery-powered, purse-size methane analyzer to quickly perform the investigation or "pinpointing" of leak indications. This 'microportable' methane analyzer, based on the same patented technology as the vehicle-based system, employs a smartphone or tablet as the User Interface. Importantly, this analyzer allow users to bridge the sensitivity gap between ppb sensitivities of advanced mobile leak detection systems and ppm sensitivity of conventional handheld detectors. The matched sensitivity dramatically decreases the time required to investigate leak indications and preliminary testing indicates the time to find goes from 30-45 min with conventional equipment to 10-15 min with ABB's portable unit.

2.5 Cost of sensors/hardware

LGR offers two purchase models for utilities interested in deploying Advanced Leak Detection Technology and analytics, rental or purchase.

Interested customers can evaluate ABB's Mobile Gas Leak Detection system for extended periods at very small rental rates of approximately $5000/week. Moreover, the rental fees can be applied towards the purchase price of the system.

The retail price for the new Mobile Gas Leak Detection solution capable of providing surveys that measure, quantify and locate leak locations on Google Earth maps in real time, sells for between $250k-$300k (hardware costs only) and does not include the vehicle.

After purchasing the system, the owner possesses and owns all the data reported by the analyzer. ABB does not sell the data back to the customer nor does ABB charge for generation of reports. Also, since the customer owns, and does not lease, the system, the equipment can be depreciated as a capital expense.

2.6 Software costs

ABB charges an annual license fee to maintain and enhance the software, provide support, and to effectively provide an evergreen software package that continuously provides new features and capabilities, in response to customer needs. ABB offers this for $45k, although the costs can be differently amortized depending on customer needs.

2.7 Estimated annual O&M costs

The operations and maintenance costs of the mobile system, excluding the vehicle, are small (typically less than $1500/year), and include re-building vacuum pumps, cleaning optics, if needed.

2.8 Cost of transport method

This is simply the cost of driving the vehicle in which the Mobile system installed and includes gas, maintenance, and driver costs. There is no need for purchasing a new vehicle for this application. In fact, utilities such as Pacific Gas and Electric, Atmos Energy, Sempra Energy, Google, Enbridge Gas, generally incorporate the system into existing (i.e. used) fleet vehicles.

2.9 Staffing requirements

After only a few days of training, virtually anyone can drive the car and operate the technology to find leaks. Aside from the power switch, the system is fully controlled with the intuitive software interface.

2.10 Product certification

The product passes all FDA and CE requirements.

2.11 GIS/geographic/mapping capabilities

The system offers several methods of viewing and analyzing the reported leak indications.

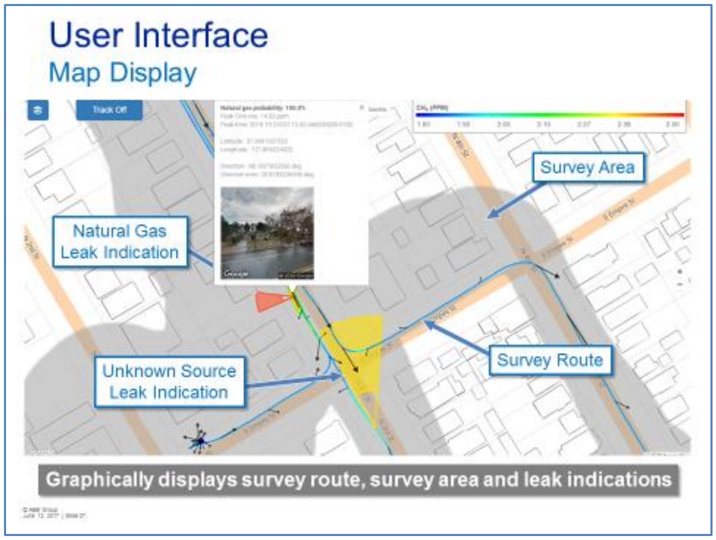
- The in-vehicle UI plots all the results on Google Maps (default or satellite view) in real-time. Leak indications can be clicked to raise additional information about gas concentration, location and time of find.

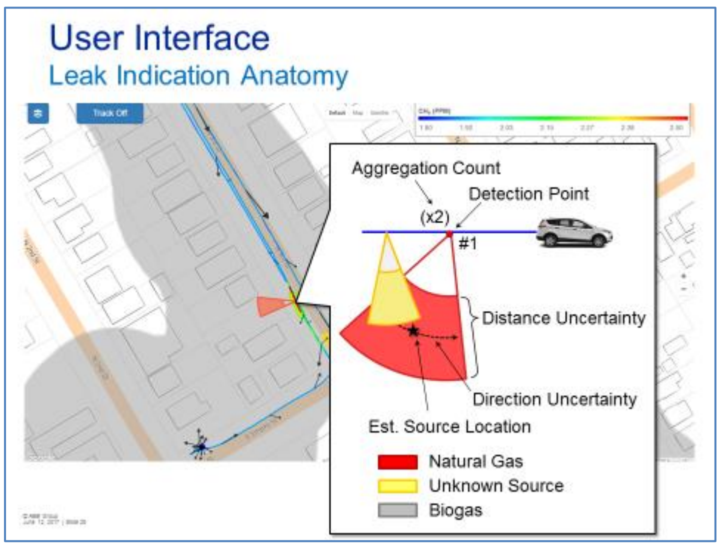
- The automatically generated report includes a KML/KMZ output of all the recorded data, including drive path with color coded methane concentration, wind velocity, estimated survey area and leak indications. All of this data can be view interactively in Google Earth.

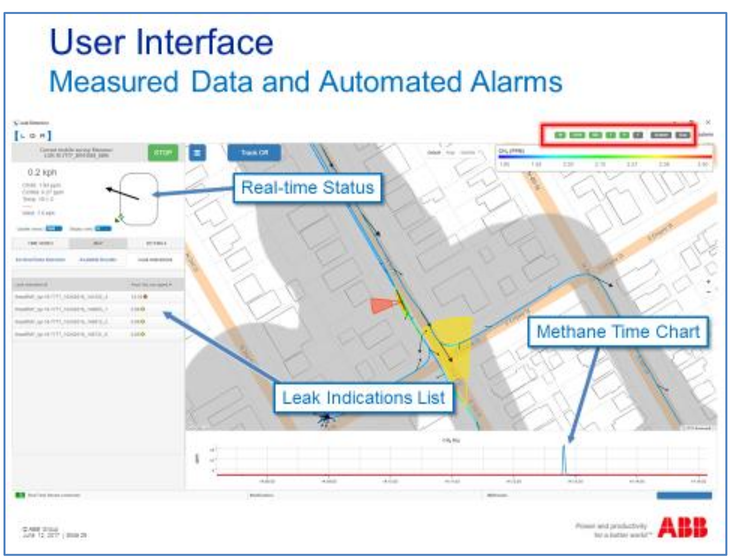
- Finally, the report also includes KML/KMZ in individual layers that can be imported into common GIS tools such as ArcGIS and Smallworld for further analysis and comparison to utility data.

Additionally, the in-vehicle UI allows users to import utility assets for viewing in real-time. This permits users to overlay and compare the locations of mains and services with the leak indications found by the vehicle.

Some examples of User Interface screens presented while driving allows users to see survey routes, surveyed areas and leak indications:


User Interface
Map Display
Track Off
Survey Area
Natural Gas
Leak Indication
Unknown Source
Leak Indication
Survey Route
Graphically displays survey route, survey area and leak indications


User Interface
Leak Indication Anatomy
Track Off
Aggregation Count
Detection Point
(x2)
#1
Distance Uncertainty
Direction Uncertainty
Est. Source Location
Natural Gas
Unknown Source
Biogas


User Interface
Measured Data and Automated Alarms
STOP
Track Off
0.2 kph
Real-time Status
Methane Time Chart
Leak Indications List
ABB

ABB

2.12 Unique capabilities of service/product offered, relative to competitors

The ABB Ability Mobile Gas Leak Detection system is based on ABB's *patented* Off-axis ICOS technology. Off-axis ICOS is superior to conventional mobile leak detection systems and cavity ringdown spectroscopy in practically every performance metric, including, but not limited to:

- **Speed of response**
  The mobile system provides a 5-Hz data rate to allow spatially resolved measurements even while driving at highway speeds (i.e. to 65 miles/hour). The microportable methane analyzer reports data at a 10 Hz data rate (and with ppb sensitivity) for similar reasons while walking. Conventional methods based on walking report data at speeds of about 1-2 miles/hour and often lack a digital record.

- **Accuracy**
  Unlike other analyzers based on older cavity based methods, these novel laser-based analyzers provide measurements that are inherently accurate because they record "fully resolved" (i.e. detailed) absorption spectra (that are displayed on screen to the user).

- **Precision**
  ABB analyzers report data with single parts per billion precision for measurements of methane and ethane. Based on field trials conducted by large utilities, this allows users to find leaks far from the source very quickly and reliably – 5 to 10 times faster than conventional legacy methods, which must be close to the leak and only report methane or total hydrocarbons, and thus get confused between natural gas leaks and other methane sources.

- **Measurement dynamic range**
  ABB reports natural gas concentrations at both extremely low concentrations with parts per billion sensitivity and precision but also reports high concentrations of methane to well over 1% in air. This large dynamic range gives users the ability to accurately detect leaks both from far away as well as nearby – i.e., there is no saturation when large leaks are detected as with cavity ringdown based advanced leak detection.

- **Overall robustness/ruggedness**
  Unlike older methods like CRDS, ABB's technology does not require extraordinary thermal control and nanometer alignment tolerances to operate. As a result, ABB analyzers can easily operate anywhere and over a far wider temperature range (0 to 45 C) compared with CRDS, which is constrained by much narrower mechanical tolerances.

- **Simplicity of service**
  Unlike older methods like CRDS, ABB's technology does not require extraordinary thermal control and nanometer alignment tolerances to operate. As a result, ABB analyzers can be easily serviced in the field – even cavity mirrors -- in the unlikely event that this is necessary. This reduces total cost of ownership and maximizes total measurement time.

- **Cost to own**

Due to higher reliability, simplicity and ruggedness, ABB technology is simpler to build and service, which leads to greater uptime, far lower purchase price (cf. $1.4 million or more for cavity ringdown systems), and easily the lowest maintenance costs. Finally, we expect the equipment to easily last for more than ten years, so the annual cost to operate the system is very low.

- **Cost to operate**
  Since the customer owns the equipment, after purchasing the system, the only annual costs are software licensing. Since ABB does not lease the solution, the customer can depreciate the capital equipment and thus reduce annual costs even further. Maintenance and service costs are typically less than $1500/year primarily for rebuilding the vacuum pump, changing particle filters, and possibly cleaning mirrors.

  In addition, ABB's mapping capability provides detailed geospatial maps of likely leak locations based on proprietary algorithms that have been proven for accuracy and reliability by numerous gas utility operators.

- **Data ownership**
  Unlike other laser-based companies that only lease their solutions, ABB sells the entire package to the customer. Thus, the customer owns and has immediate and direct access to all data recorded by the system.

  In brief, ABB's system provides users with unsurpassed capabilities at a price that is 5-10 times less on an annual basis than competitive (and less capable) systems based on conventional CRDS laser methods.

3. Leak Quantification Capabilities

3.1 What analytics packages does your company offer that are capable of quantifying leaks?

3.2 What is the cost of the quantification package?
ABB includes leak quantification metrics with the annual software licensing fee (at no additional cost). These metrics utilize evolving proprietary models that incorporate the measured data recorded by the system.

To maximize public safety and accelerate the development and testing of advanced leak quantification models, ABB collaborates openly with scientists and engineers from universities, industry and advocacy groups.

4. Operationalization and Integration

ABB's Mobile Gas Leak Detection Systems have been integrated into the operations of several major gas utilities throughout the US and Canada, and many other utilities will evaluate our systems within the next several months.

These systems provide utilities quantitative information that is available in easily read (i.e. in nonproprietary) data formats and maps of leak locations and relative sizes continuously while driving.

ABB has a long-standing tradition of collaborating with leading academic, governmental and industrial researchers worldwide through local and corporate research initiatives. We continue this practice of open collaboration for the development of the Mobile Leak Detection solution in order to refine this product quickly and most efficiently.

Exhibit __ (VP-8):

Response of Picarro, Inc. (“Picarro”) to Letter of Inquiry Dated May 9, 2017 from the Citizen’s Utility Board submitted in Illinois Commerce Commission Docket No. 16-0376

PICARRO

RESPONSE OF PICARRO, INC. to
LETTER OF INQUIRY DATED MAY 9, 2017 FROM THE CITIZEN'S UTILITY BOARD

Introduction to Picarro

Founded in 1998, Picarro is a leading provider of hardware and analytics solutions to measure greenhouse gas (GHG) concentrations, trace gases and stable isotopes across many scientific applications and industrial markets. The company holds over 50 patents, some exclusively licensed from Stanford University and has a global headquarters, R&D, manufacturing in Silicon Valley, California with offices in Europe & Asia with 145 employees, 35 PhDs and over 3,000 Picarro instruments deployed in 60+ countries world-wide.

Cavity Ring-Down Spectroscopy

Our patented Cavity Ring-Down Spectroscopy (CRDS) is at the heart of all Picarro instruments and solutions, enabling the detection of target molecules at part per billion, or better, resolution.

Natural Gas Solutions

Picarro is the industry leader in analytics-driven leak detection and quantification solutions, enabling our energy customers to increase capital efficiency while simultaneously improving the safety of their infrastructure.

Picarro helps utilities reduce O&M costs in their leak survey and repair budgets while also reducing risk. The Picarro mobile detection system coupled with customized data analytics produces leak indications ranked by potential risk. This lets utilities focus on the most important leaks without increasing leak backlogs. Picarro's Risk Ranking Analytics enables utilities to maximize the yield of important leaks per leak found. This maximizes the safety impact per dollar of expense.
The analytics can also calculate emissions on pipe segments to aid in prioritization of pipe replacement for DIMP.

Picarro's vehicles conduct multiple patrols through a natural gas infrastructure, collecting methane plume data and sending it to the Picarro cloud – driving becomes simply data collection. Leak managers then run Picarro's Risk Ranking Analytics, transforming the data into actionable results for leak investigators. Armed with the indications and locations that are most likely to lead to important leaks, crews maximize their impact while keeping costs and backlogs under control. This same data can be used with Picarro's Emissions Quantification Analytics, allowing leak density and aggregate emissions to be calculated on different pipe segments. The pipe segments can then be ranked by emissions or leak density, providing significant O&M cost avoidance due to avoided leaks when this ranking is used to inform capital replacement priorities.

Scientific Instruments
Our portfolio of Picarro gas analyzers and systems enables scientists around the world to measure GHGs, trace gases and stable isotopes found in the air we breathe, water we drink and land we harvest. The ultra-precise and easy-to-use instruments are deployed across the globe offering unmatched performance in a variety of field conditions.
Industrial Solutions
Picarro's industrial solutions range from methane detection and analytics technology for energy companies to trace gas analysis for semiconductor fabrication and pharmaceuticals isolators.

Leak Detection Capabilities

- **Type of Sensors**
  - **Methane only**
  - **Methane and Ethane**

The Picarro system consists of an analyzer that measures both methane and ethane in addition to some additional gases that aid in discriminating natural gas from other methane sources like sewers or other vehicles.

- **Sensitivity (lowest/highest detection level)**

The Picarro system detects methane with a 4ppb precision at ambient levels (roughly 0-15ppm methane concentration) and has a detection range of approximately 0-500ppm of methane in air. For comparison, 100% gas escaping from an underground leak near the vehicle is quickly diluted by the atmosphere to 10s of ppms at the point the gas enters the Picarro system's inlet.

- **Underlying technology**

The Picarro system is based on Cavity Ring Down Spectroscopy (CRDS) which is a near-infrared optical measurement technology. The Picarro system has a closed-path gas flow configuration that continuously draws air flowing from inlets on the vehicle's front bumper into the CRDS analyzer. CRDS is capable of measuring concentrations of methane at levels below one part-per-billion (ppb) in the air.

- **Type of survey using sensor technology**
  - **Mobile survey**
  - **Other**

The Picarro system is a mobile system that is typically installed in a utility's SUV, truck, car, van or equivalent.

- **Cost of sensors/hardware**
- **Software costs**

The hardware is bundled with a software license and support. The incurred cost of the entire system (hardware purchase or lease, software license and annual service and support) is approximately $105 per mile of distribution main. This assumes full utilization of the system (driving and collecting data for one standard daily shift over 250 working days per year). *Please see detailed cost information in Appendix 2 and ROI analysis in Appendix 1 of this document.*

- **Estimated annual O&M costs**

The majority of the O&M cost relates to vehicle operation and maintenance and are approximately $0.65 per mile of distribution main. This excludes the labor component to drive the vehicle. Otherwise, the maintenance costs for the system are included in the price above.

- **Cost of transport method**

The cost of transport is limited to fuel costs and is approximately $1.64 per mile of distribution main, assuming fuel is $2.50/gal.

- **Staffing requirements**
  - **new staff required**
  - **utilization of existing utility staff**

To fully utilize the Picarro system, one dedicated hourly employee is required per vehicle. This could be a contracted or current employee since no specific skills are required. To coordinate the mobile data collection and to run reports using Picarro's analytics report generation software, one employee in a functional area such as leak survey or integrity management would be utilized. For compliance leak survey or emissions quantification using Picarro, this employee would be utilized at a rate of about two (2) hours per day annually for each 3000 miles of distribution main driven by the Picarro system. Existing full time or existing contract staff that are currently used for routine compliance leak survey would be used to investigate the leak indications reported by the Picarro system. In other words, instead of conducting routine survey on the miles of distribution main and services covered by Picarro, they would instead focus just on pinpointing and grading leaks found within the leak indication areas identified by the Picarro system.

Picarro's risk ranking analytics allows utilities to concentrate their limited leak survey and repair budgets on the most important leaks. Risk ranking prioritizes the most potentially hazardous leaks and provides utilities the option to defer repair of non-hazardous leaks in favor of the higher risk leaks in their distribution system. In this way, Picarro's analytics allow mobile leak survey to be accomplished without ballooning non-hazardous leak backlogs.

- **Product certification**

The Picarro system is compliant with the following specifications, standards and regulations regarding its use in this mobile application: DOT, CSA, military MIL-STD 810F shock/vibration test standard, FCC Part15B Class A, CE: EN61326, Safety: EN61010, EN60825-1 (Class 3B laser). The product is being used for DOT Compliance Leak Survey in the following states: CA, TX, AR, MN, LA, MS by three major U.S. utilities with additional states and utilities planning to come online in 2018. The product has been tested and validated in 40 double-blind, Directed Field Trials with 25 LDCs beginning in 2011, several involving independent, third-party validation by GTI, NYSEARCH and PRCI and several natural gas utilities worldwide.

- **GIS/geographic/mapping capabilities**

The system is compatible with any utility GIS system via direct import or API and supports real-time updates and GIS visualization from utility GIS system (ESRI, SAP, GE Small World, Integraph, etc.) using a variety of file formats including GeoDB, ShapeFile, kml, etc. The GIS information is shown in a map-based user interface within the Picarro vehicle and is also viewable for live and past surveys through Picarro's web-based interface. The Picarro analytics and reporting engine produces map-based output including utility GIS information (via PDF, Shape File or via an API to a utility's GIS system). Overlaying GIS information with Picarro leak indications greatly enhances a utility's ability to locate leaks.

- **Unique capabilities of service/product offered, relative to competitors**

Multi-pass Analytics: Picarro's system combines data from multiple passes over an area, and Picarro's algorithms process these runs (often collected on different days), producing actionable results. No other available solution uses analytics to collect and combine multiple data collection runs in this way. Picarro's patented Field of View coverage area and patent-pending algorithms for leak locating, methane emissions quantification and leak indication risk-ranking all take advantage of multi-pass data collection and analytics.

Risk-Ranking and Emissions Quantification: Picarro's analytics produce leak indications that are ranked by their potential hazard and can calculate point-source methane emissions (in cubic feet per hour) and can aggregate total emissions and calculate leak density over an area or pipeline segment. There is no other available mobile solution that offers these capabilities.

Avoiding False Positive Indications: Picarro has seven independent algorithms that act to avoid false positives (and false negatives) including: discriminating between biogas and methane from gasoline and diesel vehicles using multi-gas spectroscopy and Bayesian analytics, removing redundant indications, removing false indications from natural gas vehicles, compensating for high background concentrations of methane, identifying leak indications by using plume shape analytics and identifying search areas using atmospheric and wind vectoring analytics. The removal of false positives significantly improves O&M cost efficiency during investigation of leak indications. No other available solutions have this combination of capabilities.

GIS Integration: The bi-directional integration with a utility's GIS and ERP systems described above is unique to the Picarro system.

Cloud-based Data Storage and Reporting: Picarro offers a unique cloud infrastructure for collecting, storing and visualizing data taken by one or more Picarro vehicles: This web-based platform provides the user access to the various multi-pass analytics routines and reporting engines described above. Various, customizable reports in various formats are available to the utility for download. Picarro ensures the utility has full access to the raw data produced by the Picarro hardware, available in usable *.csv format

Data Security: Picarro's system incorporates third-party audited, industry standards for backup and disaster recovery and security in the areas of information, datacenter, IT systems, cloud application and customer data. Data is encrypted and the in-vehicle computer is hardened and secure.

Support: Picarro's service offing includes on-site training, installation, guaranteed service-level support, immediate response via 24x7x365 phone support and on-demand, on-site support.

Data Quality: The Picarro system suppresses data collection if system malfunctions, drifts out of calibration, or for excessive wind conditions. The system also offers an optional inertial GPS that enables mobile survey in dense urban canyon environments where normal GPS systems fail, such as in Manhattan. These capabilities are unique to Picarro.

Field Investigation Application via Tablet or Smart Phone: Picarro's unique Mobile View application is a live, map-based tool used to investigate leak indications and catalog search results. It offers real-time GPS location and utility GIS system situational awareness for the field technician and provides a record of the walking path and survey results of ground survey crews.

Utility GIS and ERP Connectivity Options: Picarro's system has API-level interoperability with GIS and enterprise systems such as SAP for logging leak information, scheduling, etc.

- **Other relevant information relating to leak detection capabilities**

Picarro's system has been extensively tested (both in real-world and controlled settings) by dozens of utilities and multiple gas industry partners. The testing consistently shows that the Picarro system is significantly more effective than legacy methods of leak detection. The testing and validation includes metrics on leak find rate, Field of View coverage percentage, efficiency, false positives and false negatives.

Picarro's risk-ranking analytics prioritizes leak indications by potential risk, a capability that is unique in the industry. Hazardous leak plumes have unique signatures that can be measured, allowing analytics to rank indications by potential risk. By combining multiple data collection runs by multiple Picarro vehicles, Picarro's risk-ranking analytics allow utilities to maximize operational efficiency by prioritizing leak indications that are most likely to be hazardous. Addressing the highest priority leak indications retires more risk per dollar than any available survey methodology.

Leak Detection Capabilities

- **Does your leak detection equipment have the capability to detect methane, ethane, or both? Are there any other chemical constituents that your equipment detects, which would be relevant to attributing the source of methane detections? If so, please name the constituents and describe their relevance.**

The Picarro system measures and reports concentrations of methane, ethane, the ethane-to-methane ratio and the related measurement uncertainties. For any methane indication reported, it calculates and reports the confidence percentage that the indication is either natural gas, biogenic methane or methane from vehicle exhaust. These determinations are calculated based on the known ethane content in the particular utility's natural gas. This is a configurable, utility-specific parameter in the Picarro analytics. The system also compensates for the presence of H_2S, CO, N_2O, propane and higher hydrocarbons, and mercaptans in the ambient air, and measures and compensates for CO_2 and water concentration changes in the air. To accurately discriminate between natural gas and other methane sources, and to avoid false positives, the system has been designed to measure and/or compensate for these interfering gases that are often found in ambient air and is the only commercially available system that has these capabilities.

- **What is the sensitivity of the leak detection equipment (i.e. the lowest and highest calibrated levels of detection for each constituent that can be detected by the equipment)?**

The detection rages are: Methane: 0-500ppm, Ethane: 0-200ppm, All other gases (H_2S, CO, N_2O, propane and higher hydrocarbons, mercaptans, CO_2 and water) are measured and/or compensated for but not provided as calibrated outputs to the user.

- **Can the leak detection equipment be mounted to a vehicle for the purposes of detecting natural gas pipeline leaks?**

Yes, the Picarro solution is inherently mobile in design.

- **Does your company provide a vehicle with the leak detection equipment, or would a vehicle be provided by the organization that chooses to purchase the leak detection equipment?**

Picarro does not provide a vehicle. The vehicles used are typically a utility fleet vehicle or contractor's vehicle.

- **What is the cost of the leak detection technology?**

The Picarro system is offered as a bundled system including the hardware, system software, access to Picarro's web-based analytics engine, and support and maintenance. The incurred cost of the entire system (purchase or lease) is approximately $105 per mile of distribution main. *Please see detailed cost information in Appendix 2 and ROI analysis in Appendix 1 of this document.*

- **What is the cost of software that is associated with verifying the location of natural gas leaks associated with methane emission indications identified by the technology?**

The Picarro system is offered as a solution and the various elements are not priced separately. The price is inclusive of all the elements required to collect methane and atmospheric data, process and analyze it and deliver reports and other processed output.

- **What is the cost of the vehicle, if a vehicle is included with the leak detection technology system that your company offers?**

Picarro does not sell the vehicle itself and it is not included in the cost.

- **What is the estimated number of new staff required to operate the leak detection technology?**

To fully utilize the Picarro system, one dedicated hourly employee is required per vehicle. This could be a contracted or current employee since no specific skills are required. Picarro provides training to utility staff.

- **What is the estimated number of new staff required to analyze the data generated by the leak detection technology?**

To coordinate the mobile data collection and to run reports using Picarro's analytics report generation software, one employee in a functional area such as leak survey or integrity management would be utilized.

- **What is the estimated utilization of existing utility staff for the above- mentioned purposes?**

For compliance leak survey or emissions quantification using Picarro, this employee would be utilized at a rate of about two (2) hours per day annually for each 3000 miles of distribution main driven by the Picarro system. Existing full time or existing contract staff that are currently used for routine compliance leak survey would be used to investigate the leak indications reported by the Picarro system. In other words, instead of conducting routine survey on the miles of distribution main and services covered by Picarro, they would instead focus just on pinpointing and grading leaks found within the leak indication areas identified by the Picarro system.

- **Has the technology been certified for use for any particular purpose? If so, what purpose has your technology been certified for? What capability does the technology or accompanying software have to generate approximate geographic locations of leaks or the maps of the estimated field of view of areas surveyed?**

The product is being used for DOT Compliance Leak Survey in the following states: CA, TX, AR, MN, LA, MS and has been certified to do so by three major US utilities with additional states and utilities planning to come online in 2018[1].

[1] Picarro's natural gas detection system is being used by PG&E in California and by CenterPoint Energy in Minnesota, Arkansas, Louisiana, Mississippi and Texas. Due to confidentiality reasons, Picarro is not able to disclose the specific customer in other states.

The Picarro system is specifically designed to use vehicle GPS position and wind speed and direction data to localize the point of origin of natural gas plumes and to define regions that have been surveyed by the Picarro system's Field of View. The map-based visualization capability (both live and from reports produced by the software) combines satellite and street maps with utility GIS information to provide the user with information-rich, geospatial views of potential leak locations and the Field of View.

Leak Quantification Capabilities

- **Sensors/analytics packages capable of quantifying leak flow rate**

The Picarro system includes an analytics package that takes data collected by the Picarro hardware and produces output that calculates methane emissions and leak density on point sources, areas or pipe segments and ranks them by total emissions.

- **Cost of quantification capabilities**
    - **hardware**
    - **software**
    - **services**
    - **estimated annual O&M costs**

The Picarro system is offered as a solution and the various elements are not priced separately. The price is inclusive of all the elements required to collect methane and atmospheric data, process and analyze it and deliver reports and other processed output. The incurred cost of the entire system is approximately $105 per mile of distribution main.

The majority of the O&M cost relates to vehicle operation and maintenance and are approximately $0.65 per mile of distribution main. This excludes the labor component to drive the vehicle.

- **Unique capabilities of service/analytics package offered, relative to competitors**

No other competitors offer vehicle-based emissions quantification and analytics. No other competitors offer the unique capability to combine data taken on an infrastructure over a period of time and run analytics on the combined passes to improve the accuracy of the results with each pass included in the analysis.

- **Other relevant information relating to leak quantification capabilities**

Picarro's system informs pipeline replacement decisions based on current, measured emissions data. Picarro's emissions quantification analytics uses data collected by the Picarro hardware to calculate methane emissions of individual open leaks, pipeline segments, or entire infrastructures. This allows utilities to rank pipe segments by overall emissions and prioritize pipe replacement projects – construction dollars are saved by identifying and eliminating segments with the most leaks before those leaks trigger expensive repairs. Actual emissions data and leak density also informs pipeline repair vs. replace decisions.

Leak Quantification Capabilities

- **What analytics packages does your company offer that are capable of quantifying leaks?**

The standard Picarro system includes both leak quantification and leak detection capabilities. The data collection is done with the same vehicle-based hardware. The two different applications (leak quantification and leak locating) are served by two different analytics packages that are both included in the analytics software package of standard Picarro product.

- **What is the cost of the quantification package?**

The emissions quantification analytics software is included at no additional cost in the standard Picarro product.

Leak Data Analysis Capabilities

- **Sensors/analytics capable of ranking leaks by size, spatial characteristics**

The Picarro system can measure emissions of individual or aggregate sources and rank these points or segments by leak flow rate (i.e. leak size or emissions in cubic feet per hour). Since the emissions ranking takes into account a measurement of the entire plume that could come from a point source or from a larger spatial migration pattern, the ranked emissions is reflective of the entire volume of gas escaping.

- **Cost of analytics services (disaggregated by category, to the extent possible)**

The various analytics capabilities of Picarro's system are all included in the cost of the system and are not offered individually.

Leak Analysis Capabilities

- **What analytics does your company offer that are capable of ranking leaks by order of potential hazard?**

Picarro's system has the ability to rank potential leak indications by risk (i.e. likelihood of the indication being from a grade-1 or grade-2 leak for example) based on measured characteristics of the plume. Each leak indication is assigned a percentile ranking score by the analytics according to its potential risk.

- **What is the cost of this service?**

The risk-ranking analytics software is included in the cost of the overall Picarro system and not offered as an individual module.

Operationalization and Integration

- **Specific description of how products and services can be integrated into PGL's "neighborhood method" described in Appendix A**

Please see the response below regarding integration into the neighborhood method.

- **Cost of integration (disaggregated by category, to the extent possible)**

Please see the response below regarding cost.

- **Timeline for integration, including key milestones**

Please see the response below regarding timeline.

- **Number of gas distribution companies that are currently using the product, service or technology offered**

Seven (7) major natural gas utilities around the world are currently using the Picarro system; five (5) being U.S. based (including CenterPoint Energy and PG&E) and four (4) are using it for compliance leak survey. The system has been used and evaluated by a total of 37 utilities across North America, Europe, Asia and Australia.[2]

- **Description of operations or integration with other distribution utilities**

In the utilities where the system is being used actively, the use cases include DOT compliance survey, special non-compliance survey (rapid, emergency surveys, post-construction quality control, etc.), assessment surveys to inform pipe replacement (DIMP) and source discrimination and leak pinpointing applications. Please see additional information in the response below regarding integration.

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[2] Due to confidentiality reasons, Picarro cannot disclose the names of all utilities that have used the Picarro system.

Operationalization and Integration

- **Please provide a specific description of how your company's products and services can be integrated into "neighborhood method"**

The data from Picarro's emissions quantification analytics would significantly improve the accuracy with which individual pipe segments (and entire neighborhoods) could be prioritized for repair based on potential risk. As is shown in PGL Ex. 1.1 "South Austin Gas Leak Comparison" on p. 4 of the "Appendix B – PGL initial brief" there are pipe segments in the "Before AMRP" which were replaced but which appear to have no existing leaks. It has been shown, however, that traditional survey misses typically 60% of gas leaks in an area when compared to using a Picarro system. It is therefore likely that a reliance on historical leak rates will lead to errors in prioritizing pipe segments for repair. Using the Picarro system would allow *current* emissions and leak density to be used – with a higher weighting factor than the 10% now used for historical leaks. Doing so would provide a much more accurate appraisal of the actual *current* risk of each pipe segment. Segments with no emissions (and low risks from the other weighting factors) could be removed from consideration for replacement, saving significant construction costs. A stepwise plan is described in the response below on timeline.

Data from the Picarro system can be processed using emissions quantification analytics which does not calculate individual leak indications. Instead, this analytics report mode is designed to provide a measurement of aggregate emissions over a pipe segment and an estimate of the number of leaks on that segment. Importantly, since individual leak locations are not calculated when using the Picarro system in this analytics mode, the process does not trigger the duty to investigate and repair leaks. Rather, this report provides a means by which pipe segments can be ranked by emissions and/or leak density and prioritized for repair. An example of this output is shown in the figure below.

Segment ID	Segment Rank	Emissions Rate (SCFH)	Emissions range (confidence)	Segment Length (ft)	Emissions Factor (SCFH/ft)	Estimated # of leaks	# Leaks/ft	Emissions Rate / Leak
4	1	7.0	4 – 16 SCFH (90%)	1579	0.0044	5	0.0032	1.14
1	2	5.1	2 – 8 SCFH (90%)	3090	0.0017	5	0.0016	1.0
3	3	2.4	1 – 4 SCFH (90%)	2535	0.001	4	0.0016	0.6
2	4	1.5	0.5 – 2 SCFH (60%)	2514	0.0006	1	0.0004	1.5

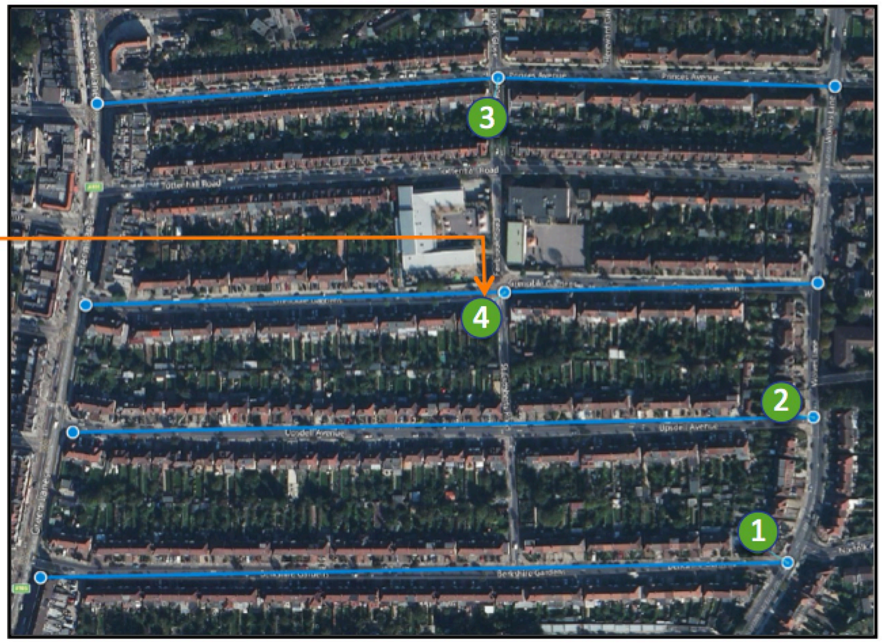

Figure 1. Picarro data processed with Picarro's Emissions Quantification Analytics to calculate emissions and leak density, allowing segments to be ranked and prioritized for replacement.

PGL also states that the "neighborhood approach" allows them to "continually evaluate" their construction priorities. The Picarro system has the ability to rapidly assess emissions and changes in leak density along leak-prone pipe in the winter months. Adding such "frost survey" data taken by the Picarro system could expose new pipe segments that should be prioritized for replacement. Picarro partnered with National Grid and GTI to study the effectiveness of this approach and concluded it was a more effective means of rapidly detecting changes in pipeline integrity under a cover of ice and snow than current practices.

- **Cost of integration**

The costs of utilizing the Picarro system for this application would be consistent with the costs described previously: $105 per mile of distribution main. *Please see detailed cost information in Appendix 2 and ROI analysis in Appendix 1 of this document.*

- **What would be the potential timeline for being able to integrate your company's products and services into the "neighborhood method?"**

Implementing Picarro to provide this informative data in the current prioritization model used by PGL could be done in a matter of a few months. A stepwise plan is detailed below:

Steps to Operationalize EQ Analytics for Optimizing Capital Pipe Replacement Decisions:

1. Identify sections of pipe that are candidates for replacement
2. Using Picarro's driving protocol, collect data on all these sections of pipe with the Emissions Quantification (EQ) mode of Picarro vehicle
    - In this mode, no leak indications are provided to the user – the system simply collects methane concentration, GPS and wind data for further processing with EQ analytics.
    - The EQ driving protocol essentially recommends six (6) or more passes at night, on at least two different nights, along street(s) near the pipe segments to be measured. Picarro's in-vehicle Field of View coverage will show if the pipelines are being sufficiently covered and measured.
3. After all data is collected, use Picarro's EQ Analytics report engine to identify the geographic location of each section that has been driven. Each section will be given an ID number by the system.
4. The report produced by EQ Analytics will rank these sections by overall emissions and provide an estimate of the total number of leaks on that section.
5. This ranking can be compared and/or used to further inform whatever current method of pipe replacement prioritization is being used. For example, PGL could assess individual pipes or an entire neighborhood and combine the resulting reports with the other data used in prioritizing pipeline replacement work.
    - EQ Analytics provides a current snapshot of the state of the infrastructure that can be superior to only using pipe type, age, pressure, historical leaks, risk etc. to prioritize replacement.
    - By selecting more leak-dense pipes for replacement than would be selected with other risk models, more O&M cost in leak repairs can be avoided. In

addition, PGL can focus on replacing the most leak-dense pipe segments first – whether on a neighborhood-by-neighborhood approach or otherwise.

- **Please describe the extent to which your company's products and services have been integrated into the operations of other distribution utilities.**

At the utilities that are using it for compliance leak survey, the Picarro system is tightly integrated with monthly GIS data input from the utility. The Picarro analytics results and leak find information from the field is tied directly into the SAP work order and data collection system at the utility. Data collection drives are scheduled by SAP over multiple days. Once complete, a utility employee runs Picarro's analytics on the collected data. This generates leak indications which are searched for leaks by utility or contract leak surveyors with the aid of Picarro's Mobile View smart phone application. Leak grade, location and other data is collected in the field and uploaded into SAP which drives leak repairs or monitor orders.

These utilities use the system for other non-compliance use cases, scheduled on an as-needed basis. Utilities not yet using the system for compliance leak survey are exclusively using the system for any number of use cases described below:

- Special Non-compliance surveys
  - Rapid, emergency survey, post-disaster evaluation (earthquakes, tornadoes, floods)
  - Surveying high-risk pipe
  - Frost survey patrols (high-frequency survey)
  - Surveying public assemblies and high-consequence areas
  - Rapid survey of areas prior to public events (NFL Super Bowl, parades, official visits etc.)
  - Pre/post building demolition
  - Identification of large lost & unaccounted for gas sources
- Emissions Quantification
  - Construction prioritization (capital main replacement)
  - Targeted emissions reduction (identification & repair of highest emitting open leaks)
  - Post-construction QC – rapid survey of new or modern infrastructure
  - Due-diligence for asset acquisition
  - Risk-based assessment surveys
  - Support DIMP initiatives and analysis (high risk pipe, business districts, annual survey)
- Special use cases
  - Pinpointing hard-to-find leaks
  - Investigation of odor complaints

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- Real-time source attribution (on-site chemical analysis: is source natural gas or not?)

Please see detailed cost information in Appendix 2 and ROI analysis in Appendix 1 of this document related to the use cases described above.

The responses to this letter of inquiry were prepared by Aaron Van Pelt, Director of Product Marketing and Product Management at Picarro Inc. Mr. Van Pelt is responsible for Picarro's energy products including the leak detection and emissions quantification hardware and analytics. Mr. Van Pelt has been in various technical and business roles at Picarro since 2007 and has managed Picarro's leak detection products since their development and introduction in 2010 and has managed the multiple campaigns with utilities and product validation by third parties.

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Leak Management Cost Savings

Summer 2017

Appendix 1

Summary

This document provides detail on the return on investment of the Picarro Leak Management System applied to various use cases within Leak Management. The financial assumptions for each use case are listed and the ROI is shown on an annual and 5-year basis. Various use cases included real examples from LDCs using Picarro, and the financial model for ROI in these cases is based on the financials of these examples. In cases where an example is not cited, the estimates come from typical estimates Picarro has obtained in its discussions with current gas distribution customers.

Common uses of Picarro Surveyor

- **Regulatory compliance leak survey**
- **Special Non-compliance surveys**
  - Rapid, emergency survey, post-disaster evaluation (earthquakes, tornadoes, floods)
  - Surveying high-risk pipe
  - Frost survey patrols (high-frequency survey)
  - Surveying public assemblies and high-consequence areas
  - Rapid survey of areas prior to public events (parades, official visits etc.)
  - Pre/post building demolition
  - Identification of large lost & unaccounted for gas sources
- **Emissions Quantification**
  - Construction prioritization (capital main replacement)
  - Targeted emissions reduction (identification & repair of highest emitting open leaks)
  - Post-construction QC – rapid survey of new or modern infrastructure
  - Due-diligence for asset acquisition
  - Risk-based assessment surveys
  - Support DIMP initiatives and analysis (high risk pipe, business districts, annual survey)
- **Special use cases**
  - Pinpointing hard-to-find leaks
  - Investigation of odor complaints
  - Real-time source attribution (on-site chemical analysis: is source natural gas or not?)

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Emissions Quantification Use Cases

1. Pipeline replacement prioritization
   - Inform repair vs. replace decisions before construction
     - Avoid leak *repair* construction costs by prioritizing removal of leaky segments
   - Evaluation of high-risk pipe – DIMP

2. Fugitive emissions reporting
   - Identification of largest emitting leaks

3. Post-construction QC evaluation
   - Quality control audits of (pre/post) construction by contractors

4. Monitoring of leak rate changes over time
   - High-frequency frost survey
   - Seasonal comparison (Fall/Spring) survey to detect frost damage
   - Long-term monitoring of Grade-3 leaks in high risk areas

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Cost Savings: Emissions Quantification (EQ)

- Pipeline replacement prioritization
  - EQ measures emissions *and* leak density on pipe segments
  - EQ is superior to using traditional leak history and identifies the *most* leak-dense pipe segments for replacement
  - Inform repair vs. replace decisions before construction
    - Avoid leak *repair* construction costs by prioritizing removal of segments with highest leak density

EQ Cost Savings

Total HARD cost savings			Total SOFT cost savings		
Yearly Replacement Budget	$146,720,000		**Risk Reduction:**		
Total Miles of Main	2,000		Hazardous leak find multiple	2.2	
Burdened cost of Picarro survey per mile of main	$156		Current annual risk reduced from replacement**	$537,600	
Total yearly cost to survey "Yearly Replaced Miles"*	$34,944		Annual risk reduced from replacement with EQ	$1,164,800	
Cost per Mile Replaced	$1,310,000		Five year risk reduction:	-->	**$5,824,000**
Cost per Leak	$3,000				
Yearly Replace Miles	112				
			Reduction in Odor Calls:		
Leaks/mile without EQ**	0.6		Cost of Odor Calls	$300,000	*($150/call, 1 call/ mi)*
Yearly Cost Avoidance without EQ	$201,600				
			Reduction or Odor Call by replacement	28.56%	
Leaks/mile with EQ**	5.7		Reduced Cost from Odor Calls	$85,680	
Yearly Cost Avoidance EQ	**$1,880,256**				
EQ Extra Savings	$1,678,656				
Five year cost savings-->		**$8,393,280**	Five year cost savings:	-->	**$428,400**

*Assumes to prioritize the Yearly Replace Miles, that you have to drive 2x that many of miles of pipe to prioritize the sections needing replacement

**Assumes 0.6 hazardous leaks/mi (traditional), 1.3 hazardous leaks/mi (Picarro), 5.7 total leaks/mi (Picarro) from Field Trial data

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Cost Savings: Compliance Leak Survey

- Hard savings from increased efficiency with Picarro
- Soft savings from:
  - Risk reduction due to finding more hazardous leaks with Picarro
  - Reduction of penalties from losing paper survey records due to Picarro digital records

Routine Regulatory Compliance Leak Survey

Total HARD cost savings			Total SOFT cost savings		
Annual spend on leak survey	$1,800,000		Hazardous leak find multiple	2	*(x traditional, typical)*
Miles of mains surveyed annually	10000		**Risk Reduction:**		
Picarro efficiency gains	38%	*(typical)*	Current annual risk reduced from leak survey activity	$1,000,000	
Survey cost per mile	$180		Five year incremental risk reduction:	-->	**$5,000,000**
			Non-Compliance Penalties:		
Five year savings:	-->	**$3,420,000**	Cost of losing a survey record	$25,000	
			Surveys completed per year	3000	
			Risk of record loss per survey	0.10%	
			Five year risk reduction:	-->	**$375,000**

*Customers report savings from 15% to 60% over traditional survey. 38% is an average.
**Based on risk reduction at higher leak find rate
***Estimate of lost productivity and labor cost to find replicate lost records

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Cost Savings: Customer Odor Calls

Investigation of Odor Complaints

Total HARD cost savings			Total SOFT cost savings		
Annual odor calls	10000	*(10k mi x 1 call/mi)*	Risk per missed hazardous leak	$8,000	
Response cost	$150	*(typical)*	No-leaks where Picarro finds a hazardous leak	16%	*(CenterPoint example)*
Picarro reduction from repeat calls	10%	*(CenterPoint example)*	Number of no-leaks	2000	
Five year savings:	-->	**$750,000**	Five year risk reduction:	-->	**$12,640,000**

- **CenterPoint Energy Example:**
  - Respond to 81k odor calls per year
  - 31% of leaks are from customer odor calls
  - In 34% of cases, technicians come back reporting no gas found
  - When they send a Picarro vehicle to a no-gas-found case, it finds gas 79% of the time
  - Of those cases, 20% are hazardous leaks
  - This means: 81k x 34% x 79% x 20% = 4,351 hazardous leaks are found that would not otherwise be found
- CenterPoint's goal to reduce the 34% NGF by half
  - Picarro would be key to quantifying & tracking
  - Could institutionalize use of Picarro for no gas found reports from odor calls
  - Expand use to construction monitoring, etc. using Picarro

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Cost Savings: Large Odor Cloud, Emergencies, Hard-to-Find Leaks

- There are several examples from current Picarro customers of these use cases

Responding to Massive False Odor Clouds

Total HARD cost savings

Large-scale false alarms per year	1	
Calls needing a response per incident	1000	
Cost per odor call response	$150	
Cost to respond with Picarro vehicle	$2,000	
Five year savings:	-->	**$740,000**

Rapid Post-Emergency Survey

Total HARD cost savings

Emergencies per year	0.3	
Extra cost for emergency survey	$500,000	
Five year emergency survey savings:	-->	**$750,000**

Total SOFT cost savings

Goodwill from gas company driving streets post-incident	$100,000	
Five year value of goodwill	-->	**$150,000**

Locating Hard-to-find Leaks

Total HARD cost savings

Overnight cost of crew	$5,000	
Avg number of nights spent in field on unfound leaks	1.5	
Hard to find leaks per year	20	
Amount Picarro finds before nightfall	65%	
Five year pinpointing savings:	-->	**$487,500**

Total SOFT cost savings

Morale and health impact of emergency all night work	$2,000	
5-year avoidance:	-->	**$195,000**

Cost Savings: Special Survey & QC after Construction

- There are several examples from current Picarro customers of these use cases

Non-Scheduled Mandated Leak Survey

Total HARD cost savings

Annual spend on non-scheduled survey	$500,000	
Efficiency savings	38%	
Five year savings:	-->	**$190,000**

- Public news report: PG&E dispatched 64 workers to a recent over-pressurization event:
  - http://www.kcra.com/article/pgande-gas-problem-prompts-concern-in-folsom/8643190
  - There is also a benefit for finding leaks faster, if they actually occurred due to the overpressure event

Post-construction Quality Control

Total HARD cost savings

Total annual repair costs	$5,000,000	
Construction jobs that will cause a problem in the next survey cycle	5%	
Five year future cost avoidance:	-->	**$1,250,000**

- Amount spent on repairing or replacing assets
- Contractors should fix problems if they are discovered quickly

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Cost Savings: Source Attribution, Auditing Traditional Survey, Asset Acquisition

- There are several examples from current Picarro customers of these use cases

Real-time Source Attribution

Total HARD cost savings			Total SOFT cost savings		
Gas samples processed per year	500		Hourly crew cost	$500	
Cost per gas sample	$100		Hours for a crew to collect a sample	2	
Cases resolved with Picarro	50%		Five year collection savings:	-->	**$1,250,000**
Five year gas sample savings:	-->	**$125,000**			

- There is also a reduction in risk from finding out faster if there is actual risk due to a gas leak

Auditing walking survey

Total HARD cost savings			Total SOFT cost savings		
Annual spend on survey	$1,000,000		Risk per missed leak	$10,000	
Improvement knowing Picarro auditing	20%		Current annual leaks found	2000	
Five year value of additional survey:	-->	**$1,000,000**	Improvement from Picarro audits	20%	
			5-year risk reduction:	-->	**$20,000,000**

- Utilities have seen an improvement in leak survey quality when traditional surveyors know they are being followed by Picarro

Due-diligence for Asset Acquisition

Total SOFT cost savings		
Gas systems purchased per five years	2	
Value of knowing if system was well maintained	$500,000	
Five year risk avoidance on acquisitions:	-->	**$1,000,000**

Cost Savings: Lost Gas & Community Outreach

- There are several examples from current Picarro customers of these use cases

Identification of Lost and Unaccounted for Gas Sources

Total HARD cost savings			Total SOFT cost savings		
Gas delivered per day (Bcf)	2.0		Social cost of carbon† per ton of CO_2	$42	(highly variable)
Cost per Mcf	$3.50		Tons of CO2 equilivent‡ per Mcf methane	0.054717	
Lost gas rate	1.50%		Carbon impact avoided over five years	-->	**$10,065,739**
Picarro leakage reduction	40%				
Five year ratepayer gas savings:	-->	**$3,832,500**			

† In the year 2020 for 3.0 percent discount rate in 2007 dollars. Source: nap.edu/read/24651
‡ Source: epa.gov/energy/ghg-equivalencies-calculator-calculations-and-references

- Helpful if companies have a target for emissions reduction
  - Can be calculated as tons of CO2 avoided as well

Community Outreach

		Total SOFT cost savings		
Public events per year	1	Goodwill from showcasing advanced utility technology	$10,000	
		Five year goodwill value:	-->	**$50,000**

  - Community outreach is worth spending money on

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Cost Schedule

In the detail that follows, costs of acquisition and operation of the Picarro system are listed per mile of distribution main and are calculated for PGL's planned 2,000 mile infrastructure. Costs are also compared to industry averages for leak management.

Item	Itemized cost	Multiplier	Subtotal
Cost of leasing the system	$105 per mile of distribution main	2,000 miles* of distribution main per year	$210,000
Vehicle operation and maintenance	$0.65 per mile of distribution main	2,000 miles of distribution main per year	$1,300
Fuel costs (SUV, Ford Escape or similar)	$1.72 per mile of distribution main	2,000 miles of distribution main per year	$3,440
Annual cost of Driver and Analyst	$49.10 per mile of distribution main	2,000 miles of distribution main per year	$98,200
		Grand Total	**$312,940**

*2000 miles of distribution main is used in this example to match PGL's total replacement project mileage.

The average cost per mile, including all expenses listed above is approximately $156.22/mile. This compares to industry ranges of $180 to over $2600 per mile[1] of main for leak survey.

Rate per mile calculations are based on the Picarro multi-pass driving protocol and current driving productivity rates of Picarro customers, one car driven 7 hours per day and 250 days per year can survey up to 3055 miles of main per year, on average, providing over >90% coverage of mains and services. Productivity for mains-only survey could be as high as 9165 miles of main annually, at a cost of $52.07 per mile of main. This compares to the industry standard[2] of 9.9 services per hour and 2.5 miles of main per hour, the productivity of which depends on mains/services density.

[1] Pacific Gas and Electric Company 2017 General Rate Case, Exhibit (PG&E-3), Chapter 6c, Leak Management Expenses by Major Work Category. Leak survey cost per service in 2017 is projected to be $33 per service. PG&E has approximately 79 services per mile of main, yielding a leak survey cost of $2607 per mile of main including associated services and other inspection requirements. Contract leak survey can range between $180-$350 per mile of main according to estimates obtained by Picarro.

[2] *Picarro Surveyor™ Leak Detection Study Diablo Side-By-Side Study*, Timothy Clark, et al., November 2012, Pipeline Research Council International & Pacific Gas & Electric Co.

Exhibit __ (VP-9):

Picarro Emissions Quantification Results Final Report in Support of the Methane Leak Surveying Report for the Public Service Electric and Gas Company ("PSE&G") Gas System Modernization Program ("GSMP") II Program

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Picarro Emissions Quantification Results Final Report

in Support of the Methane Leak Surveying Report for the PSE&G GSMP II Program

Prepared by Picarro, Inc.

December 14, 2018

Introduction

Picarro has completed mobile methane emissions measurements for use in the next phase of PSE&G's Gas System Modernization Program (GSMP II). Methane data was gathered along approximately 280 miles of Utilization Pressure Cast Iron ("UPCI") gas mains contained in 44 map grids. The replacement of mains within GSMP II will follow the prioritization based on the grid-based Leak Hazard Indices developed by PSE&G, and the Picarro methane emissions results will be used as a sub-prioritization metric within that framework. Including methane emission rate (volumetric flow rate) as part of the replacement prioritization process may result in the reduction of natural gas emissions and reduce the environmental impacts of such emissions. This document describes the measurement campaign results, data collection methodology, protocol and validation as well as details about Picarro's hardware, software and data analytics platform used to gather and process the data.

Picarro System Hardware

Picarro's mobile natural gas leak detection system is driven through a natural gas distribution infrastructure gathering methane, wind, atmospheric and GPS data which is later processed by Picarro's algorithms to detect and localize leaks and calculate methane emission rates. The Picarro hardware consists of the following elements (shown in figure 1 below) forming a completely integrated solution mounted in a vehicle:

- A parts-per-billion sensitivity gas analyzer based on Cavity Ring Down Spectroscopy (CRDS) measuring atmospheric gas composition and other tracers such as ethane
- An anemometer mounted on a mast for detecting wind speed, direction and wind variability
- Two antennas on the vehicle roof, one for the 4G wireless connectivity and one for sub-meter GPS vehicle positioning
- A 4G wireless router enabling the internet connection and data transmission to and from the Picarro Cloud and WiFi connection to the in-vehicle tablet

- A tablet computer which allows the operation and visualization of the system and data
- A supporting equipment module containing pumps, a backup battery, GPS receiver and various power supplies and gas handling equipment
- A gas inlet system mounted on the front of the vehicle

Air is continuously collected on the front of the vehicle routed to the gas analyzer via tubing. The entire system and accessories are directly connected to the vehicle battery.

Figure1. Picarro System Hardware.

Picarro Software & Data Analytics

The Picarro system identifies the characteristic signature of natural gas leaks by analyzing the methane plumes as they propagate in the atmosphere and intersect with the path of the vehicle. The system also measures atmospheric and meteorological conditions and uses algorithms to identify the origin and degree of hazard of the natural gas leak indication while virtually eliminating indications triggered on other non-natural gas sources of methane.

The most powerful feature of the Picarro system is its ability to combine information from multiple measurement sessions over a region, taking advantage of varying atmospheric conditions (wind direction, wind speed, atmospheric stability), to produce aggregated survey results over a certain period of time. This unique capability increases territory coverage with successive passes by the vehicle and allows statistics to be built up on location and risk for every leak indication. Reports and other data outputs can be generated from this processed data specific to the intended use case – leak survey, forecasting, targeted emissions reduction, risk management, etc.

Picarro's Emissions Quantification Analytics is one of the analytical models that generates outputs and reports that can be applied to data taken by the Picarro vehicle. After multiple passes are driven in an area of interest where the vehicle path intersects methane plumes typically multiple times, the analytics process the data using four basic steps:

1. Calculate the emission rate from individual methane plume detections. Here, the methane concentration is represented as a function of distance along the vehicle's path and that "line integral" is evaluated, as described below, to calculate the flow (emission) rate.
2. Geographically associate (cluster) these detections to identify emission source locations.
3. Calculate "average" emission rate of each cluster using individual detections using a Bayesian framework.
4. Aggregate sources (clusters) over areas (grids) or pipe segments and sum emissions from individual sources to determine total emission rate and uncertainty.

The methane flow rate Q is derived from the volumetric flux equation which uses a "Mobile Flux Plane" measurement as input:

$$Q=u\iint[C(y,z)-Co]\,dy\ \ dz$$

where $C(y,z)$ is the concentration at each measurement point of the cross-sectional area of the plume (the vehicle samples the concentration along a line through this plume in the y direction and the plume is assumed to be homogenous in concentration across this surface), C_0 is the background methane concentration, u is the mean wind speed (the wind is measured by the anemometer on the vehicle and is assumed to be roughly vertically constant over the size of the plume; the height of the plume is inferred from its measured width in the y direction). In standard engineering terminology the flux plane method is analogous to a control volume approach for quantifying gas flow rates. The vehicle drives downwind of the leak and captures methane emissions over a control surface along the vehicle's path. The inflow condition for the control volume is determined from highly sensitive measurements of the background methane concentration. The Picarro methane emission rate measurement system is consistent with the provisional EPA test method OTM 33 for gas leak detection and emissions quantification (EPA, 2014). For plume intersections where the angle of the wind is too shallow (i.e. the wind is along the direction of vehicle travel and the plume is propagating parallel or nearly parallel to the vehicle path) the wind direction data allows these plumes to be excluded from the analysis since their line integrals are not meaningful in this instance).

The power of the flux plane method for natural gas leak rate quantification is the simplicity of the approach. A prediction of emission rate is made directly by multiplying the measured crosswind concentration profile by the measured wind speed. Accurate emissions estimates are achieved through a combination of enhanced spatial resolution of the concentration profile, accurate measurements and models of the instantaneous vertical wind speed gradient, and averaging of multiple plume transects downwind of the leak. The fast response time (4 Hz) of the Picarro methane gas analyzer provides high spatial resolution in the crosswind direction. This produces a high-resolution concentration map without loss of spatial information content.

Comparison to Traditional Survey Equipment and Methods

The Picarro system takes methane data at a speed and scale not possible with traditional instrumentation, eliminating human bias and operator error associated with these legacy methods. It has been shown in over 60 field studies to consistently identify an average of *three times* as many gradeable leaks (and a three times more hazardous leaks) as compared to traditional survey equipment and methods. In comparison to traditional leak survey equipment, the Picarro hardware is 1000 times more sensitive, with the ability to detect methane and ethane at better than one part-per-*billion* (traditional systems have only 1-part-per-*million* methane sensitivity and do not use ethane to remove false positive leak indications from biogenic methane sources (sewer, etc.) as the Picarro system does. The system can take data at vehicle speeds over 40mph and in rain and snow conditions. The system's reliance on the wind enables it to sense leaks without driving directly over the gas main, and the analytics can rank methane plumes according to their potential hazard, emission rate and likelihood of emanating from an aboveground or belowground leak.

Comparing the Picarro system and analytics to other mobile methane detection technologies (including that which was used during the methane mapping done for GSMP I), there are some key technological advantages of the Picarro system which result in even higher-quality methane quantification results than were achieved for GSMP I.

The key advantage of the Picarro system and methodology is its use of wind information to both localize emission points and calculate emission rates. The use of wind information to calculate emission rates is critical to obtaining accurate results. The Picarro system also has a high collection rate and gas sampling rate so that gas plumes are measured with very high spatial resolution, resulting in high precision emissions quantification. Picarro's six-pass, two-night protocol results in high leak detection rates and high-precision emissions measurements. Picarro's analytics further improve these results by identifying and rejecting false-positive indications. Picarro's analytics can also statistically differentiate between aboveground and belowground leaks and therefore preferentially aggregates plumes judged to be coming from belowground leaks for emissions quantification (i.e. it will preferentially exclude aboveground leak plumes from the emissions calculations).

Data Collection Methodology & Protocol

Picarro's Advanced Leak Detection technique utilizes the wind to bring methane plumes to Picarro's vehicle-based methane and atmospheric sensing platform. Picarro's data collection methodology is based on the ability of Picarro system to detect methane emissions below as well as at some distance away from the vehicle when the methane emission point is upwind of the vehicle. The reach of Picarro's Field of View coverage area is calculated at each point along the vehicle path to provide a documented record of survey coverage. This concept is shown in figure 2 below.

There are qualities of methane plumes that the system measures (size, emissions, concentration, ethane content, etc.) that allow analytics to predict the location and relative risk of the leak indication (i.e. if it is likely originating from a hazardous leak or not). Leak Indication Search Area (LISA) markers are computed for each potential leak to aid crews in pinpointing leaks for repair.

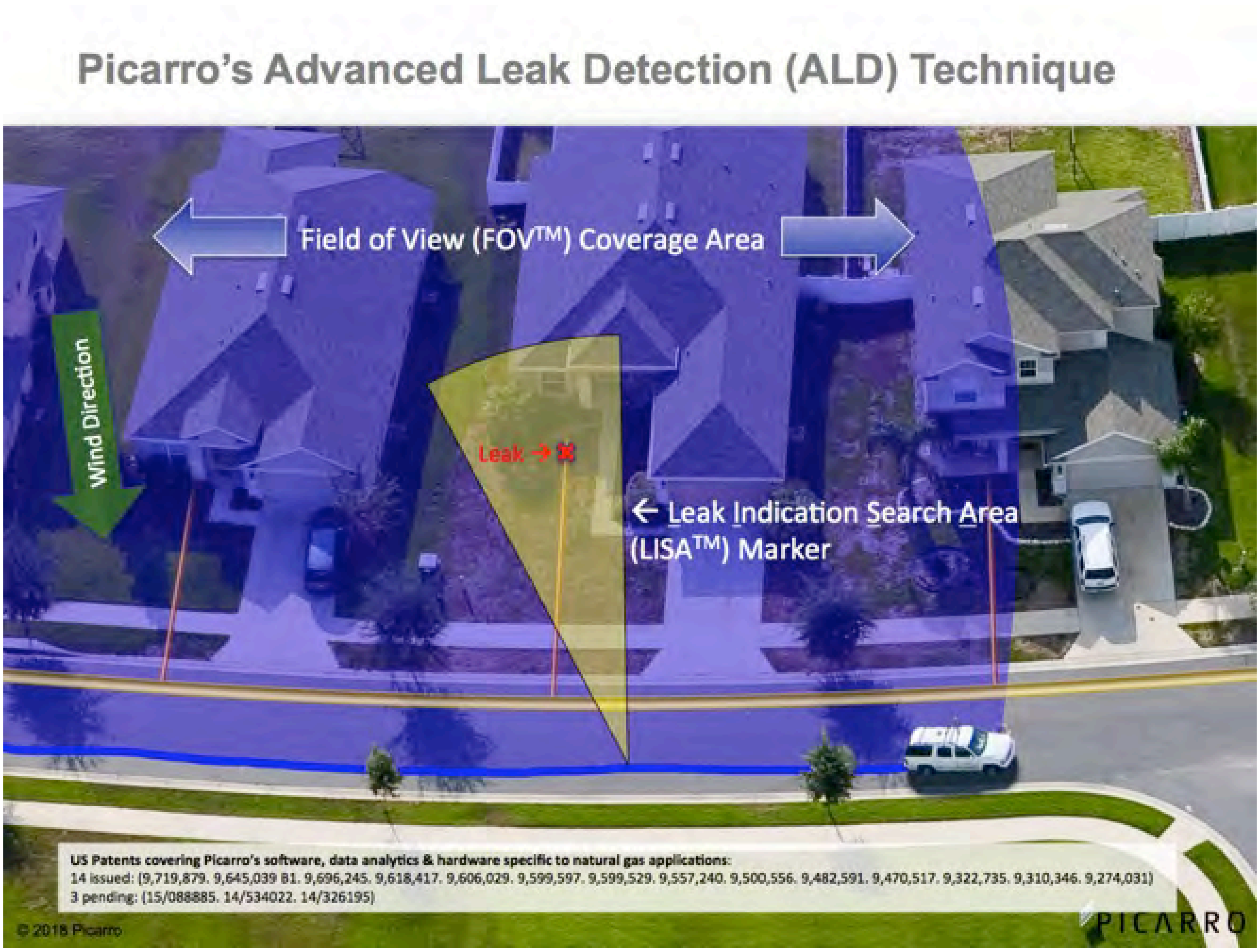

Figure 2. Picarro ALD technique concept.

Picarro collected data on PSE&G UPCI mains sections using a standard "three-drives" protocol that prescribes that each street along which mains were located be driven twice (one pass on each side of the street) and that this be repeated three times on at least two different nights (so that either two or four passes were completed on one night) between sunset and sunrise. This results in six passes per street along the defined sections of main. Data is taken at night to maximize plume detectability and minimize measurement noise due to higher atmospheric turbulence that is present during the day. Nighttime survey also avoids traffic that disturbs plumes.

The reasons for multiple passes over multiple nights is to collect data in a variety of wind conditions (multiple wind directions) to achieve complete Field of View coverage of the mains. Multiple passes also ensures the leak detection rate is >95% since the single-pass detection for a given leak is generally only 25-35% and the detection probability scales as the probability of independent events, reaching >95% for these belowground leaks that are generally near the vehicle. An example of one night's driving on a grid is shown below in figure 3.

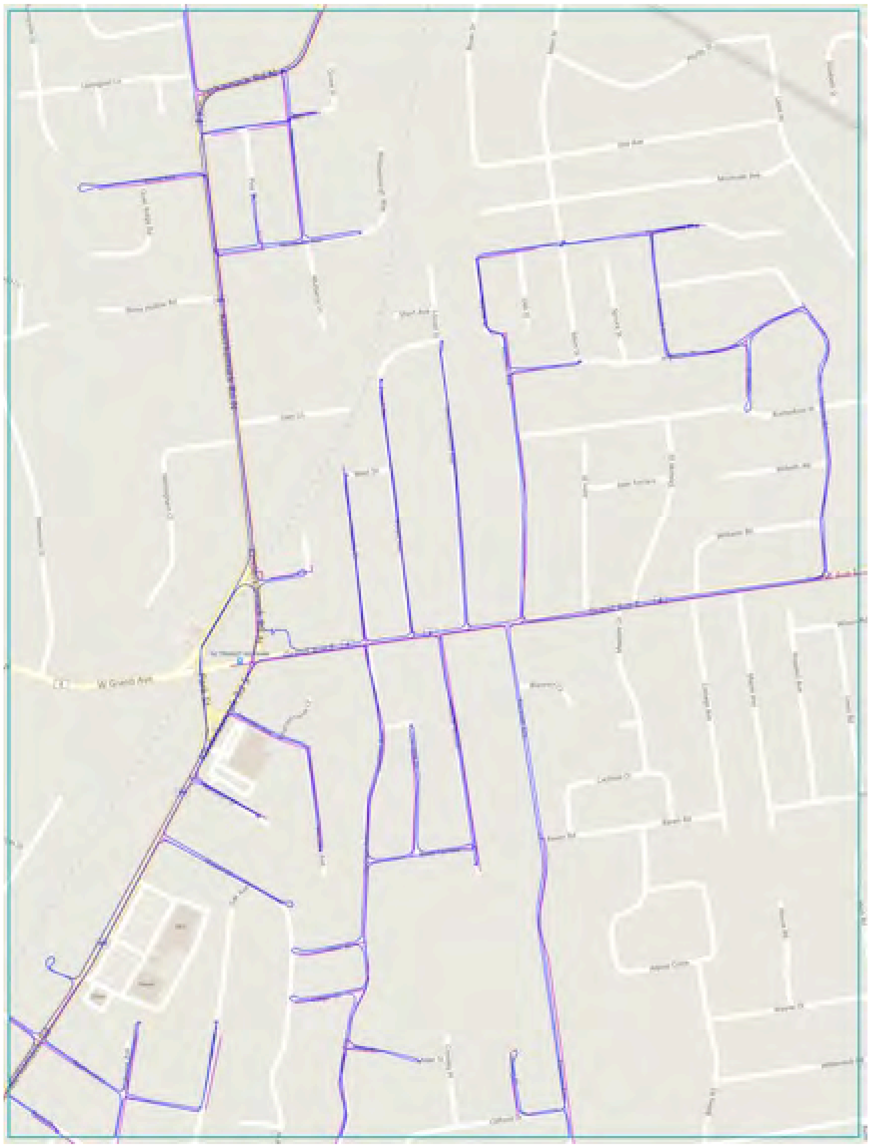

Figure 3. Driving example during one night (two passes per street). Vehicle breadcrumb (blue), UPCI mains (magenta).

Picarro provided a driver and vehicle outfitted with the Picarro equipment to accomplish this task, during the period from 10/23/18 through 11/27/18. PSE&G provided to Picarro shape files (for importation into Picarro's analytics platform) defining: 1) the 44 grid boundaries and 2) the sections of mains to be measured. Using the GIS data, the driver was able to visually identify specific streets to drive and capture data on and those to avoid. During post processing, only emissions that were measured along the sections of mains defined in the GIS were reported – any other data not associated with these mains was excluded and not processed. The system also automatically suspends data collection when the vehicle traverses outside a grid boundary.

PSE&G Results & Discussion

The complete set of tabulated numerical results is in Appendix I, and geographical methane maps for each grid along with summary statistics for each grid are presented in Appendix II).

In figure 4 below, various metrics are plotted against the total emissions per grid. For each grid, the number of measured emissions clusters and the estimated number of belowground leaks (as determined by Picarro's analytics) are plotted versus total grid emissions. Similarly, the emission rate per mile for each grid is plotted versus total grid emissions.

There is generally – but not always – a correlation between these metrics and total grid emissions. The fact that there are large departures from a perfect correlation shows that it would not be possible to accurately predict total grid emissions (nor leaks per mile) based on a "representative" per-mile emission rate (which might be inferred from pipe age, type, etc.) using an inventory approach. In other words, the emission rates and locations must be measured and mapped. With methane maps and their aggregated emissions data, however, it is possible to make accurate, surgical construction decisions at the grid or individual pipeline section level as desired.

It interesting to note that in the comparison of the number of emission clusters below (red squares) to the total grid emissions, the trend is linear up to about 20 liters/minute and then becomes nearly flat. The interpretation of this result – which has been observed in the study[1] of natural gas distribution system emissions previously – is that, a very few number of so-called "super emitters" (i.e. the largest emitting sources) are responsible for a significant fraction of the overall emissions. Here we see examples of where the number of clusters hardly changes, but the overall grid emissions more than doubles.

[1] Lamb BK, Edburg SL, Ferrara TW, Howard T, Harrison MR, Kolb CE, Townsend-Small A, Dyck W, Possolo A, Whetstone JR, 2015, Direct Measurements Show Decreasing Methane Emissions from Natural Gas Local Distribution Systems in the United States, *Environmental Science and Technology* 49, 5161-5169.

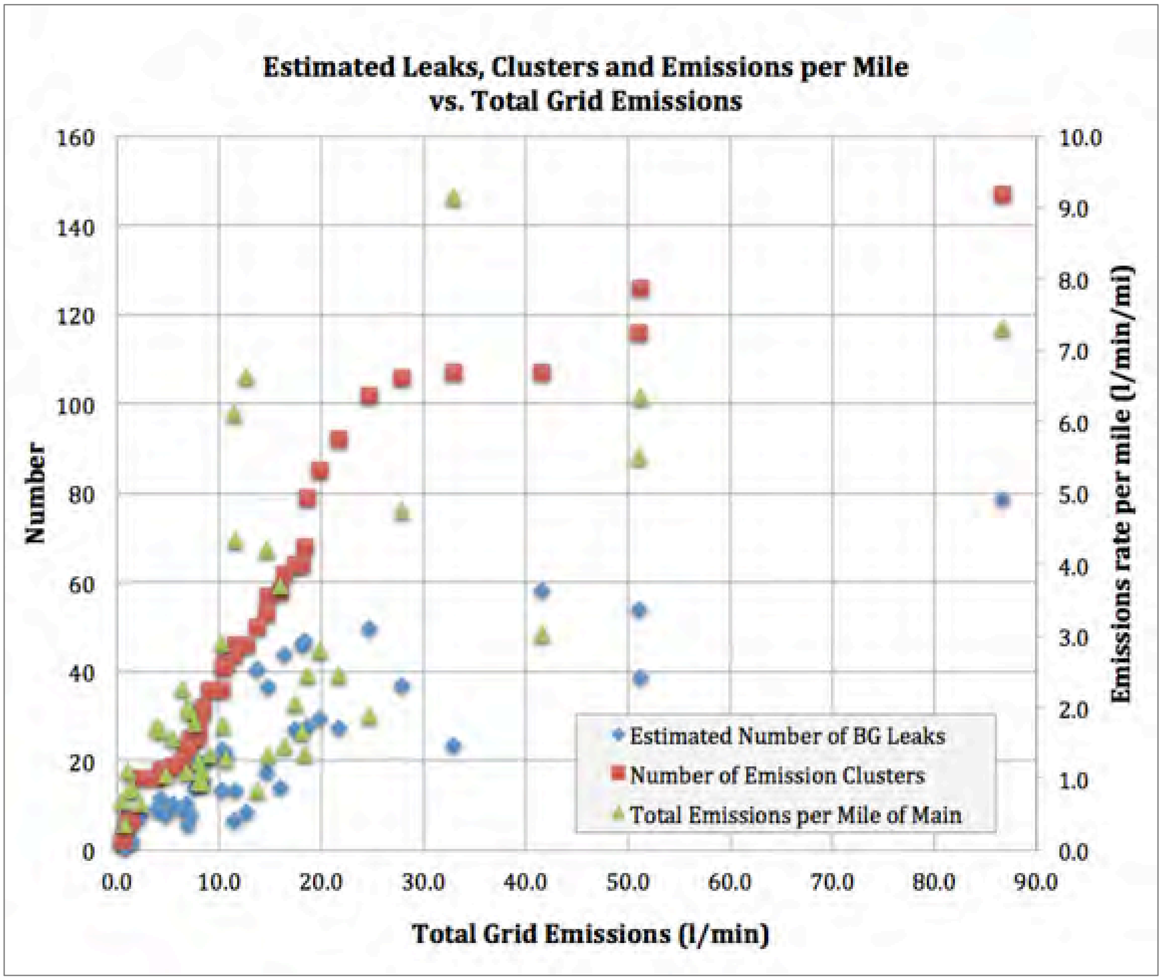

Figure 4. Comparison of total emission rate to per-mile emission rate and per-mile leak number estimation derived from methane mapping data.

The following data is summarized in Appendix 1 for each grid:

- Grid ID
- Miles of UPCI pipe in grid
- Total estimated flow rate (emission rate) (liters/minute)
- Estimated flow rate per mile (liters/minute/mile)
- Rank by total flow rate
- Rank by flow rate per mile
- Total number of emissions clusters within grid
- Total estimated belowground leaks on UPCI mains within grid

The following metrics will be provided or determined by PSE&G after combining the methane emissions results with the existing grid ranking information:

- Hazard Index per mile
- GSMP II UPCI Grid Rank
- Ranked Year of Construction using methane flow rate data
- Planned Year of Construction
- Description of factors contributing to grid bypass decisions (if Planned Year of Construction does not match Ranked Year of Construction)

Summary of PSE&G GSMP II Methane Mapping Project

Some key figures of merit from the data collection and analysis has shown the following summary statistics from the 44 grids:

- Highest emitting grid: 86.6 l/min
- Lowest emitting grid: 0.6 l/min
- Mean grid emissions: 15.3 l/min
- Median grid emissions: 10.5 l/min

The statistics for the emission rate per mile of main were:

- Highest: 9.2 l/min/mi
- Lowest: 0.4 l/min/mi
- Mean: 2.5 l/min/mi
- Median: 1.7 l/min/mi

- Although the total grid emissions trends essentially with the per-mile emission rate, there are exceptions to that trend, also evidenced by visual comparison of the methane maps – there are large variations in both per-mile leak density as well as variability of over two orders of magnitude in leak rates.

- This variability shows the power of the methane mapping technique for providing additional granularity that can be used to maximize methane emissions reductions and/or maximize remediation of the maximum number of belowground leaks through changes to construction priorities based on these methane maps and associated data.

Appendix I: Tabulated Data on GSMP II Grids

Table 1. Detailed statistics for all 44 grids sorted by Grid Rank by Total Grid Emissions. Emissions estimates have a quoted confidence level of 80% (i.e. 10-90% of the distribution). The error estimates are non-symmetric (e.g. Grid 2C-44 has a total grid emission of 86.6 (+23.0 / -15.1) l/min). The terms "flow rate", "emissions" and "emission rate" are synonymous. Mileage is always in terms of miles of UPCI mains.

Grid ID	UPCI Main Pipe Length (mi)	Grid Rank by Total Grid Emissions	Grid Rank by Total Emissions per Mile	Total Grid Emissions (l/min)	Total Emissions Upper Error Bar (l/min)	Total Emissions Lower Error Bar (l/min)	Estimated Number of Belowground Leaks	Number of Emission Clusters	Total Emissions per Mile of Main	Total Emissions per Main Mile, Upper Error Bar (l/min/mi)	Total Emissions per Main Mile, Lower Error Bar (l/min/mi)
2C-44	11.8	1	2	86.6	23.0	15.1	79	147	7.3	1.3	1.9
2H-48	8.1	2	4	51.2	21.6	12.4	39	126	6.4	1.5	2.7
4E-13	9.3	3	6	51.0	7.8	5.2	54	116	5.5	0.6	0.8
1Y-49	13.7	4	11	41.6	6.9	4.7	58	107	3.0	0.3	0.5
2P-51	3.6	5	1	33.0	8.2	5.7	23	107	9.2	1.6	2.3
2R-42	5.9	6	7	27.9	6.5	4.4	37	106	4.8	0.7	1.1
2J-54	13.1	7	20	24.7	3.5	2.3	50	102	1.9	0.2	0.3
2J-46	8.9	8	14	21.8	6.3	4.0	27	92	2.5	0.4	0.7
2J-50	7.1	9	13	19.9	4.2	2.9	29	85	2.8	0.4	0.6
3D-38	7.6	10	15	18.6	4.6	3.0	28	79	2.5	0.4	0.6
1Z-54	13.7	11	28	18.4	2.5	1.7	47	68	1.3	0.1	0.2
3E-37	10.9	12	25	18.1	2.7	1.8	46	64	1.7	0.2	0.2
2L-56	8.5	13	17	17.5	3.3	2.2	27	64	2.1	0.3	0.4
3E-35	11.2	14	27	16.4	2.6	1.7	44	62	1.5	0.2	0.2
2K-54	4.3	15	10	15.9	8.6	5.7	14	58	3.7	1.3	2.0
2J-55	11.1	16	30	14.9	2.4	1.6	36	57	1.3	0.1	0.2
2K-43	3.5	17	9	14.6	4.0	2.9	17	53	4.2	0.8	1.2

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2F-53	16.4	18	40	13.7	2.4	1.6	41	50	0.8	0.1	0.1
2R-48	1.9	19	3	12.6	3.9	2.9	9	46	6.6	1.5	2.1
2Y-48	2.7	20	8	11.6	4.4	3.0	13	46	4.3	1.1	1.7
1U-51	1.9	21	5	11.4	9.8	5.5	7	44	6.1	2.9	5.2
2F-48	8.4	22	31	10.7	2.0	1.5	21	42	1.3	0.2	0.2
3F-36	5.9	23	22	10.4	3.0	1.8	23	41	1.8	0.3	0.5
3J-49	3.6	24	12	10.3	3.2	2.1	13	36	2.9	0.6	0.9
2A-02N	6.8	25	29	9.1	1.7	1.2	20	36	1.3	0.2	0.3
1V-59	9.0	26	38	8.3	2.5	1.8	16	32	0.9	0.2	0.3
3B-44	7.5	27	34	8.2	2.1	1.3	16	31	1.1	0.2	0.3
2A-58	8.4	28	37	8.0	2.0	1.3	20	29	1.0	0.2	0.2
2B-59	6.5	29	32	8.0	1.9	1.2	19	26	1.2	0.2	0.3
2N-54	4.3	30	21	7.6	1.8	1.2	14	25	1.8	0.3	0.4
2G-57	3.7	31	19	7.2	2.9	2.0	8	25	2.0	0.5	0.8
2Y-41	3.5	32	18	6.9	6.0	3.9	6	23	2.0	1.1	1.7
3D-45	6.3	33	35	6.8	2.6	1.6	10	23	1.1	0.3	0.4
2P-54	2.8	34	16	6.3	1.8	1.2	9	20	2.3	0.4	0.6
1T-57	3.5	35	26	5.4	1.9	1.2	10	19	1.6	0.3	0.5
3G-47	4.5	36	36	4.7	1.7	1.3	8	18	1.1	0.3	0.4
2C-45	2.6	37	24	4.3	1.1	0.7	12	18	1.7	0.3	0.4
2C-60	2.3	38	23	3.9	1.0	0.7	9	16	1.7	0.3	0.4
3E-30	3.4	39	43	2.2	0.9	0.6	8	16	0.6	0.2	0.3
2C-02N	1.7	40	39	1.5	1.5	0.9	2	7	0.9	0.5	0.8
3F-48	1.5	41	41	1.2	0.6	0.4	3	7	0.8	0.3	0.4
2L-52	1.0	42	33	1.1	0.8	0.5	2	6	1.1	0.5	0.8
3E-48	2.1	43	44	0.8	1.0	0.5	1	3	0.4	0.3	0.5
2C-48	0.8	44	42	0.6	0.2	0.2	2	2	0.7	0.2	0.3

Appendix II: Methane Emissions Maps on GSMP II Grids

In the following pages, methane heat maps are shown for each of the 44 grids along with summary information for each grid. Figure 5 shows these grids on a map.

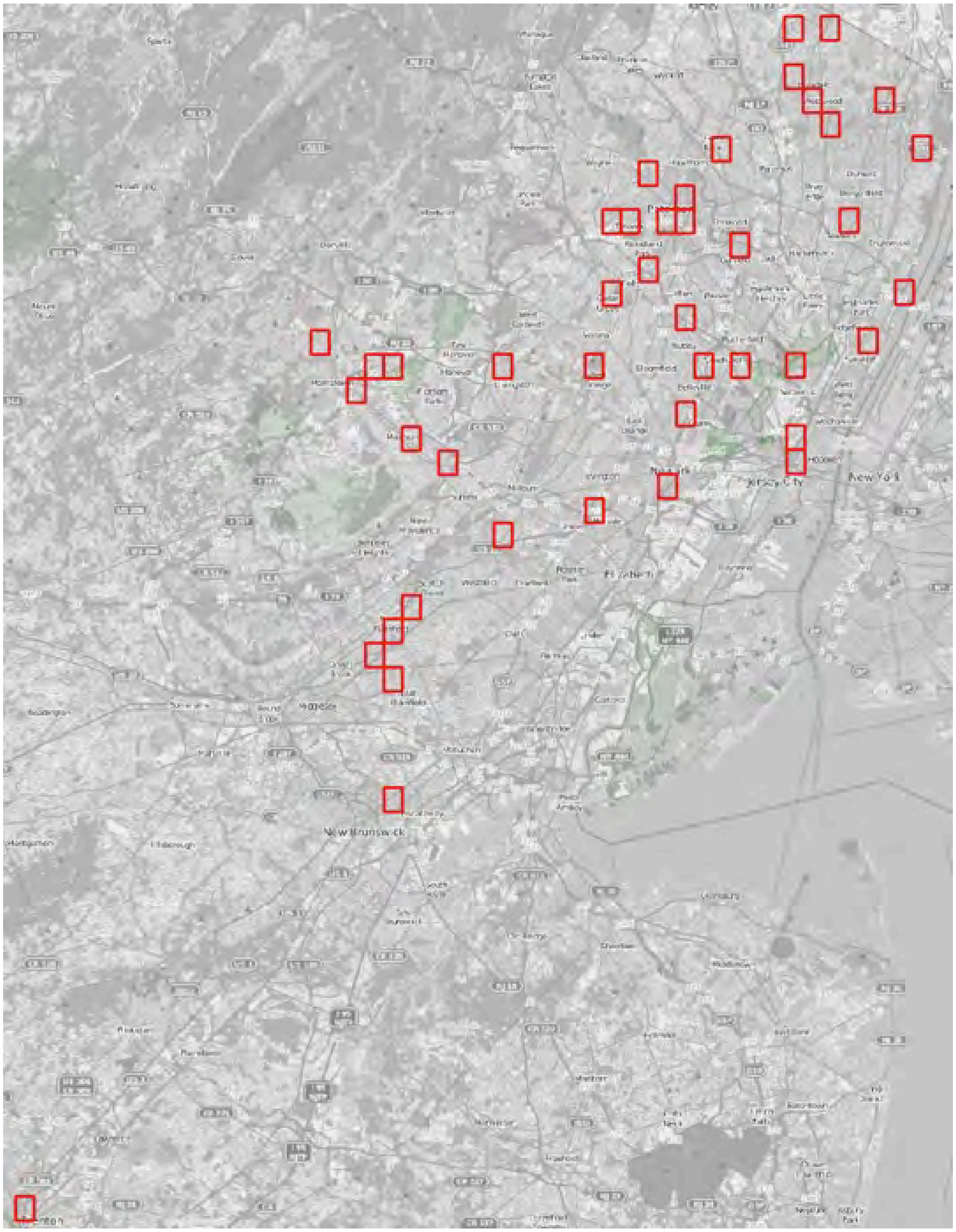
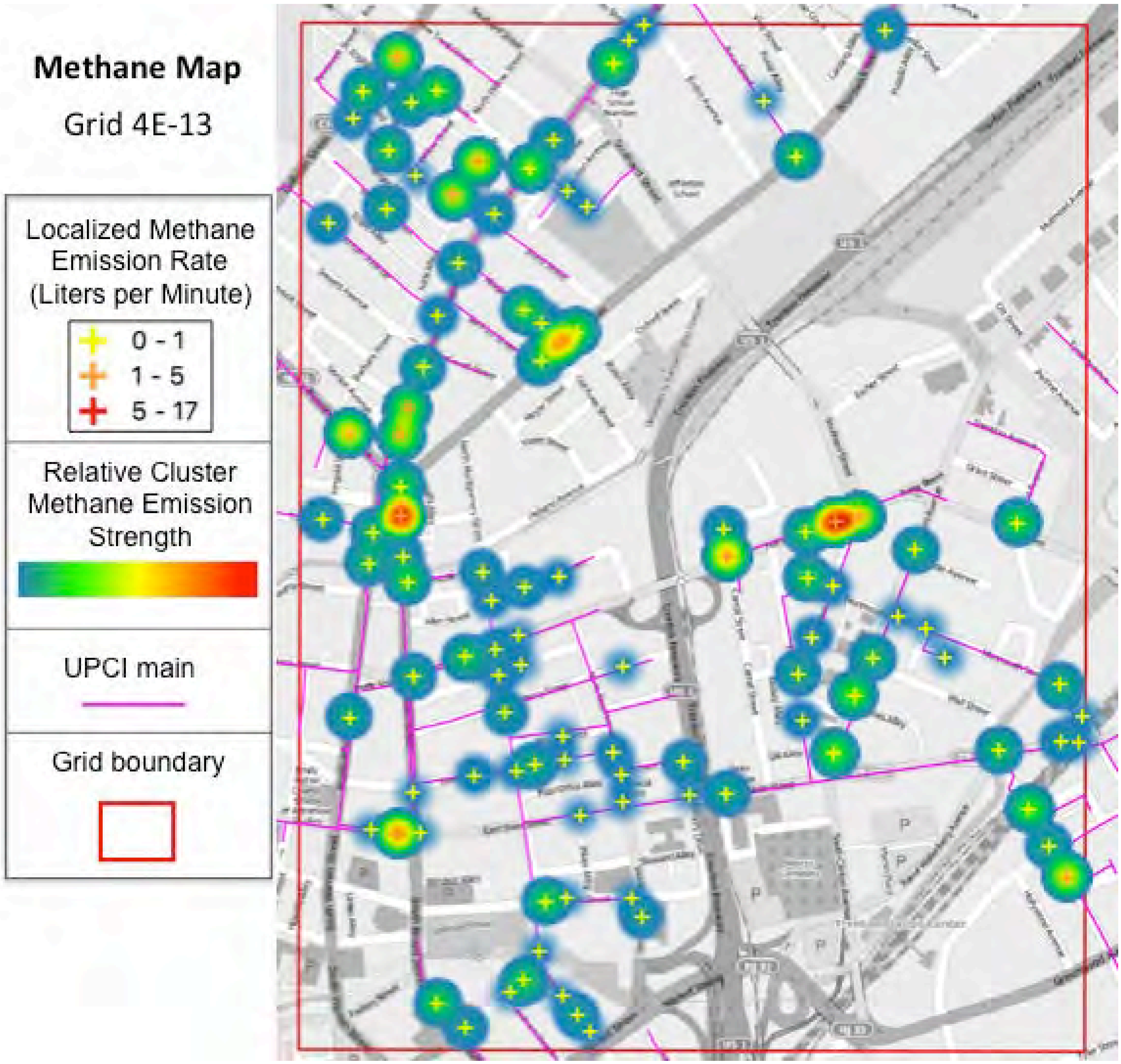
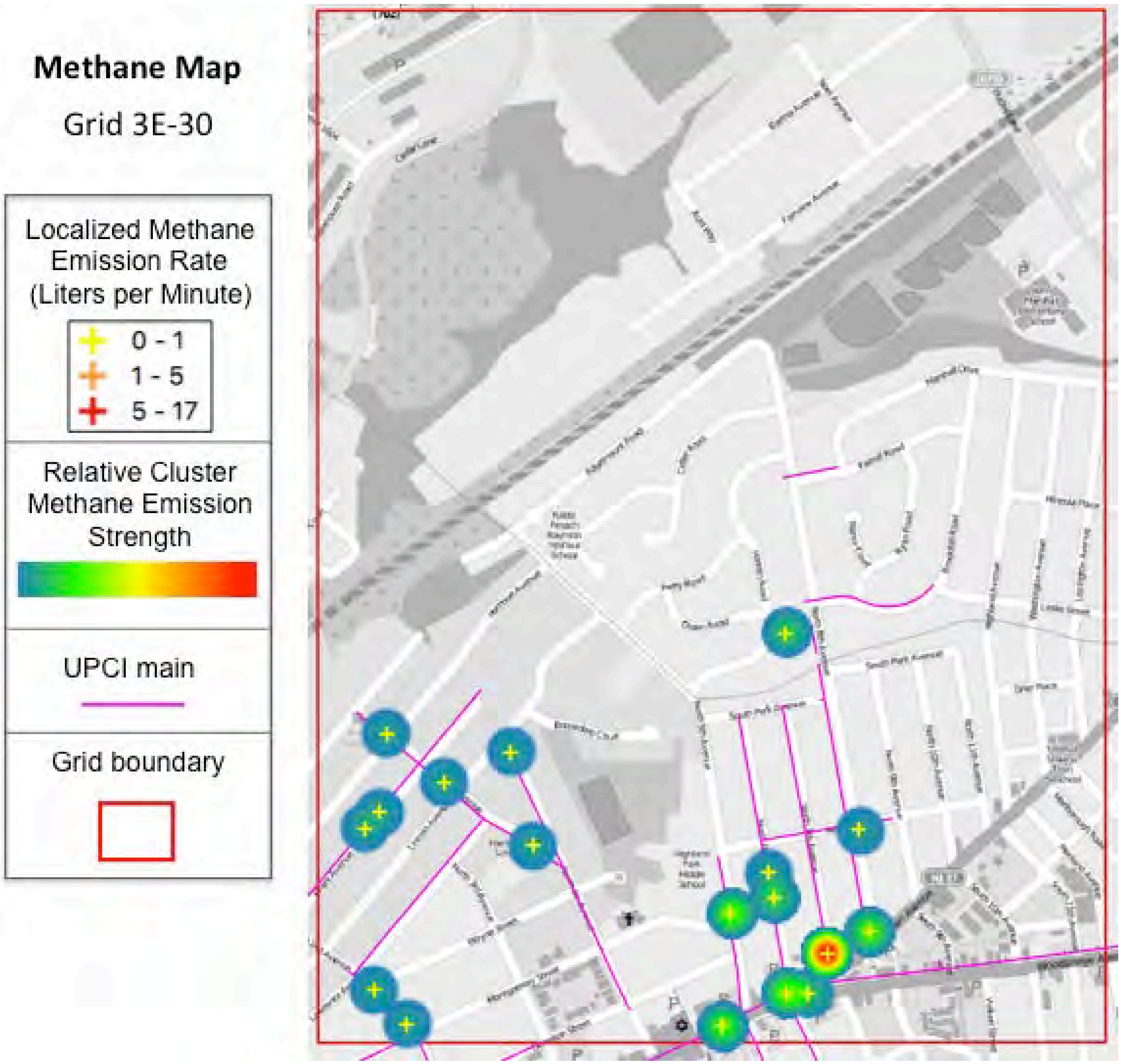


Figure 5. Relative locations of the 44 grids.


Methane Map
Grid 4E-13
Localized Methane Emission Rate (Liters per Minute)
0 - 1
1 - 5
5 - 17
Relative Cluster Methane Emission Strength
UPCI main
Grid boundary


Methane Map
Grid 3E-30
Localized Methane Emission Rate (Liters per Minute)
0 - 1
1 - 5
5 - 17
Relative Cluster Methane Emission Strength
UPCI main
Grid boundary

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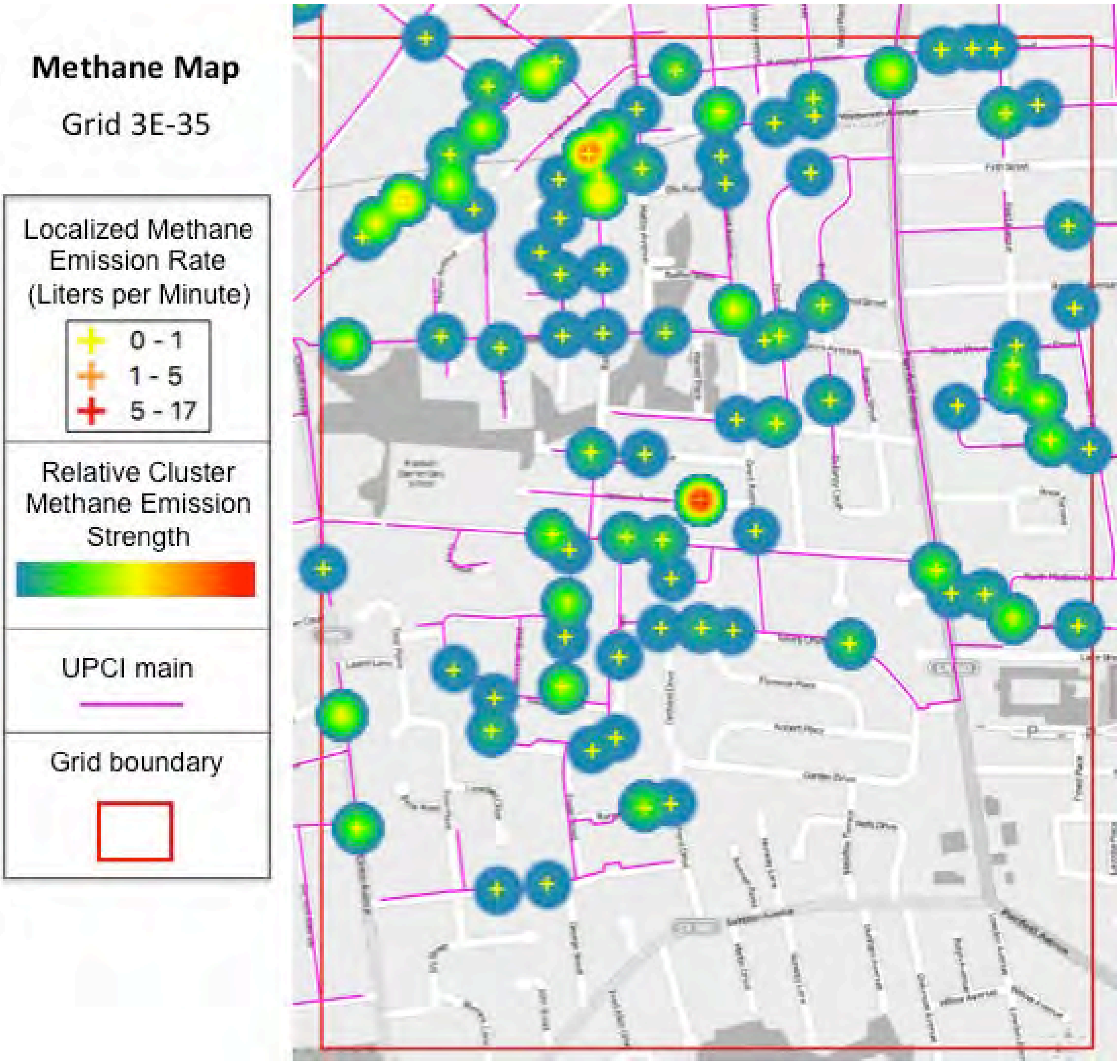
Methane Map

Grid 3E-35



ATTACHMENT D

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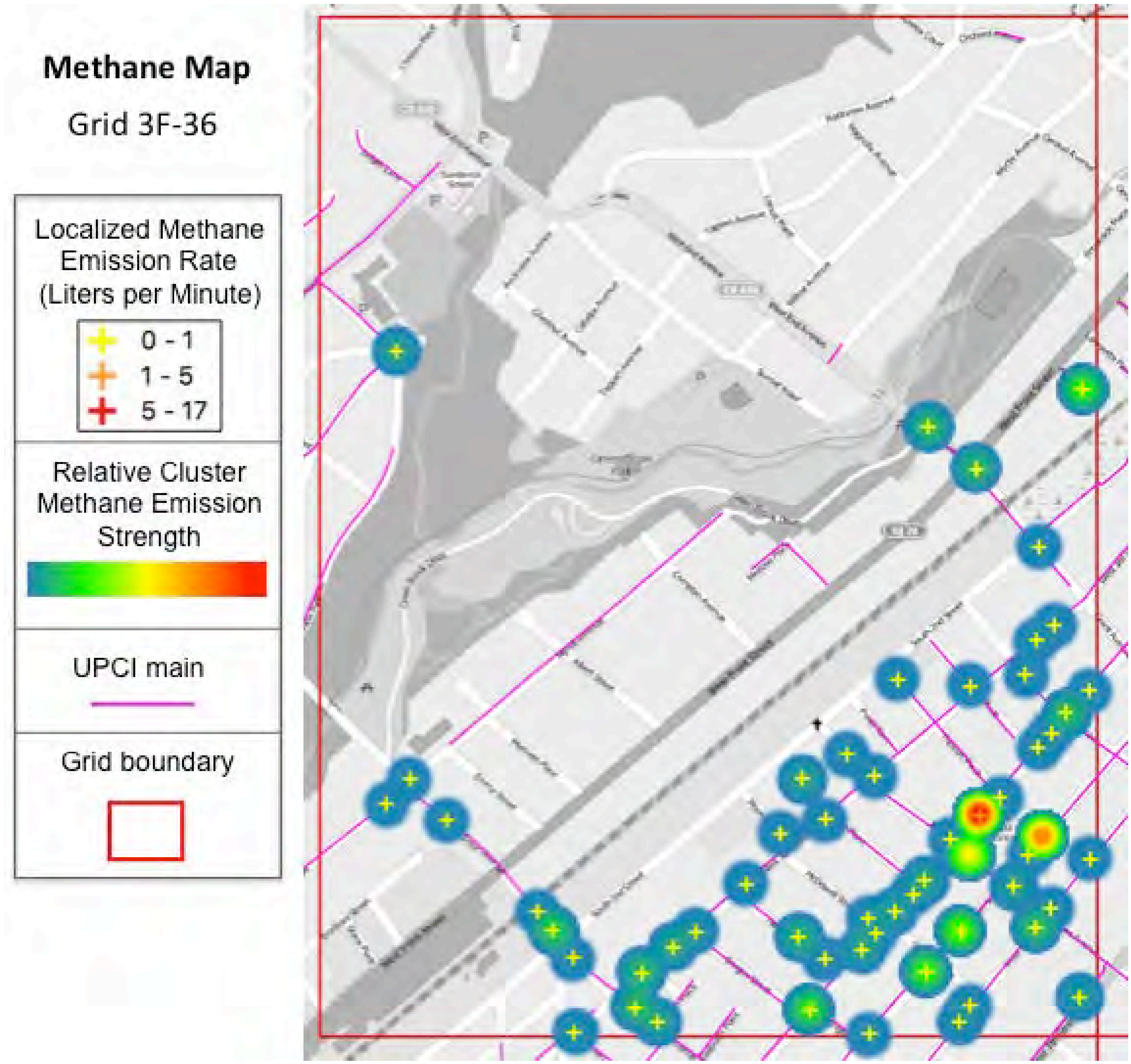

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Methane Map

Grid 3E-37

Localized Methane Emission Rate (Liters per Minute)

0 - 1
1 - 5
5 - 17

Relative Cluster Methane Emission Strength

UPCI main

Grid boundary

PICARRO

Methane Map

Grid 3D-38

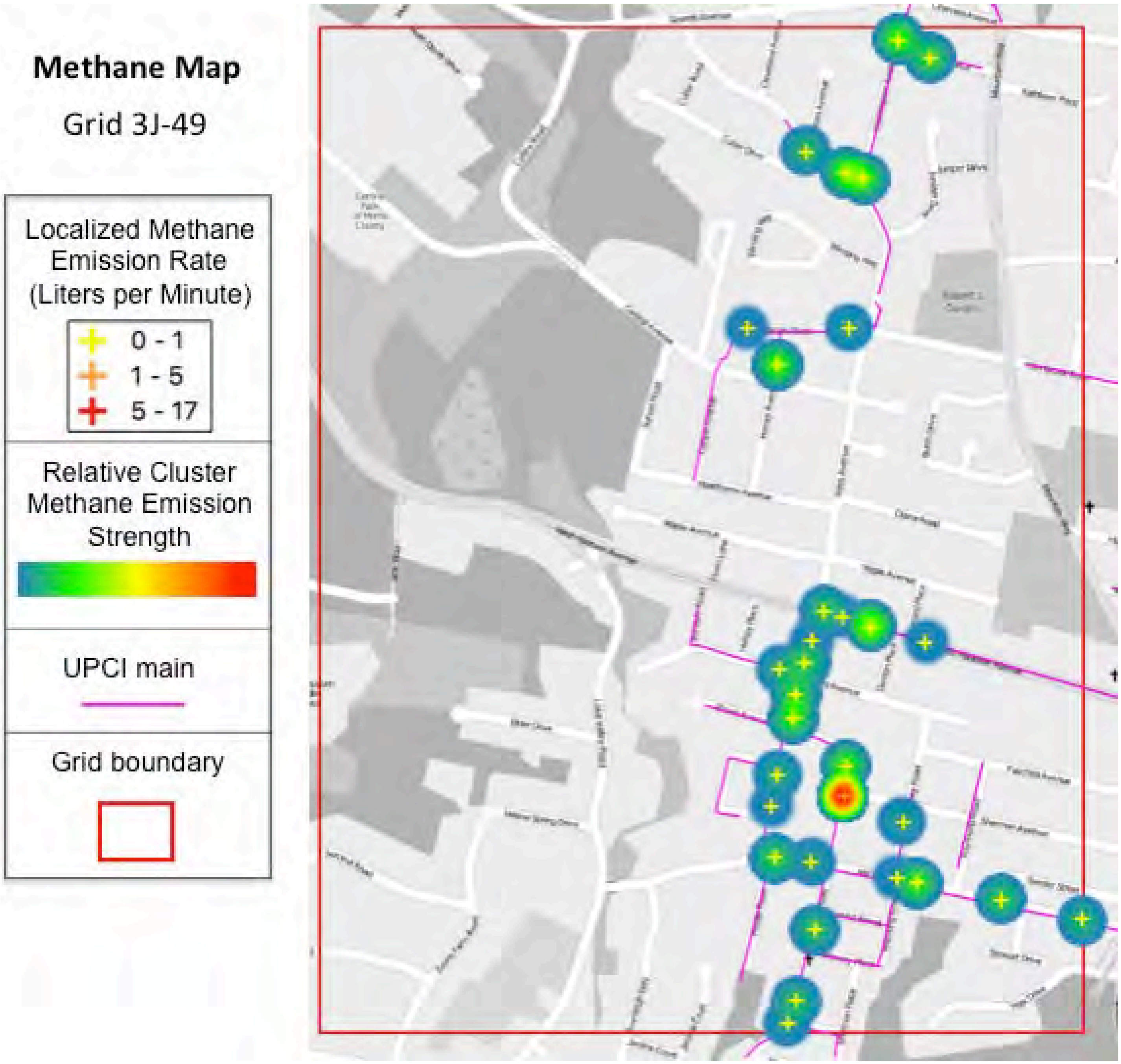
Localized Methane Emission Rate (Liters per Minute)

- 0 - 1
- 1 - 5
- 5 - 17

Relative Cluster Methane Emission Strength

UPCI main

Grid boundary


Methane Map
Grid 3J-49
Localized Methane Emission Rate (Liters per Minute)
0 - 1
1 - 5
5 - 17
Relative Cluster Methane Emission Strength
UPCI main
Grid boundary

PICARRO

Methane Map

Grid 3G-47

Localized Methane Emission Rate (Liters per Minute)

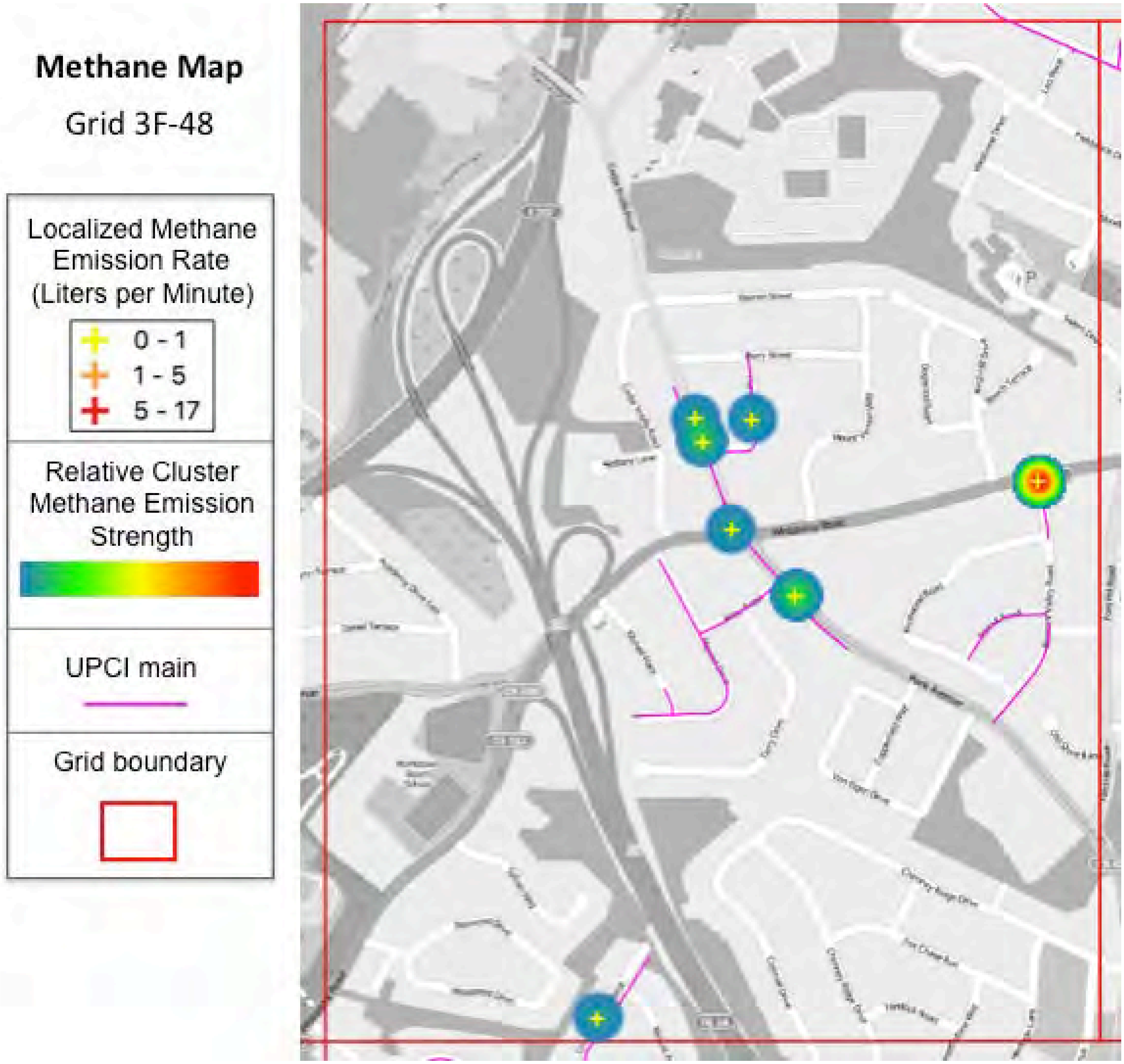
- 0 - 1
- 1 - 5
- 5 - 17

Relative Cluster Methane Emission Strength

UPCI main

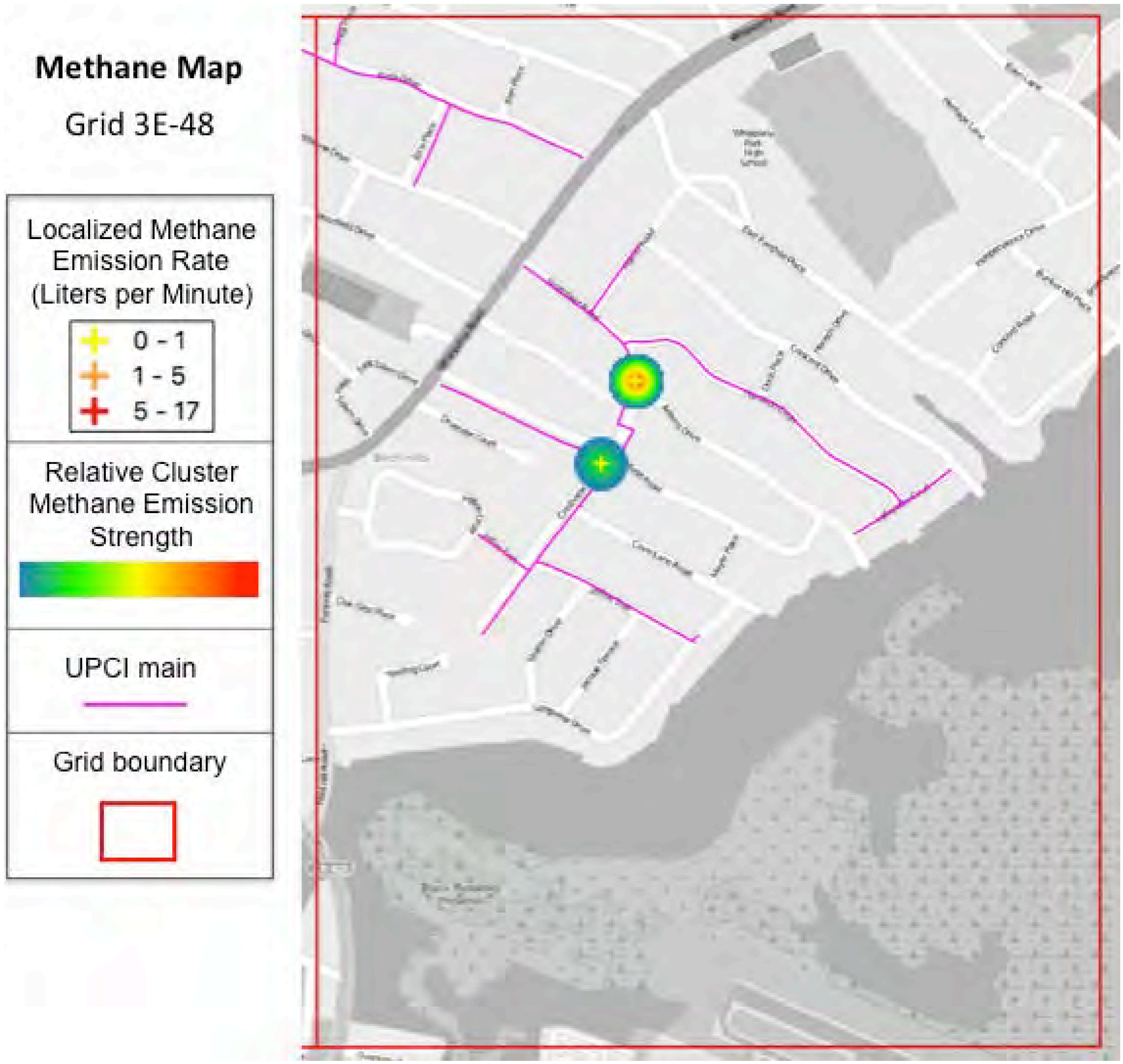
Grid boundary

PICARRO


Methane Map
Grid 3F-48
Localized Methane Emission Rate (Liters per Minute)
0 - 1
1 - 5
5 - 17
Relative Cluster Methane Emission Strength
UPCI main
Grid boundary

ATTACHMENT D

PICARRO



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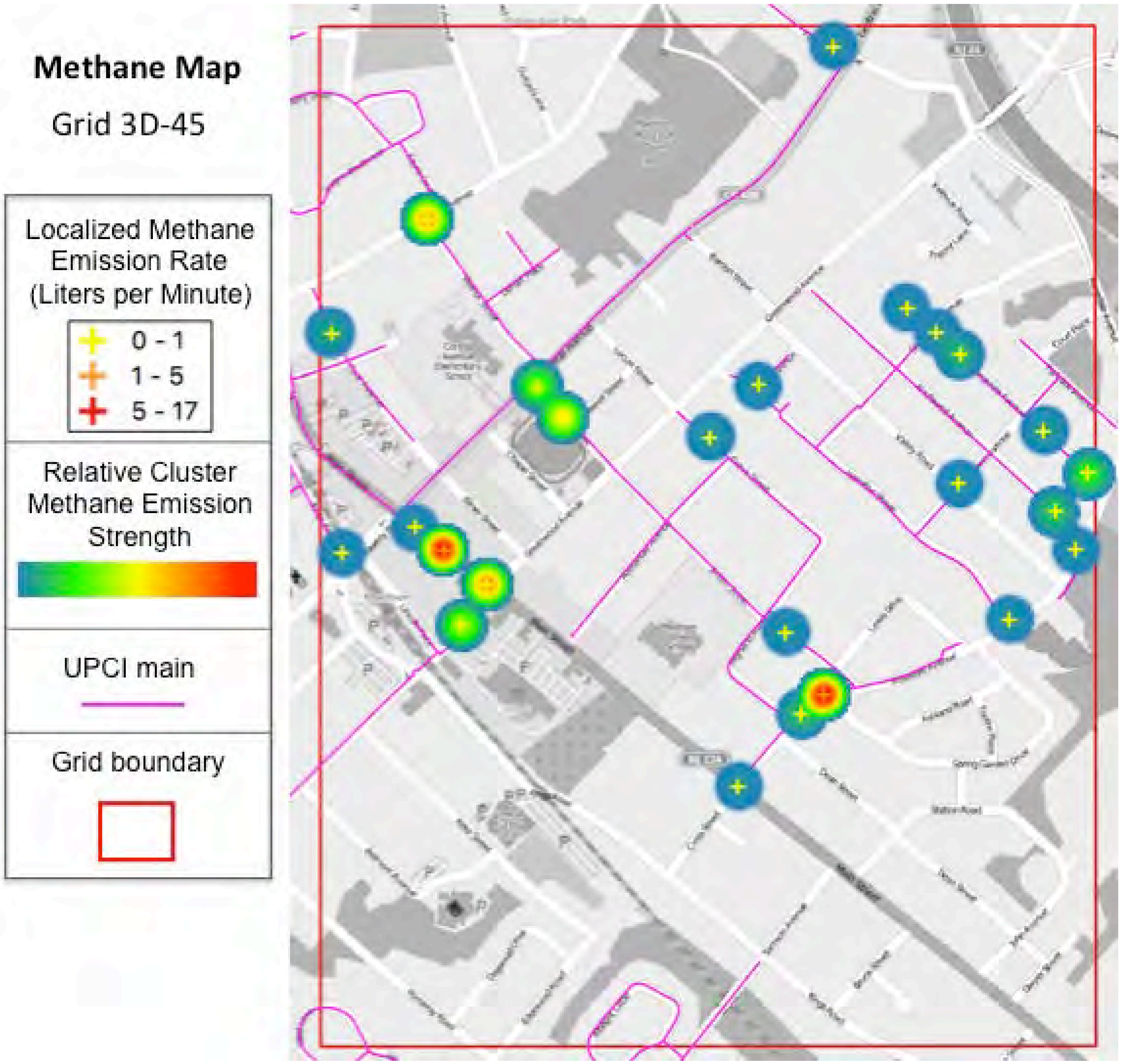
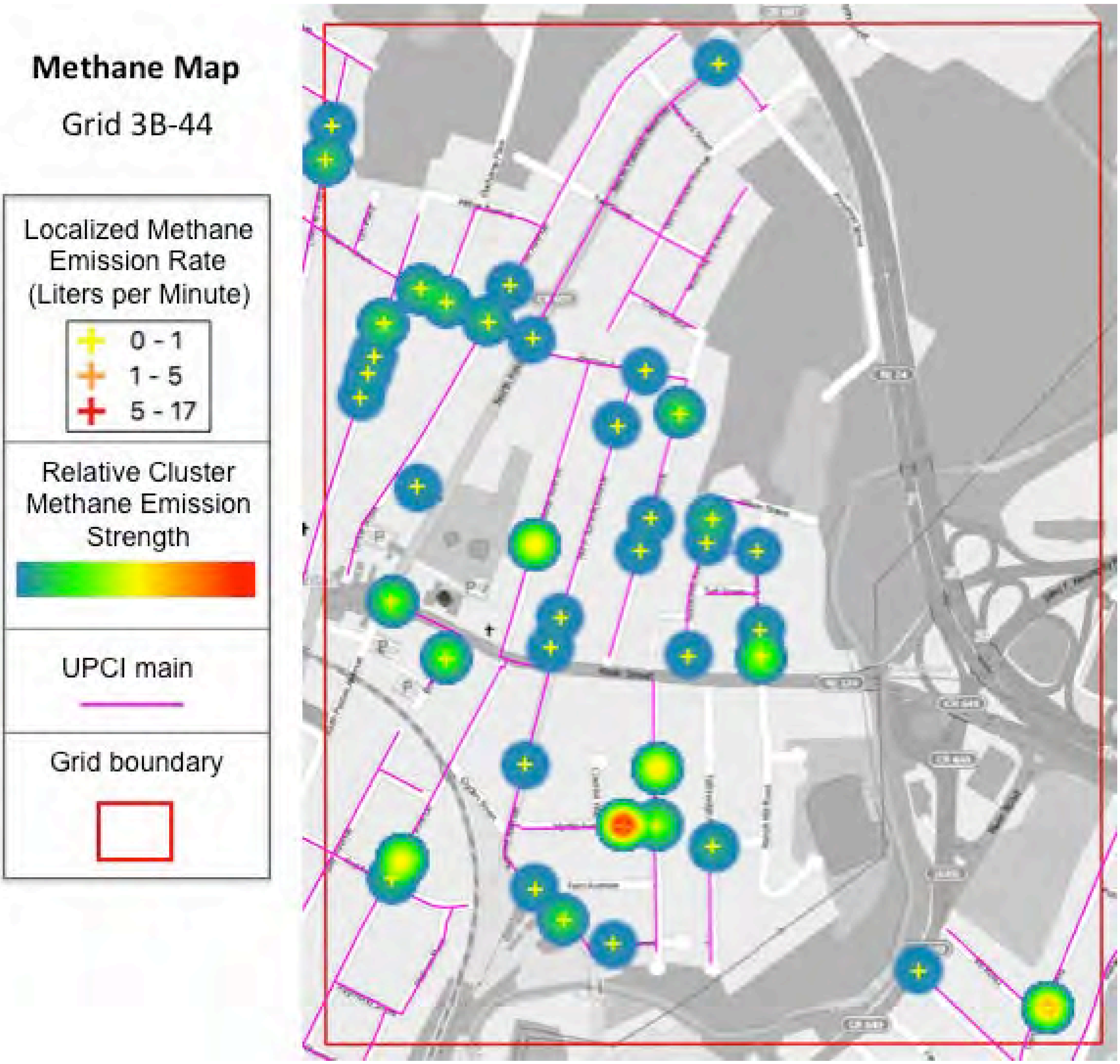

Methane Map
Grid 3D-45
Localized Methane Emission Rate (Liters per Minute)
0 - 1
1 - 5
5 - 17
Relative Cluster Methane Emission Strength
UPCI main
Grid boundary

ATTACHMENT D

PICARRO



Methane Map

Grid 2Y-41

Localized Methane Emission Rate (Liters per Minute)

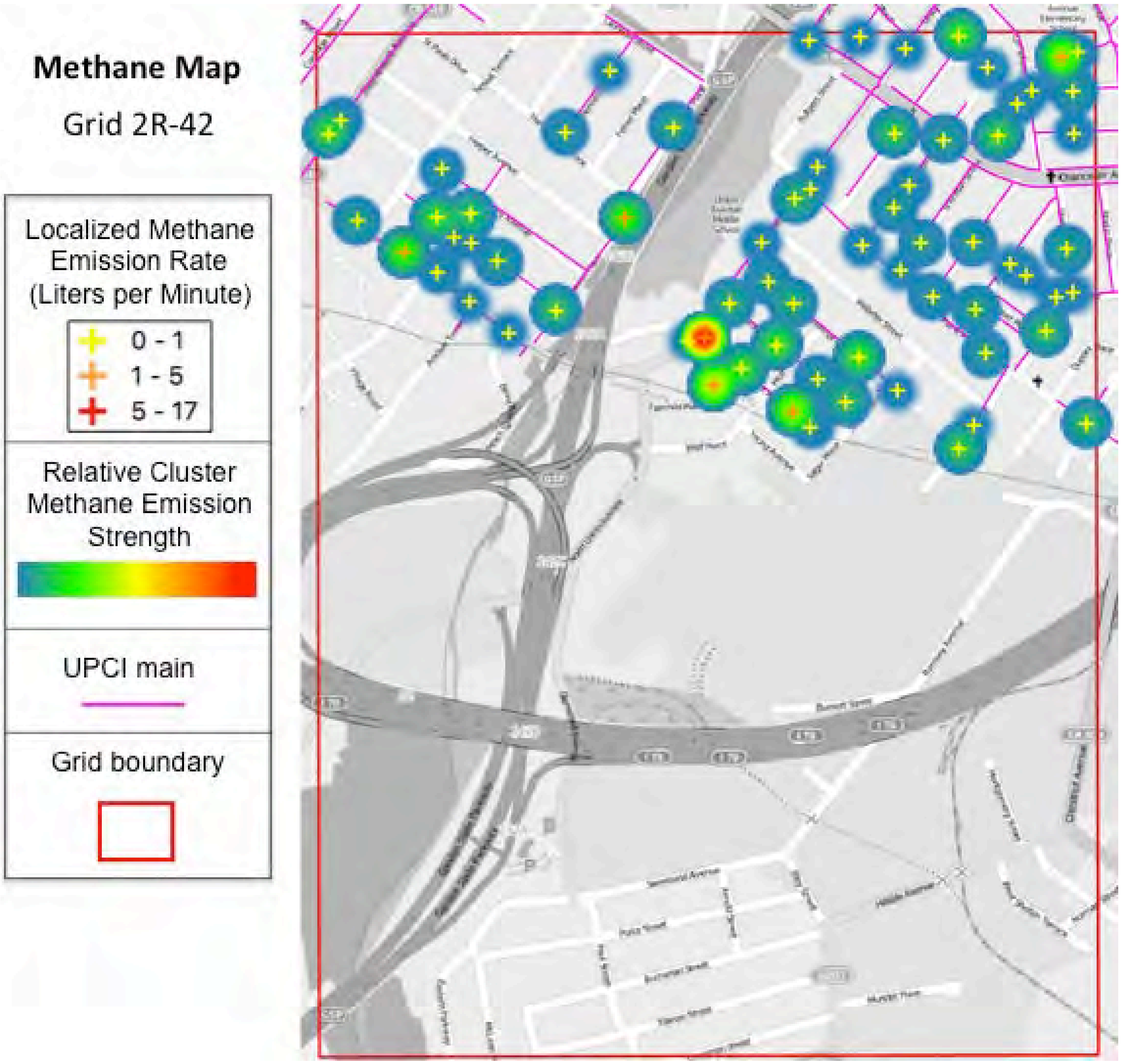
- 0 - 1
- 1 - 5
- 5 - 17

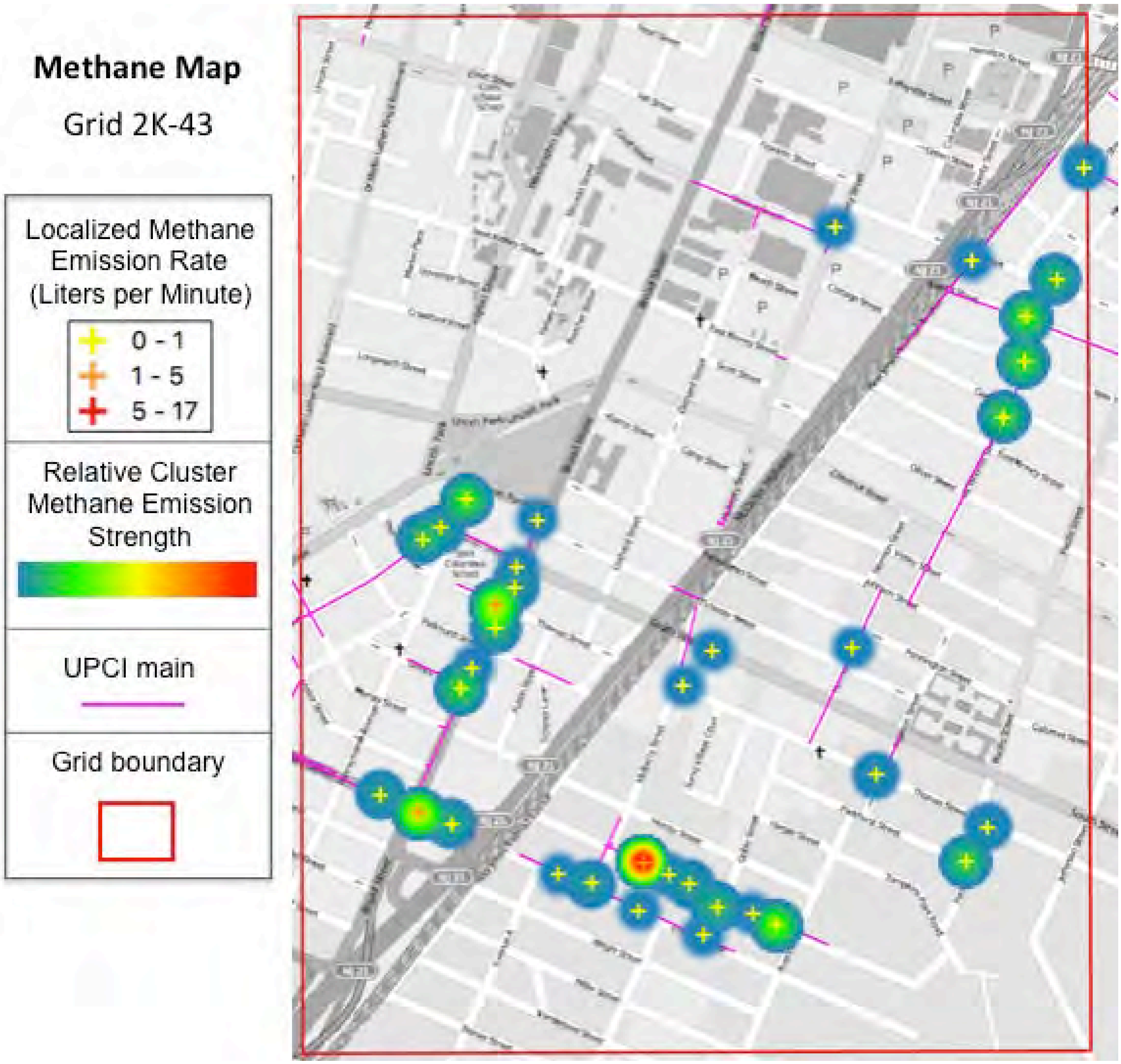
Relative Cluster Methane Emission Strength

UPCI main

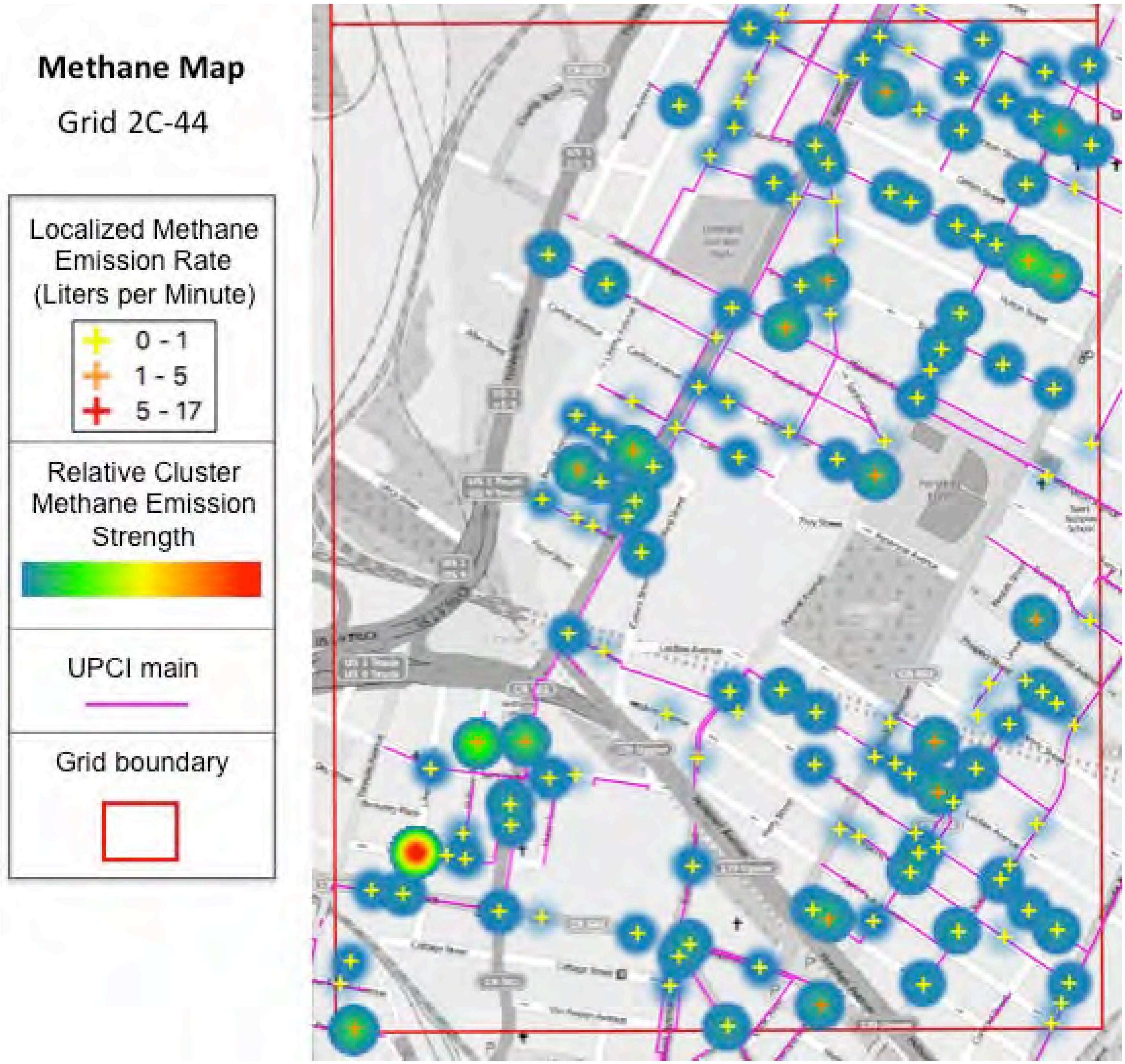
Grid boundary

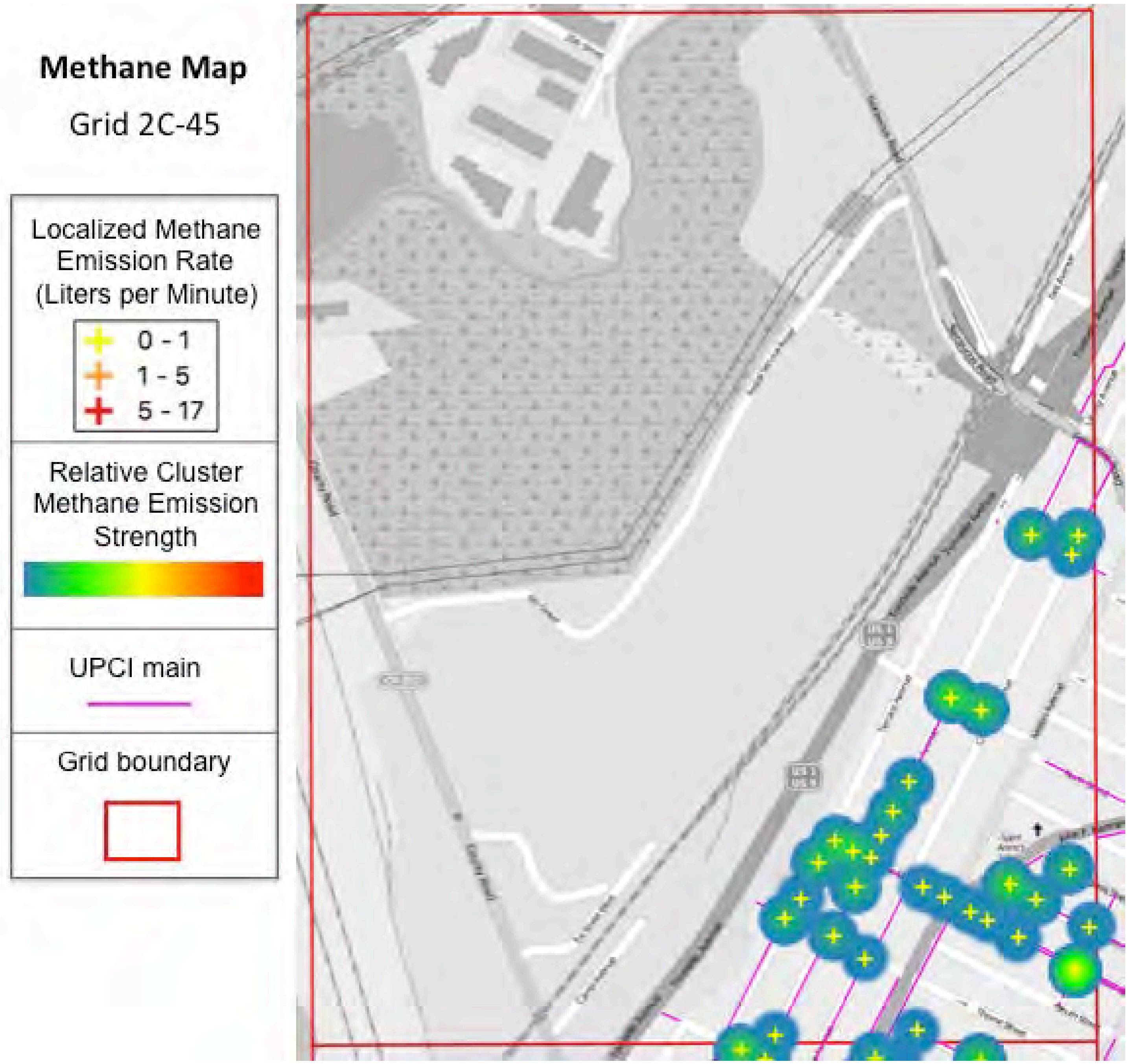
PICARRO


Methane Map
Grid 2R-42
Localized Methane Emission Rate (Liters per Minute)
0 - 1
1 - 5
5 - 17
Relative Cluster Methane Emission Strength
UPCI main
Grid boundary


Methane Map
Grid 2K-43
Localized Methane Emission Rate (Liters per Minute)
0 - 1
1 - 5
5 - 17
Relative Cluster Methane Emission Strength
UPCI main
Grid boundary

PICARRO


Methane Map
Grid 2C-44
Localized Methane Emission Rate (Liters per Minute)
0 - 1
1 - 5
5 - 17
Relative Cluster Methane Emission Strength
UPCI main
Grid boundary


Methane Map
Grid 2C-45
Localized Methane Emission Rate (Liters per Minute)
0 - 1
1 - 5
5 - 17
Relative Cluster Methane Emission Strength
UPCI main
Grid boundary

PICARRO

Methane Map

Grid 2Y-48

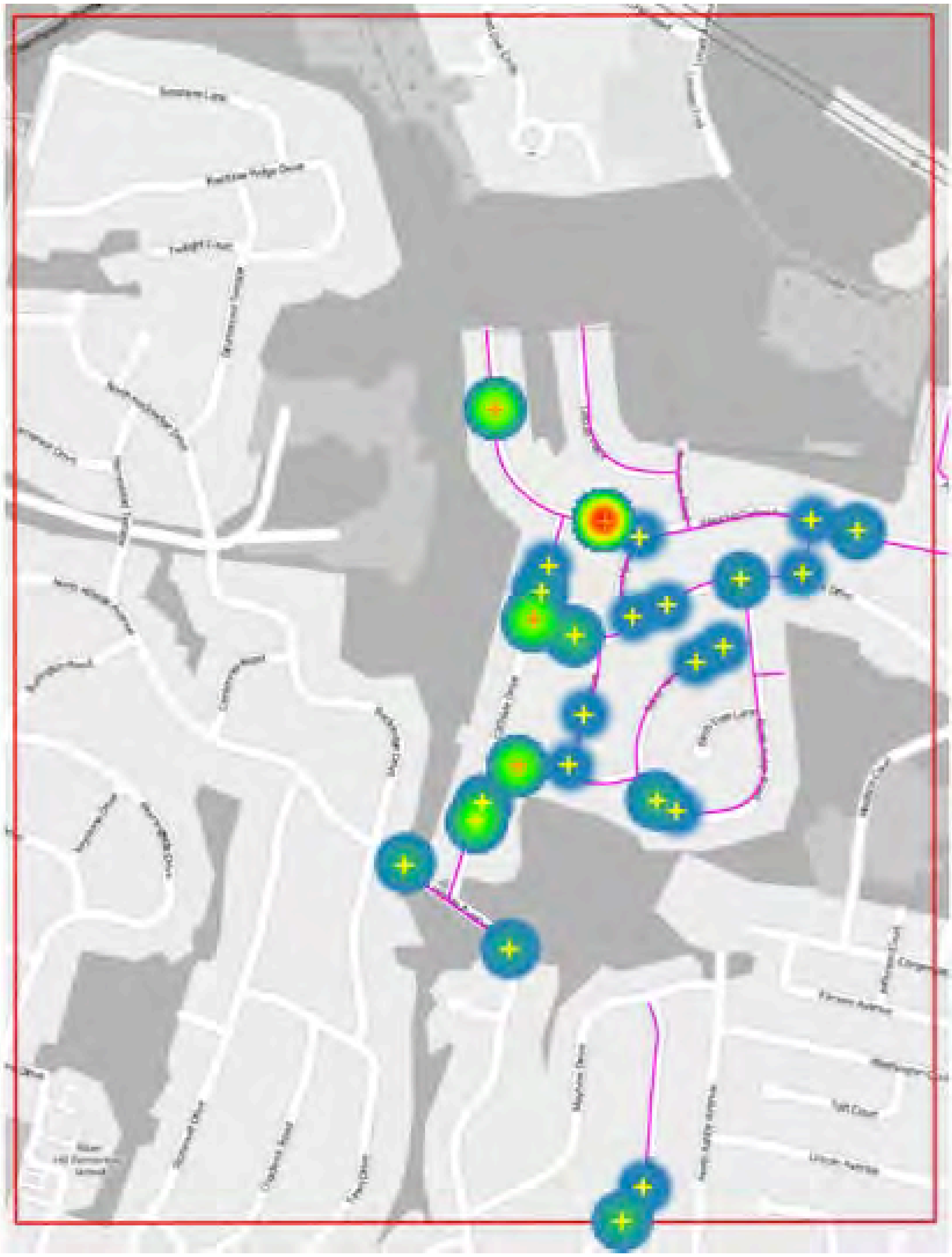
Localized Methane Emission Rate (Liters per Minute)

- 0 - 1
- 1 - 5
- 5 - 17

Relative Cluster Methane Emission Strength

UPCI main

Grid boundary



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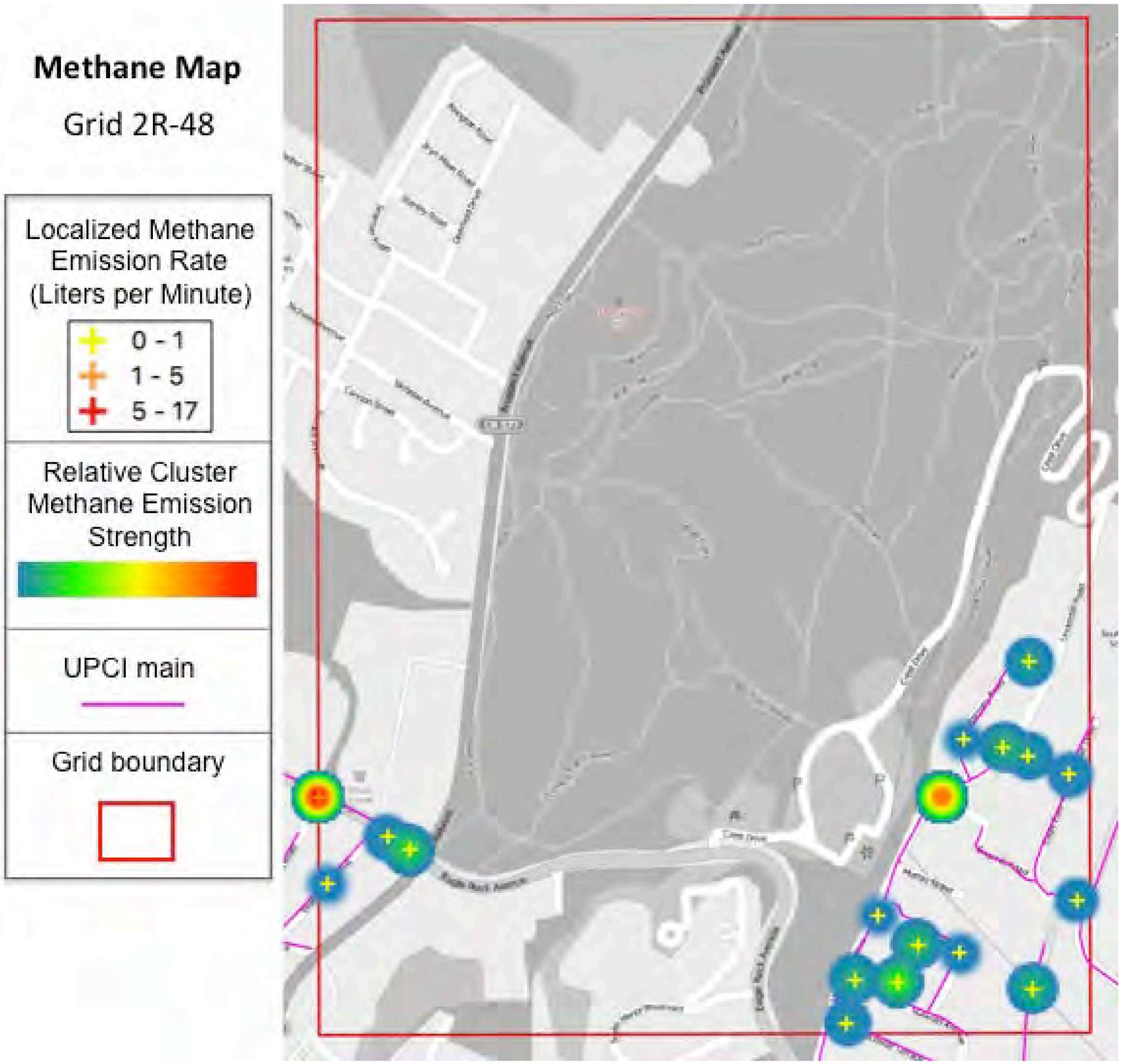
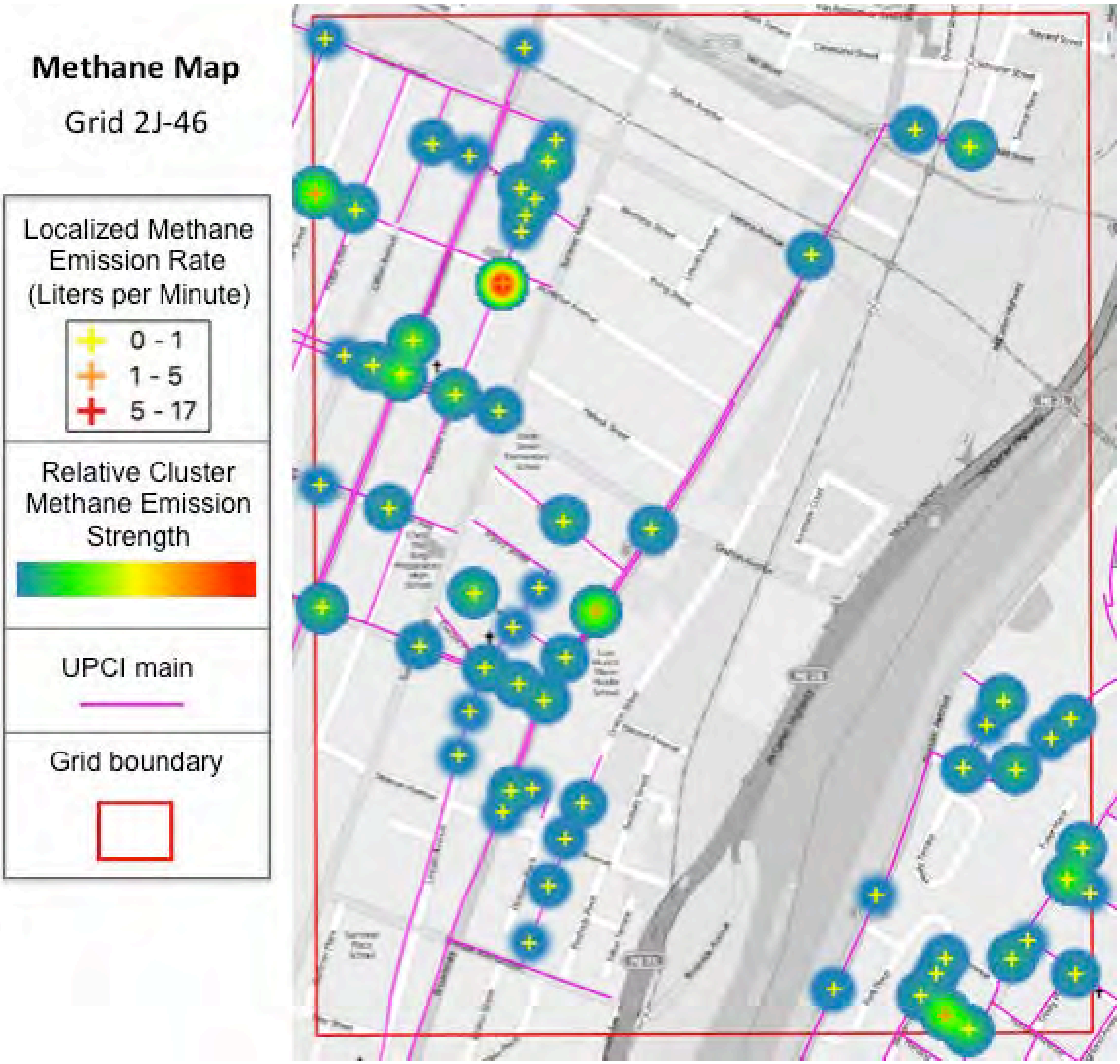

Methane Map
Grid 2R-48
Localized Methane Emission Rate (Liters per Minute)
0 - 1
1 - 5
5 - 17
Relative Cluster Methane Emission Strength
UPCI main
Grid boundary

PICARRO


Methane Map
Grid 2J-46
Localized Methane Emission Rate (Liters per Minute)
0 - 1
1 - 5
5 - 17
Relative Cluster Methane Emission Strength
UPCI main
Grid boundary

Methane Map

Grid 2C-48

Localized Methane Emission Rate (Liters per Minute)

- 0 - 1
- 1 - 5
- 5 - 17

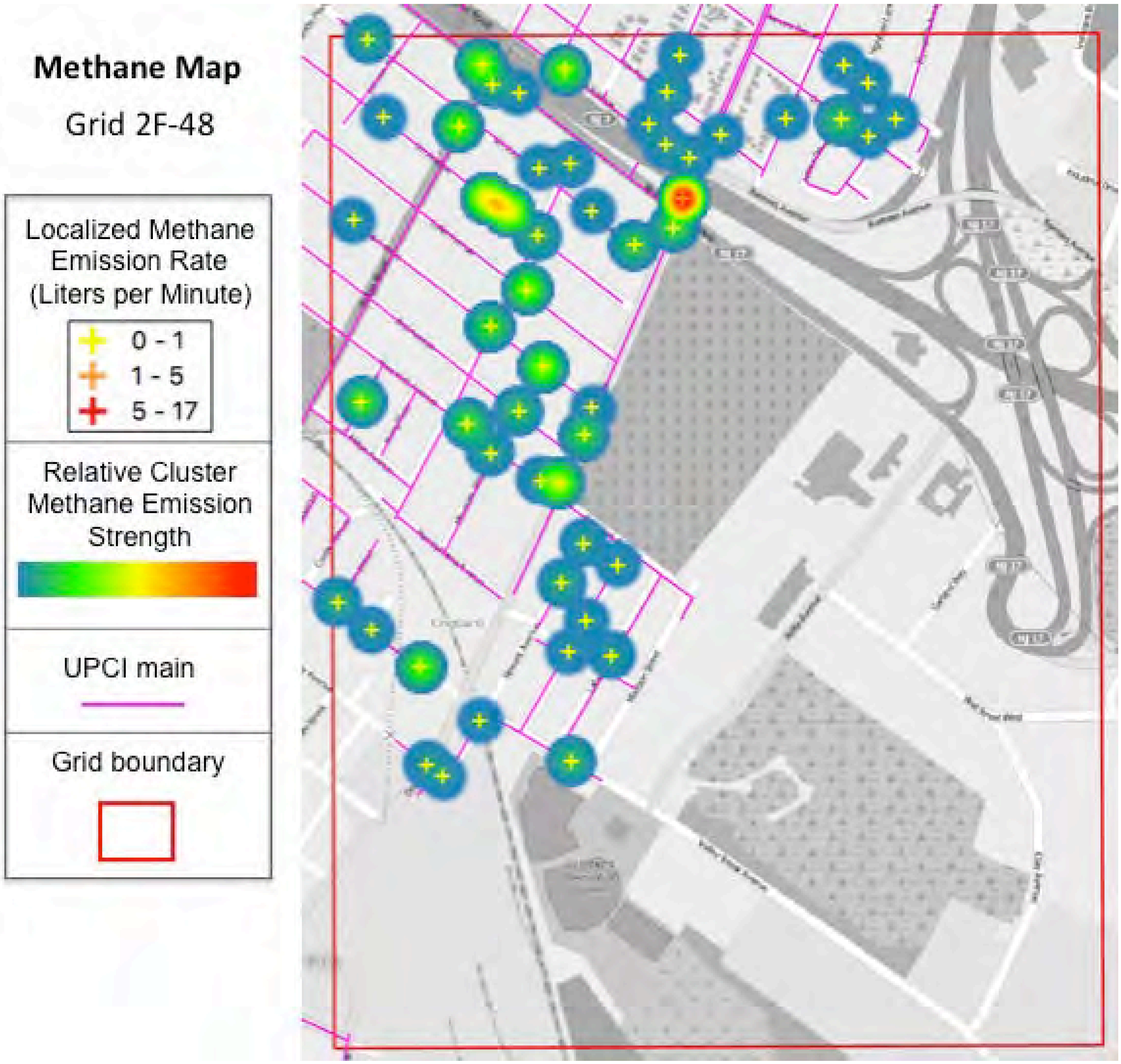
Relative Cluster Methane Emission Strength

UPCI main

Grid boundary

ATTACHMENT D

PICARRO



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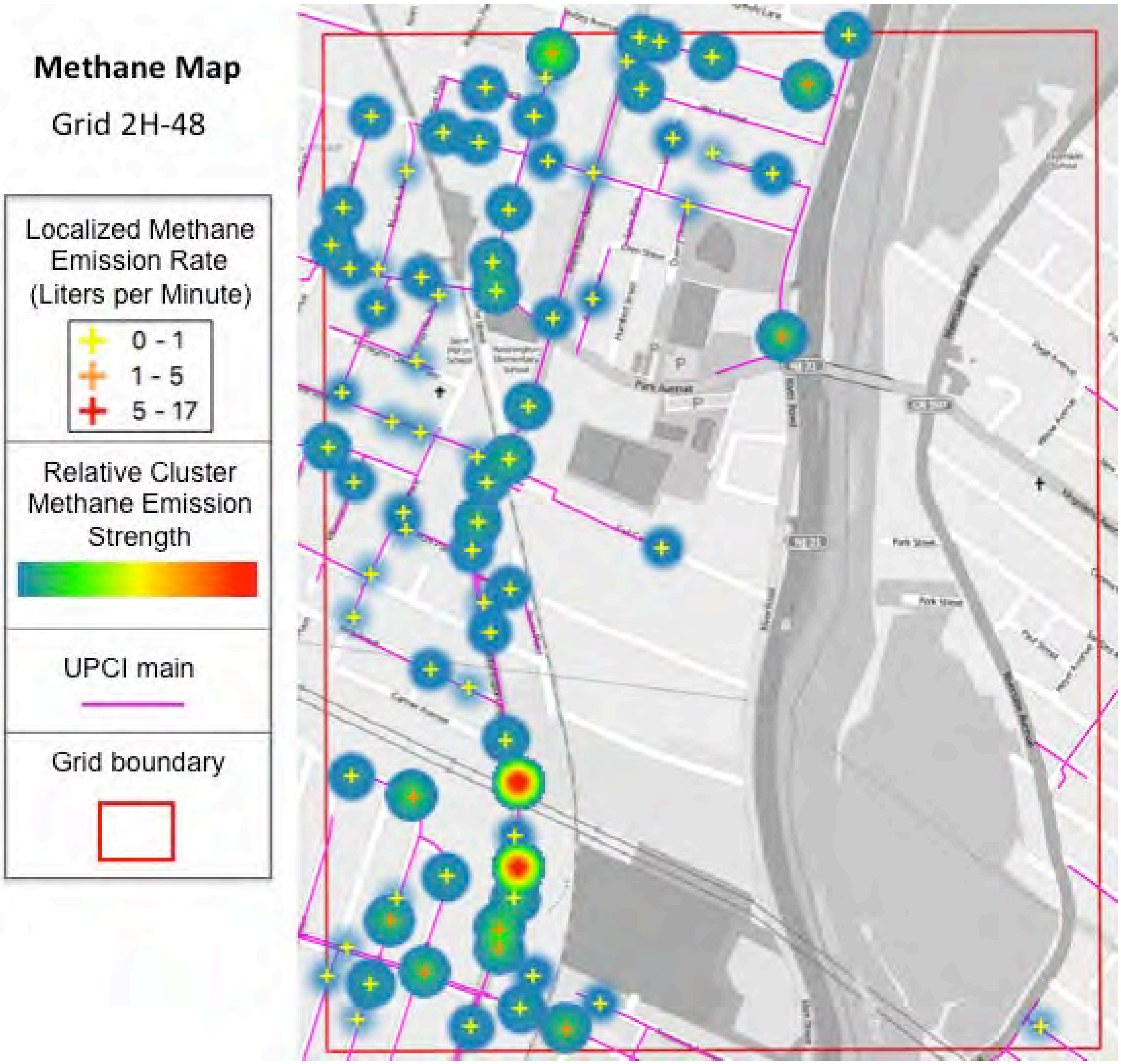
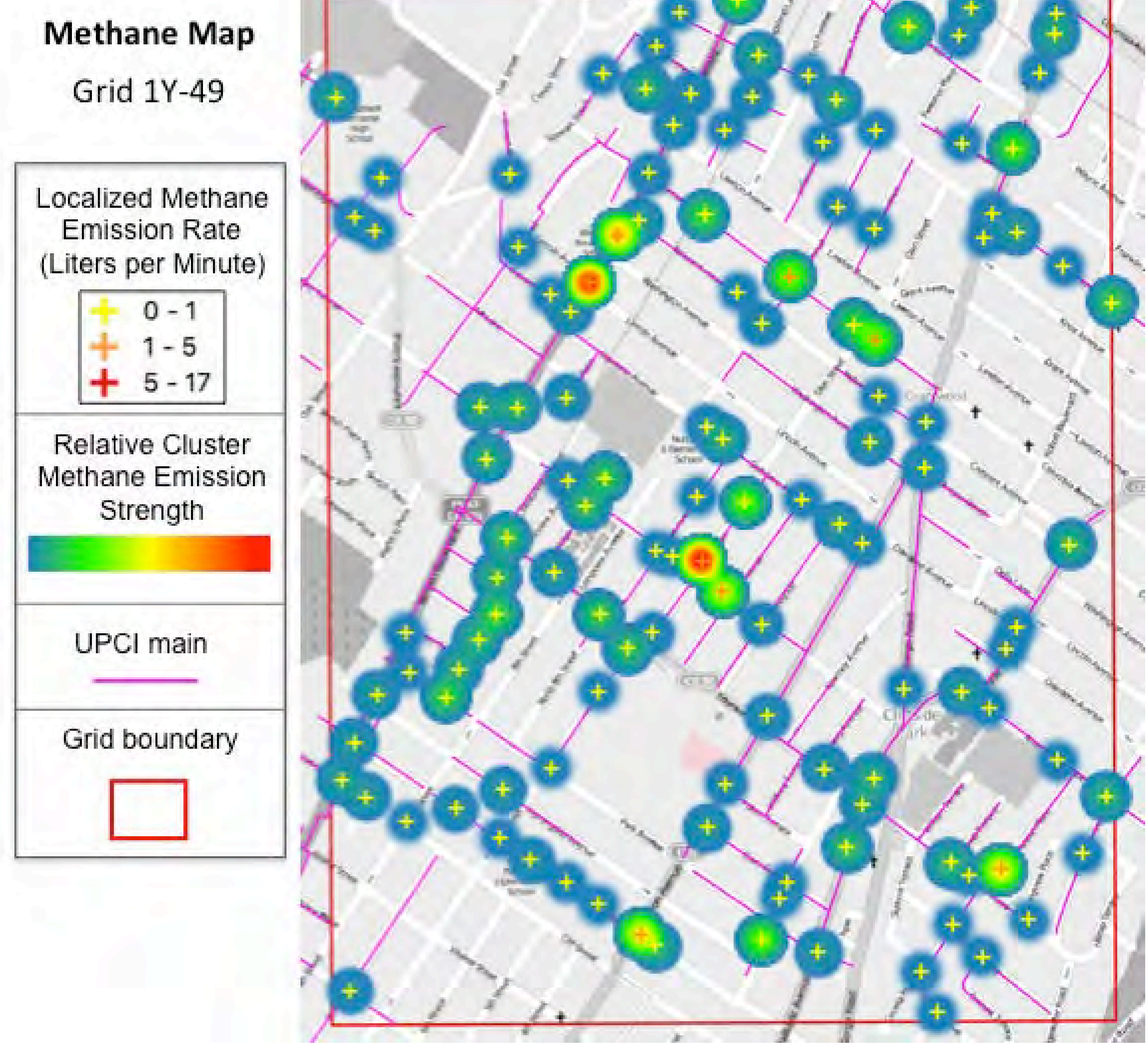
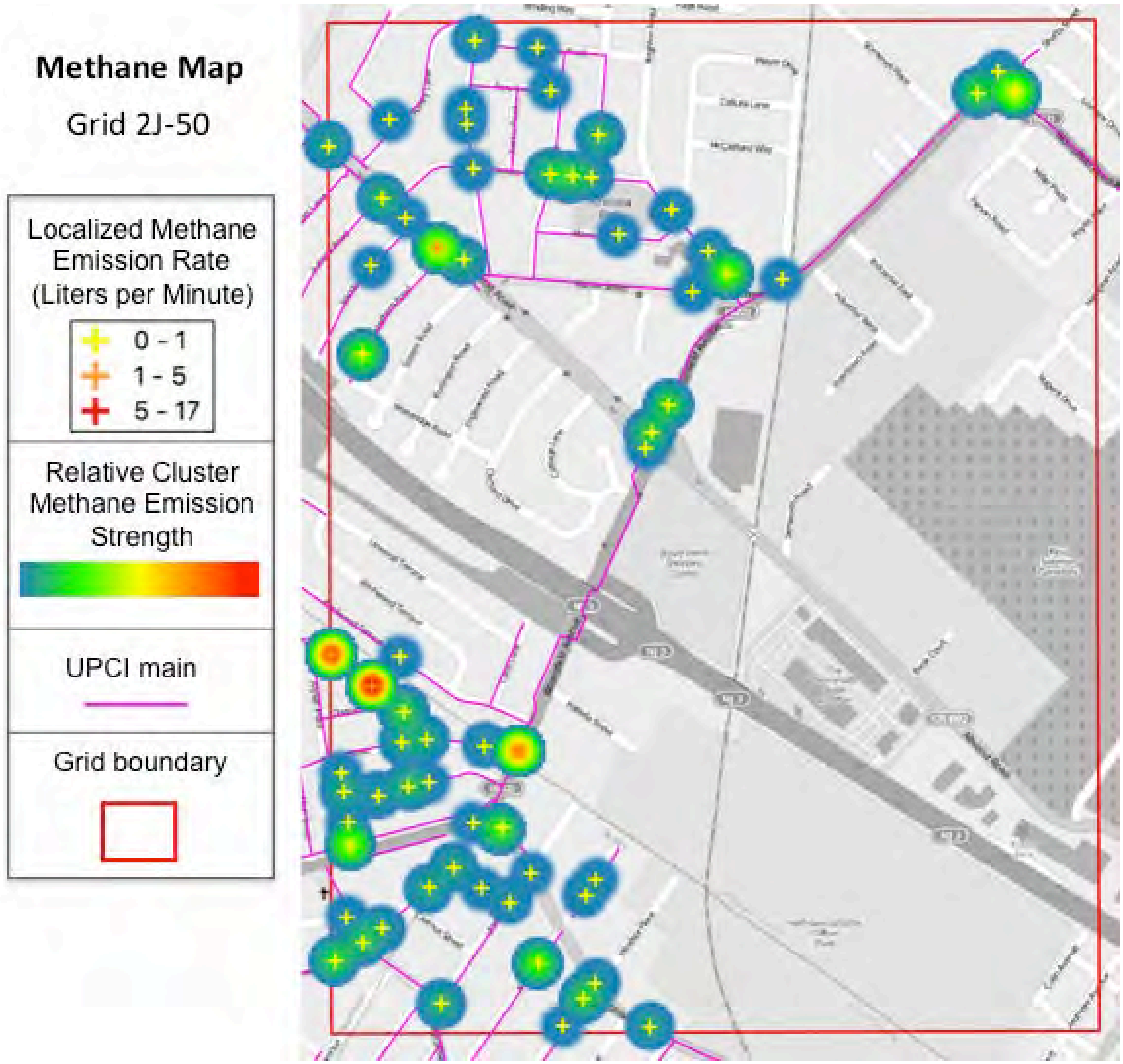
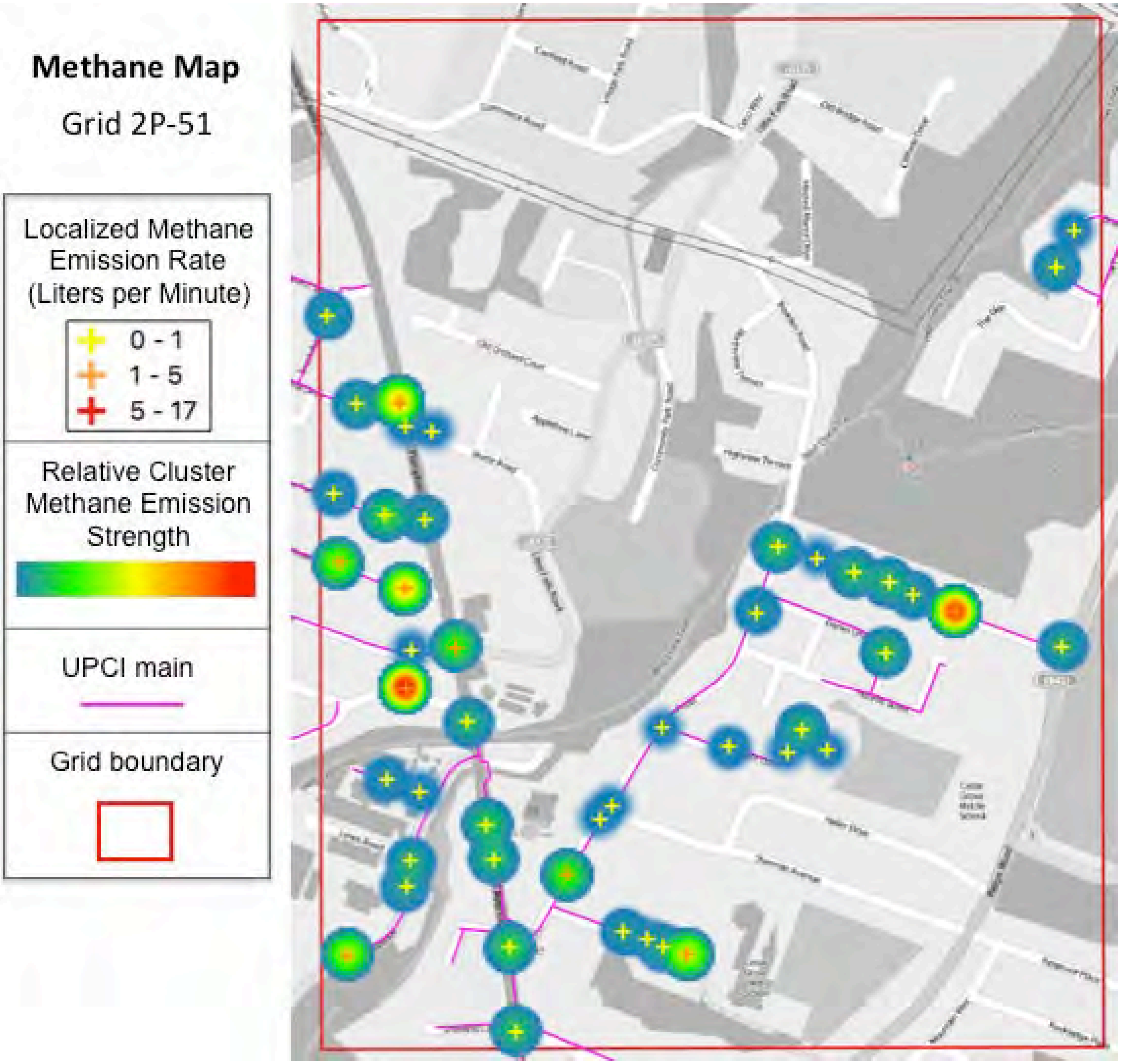

Methane Map
Grid 2H-48
Localized Methane Emission Rate (Liters per Minute)
0 - 1
1 - 5
5 - 17
Relative Cluster Methane Emission Strength
UPCI main
Grid boundary


Methane Map
Grid 1Y-49
Localized Methane Emission Rate (Liters per Minute)
0 - 1
1 - 5
5 - 17
Relative Cluster Methane Emission Strength
UPCI main
Grid boundary

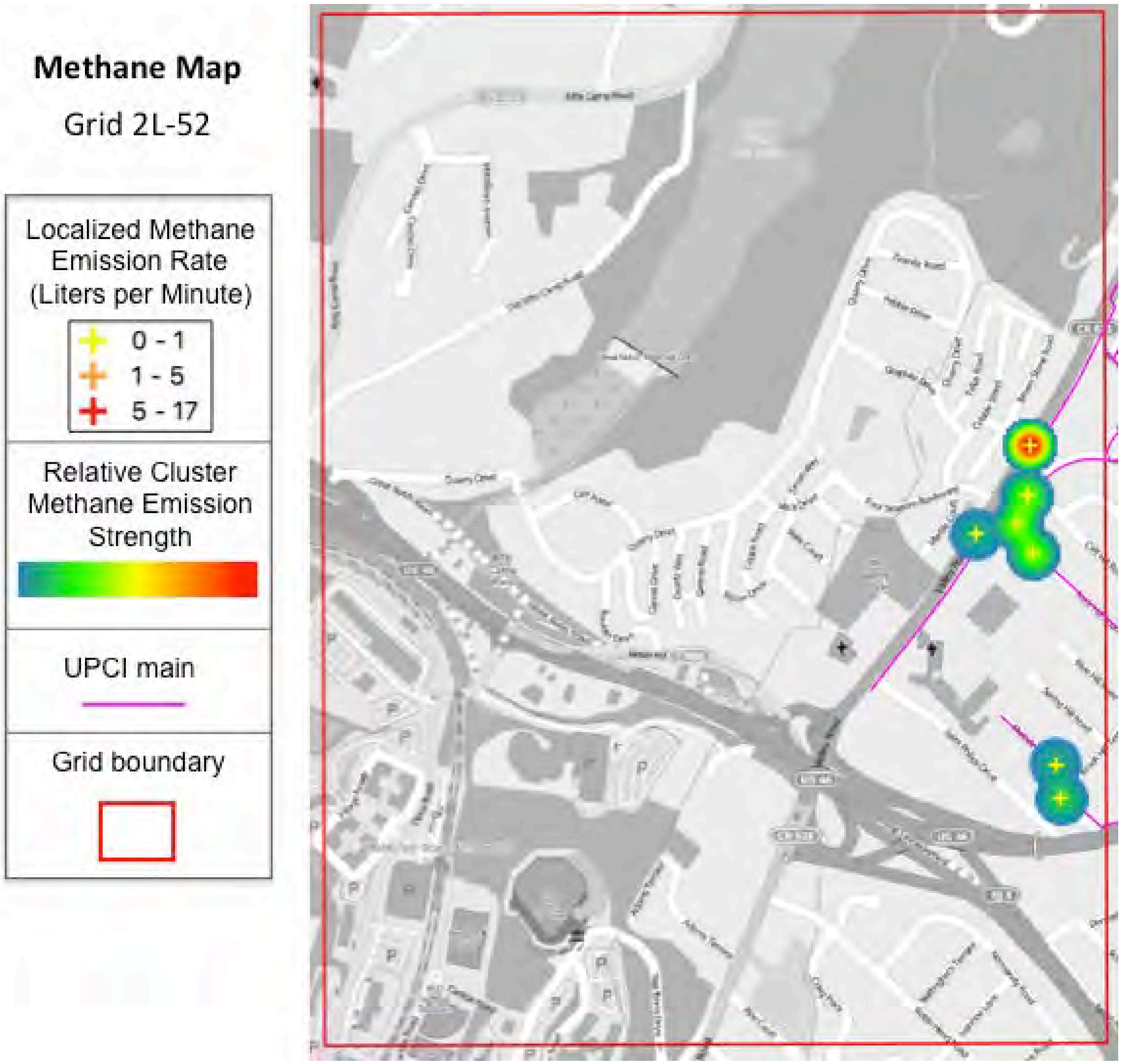
PICARRO


Methane Map
Grid 2J-50
Localized Methane Emission Rate (Liters per Minute)
0 - 1
1 - 5
5 - 17
Relative Cluster Methane Emission Strength
UPCI main
Grid boundary

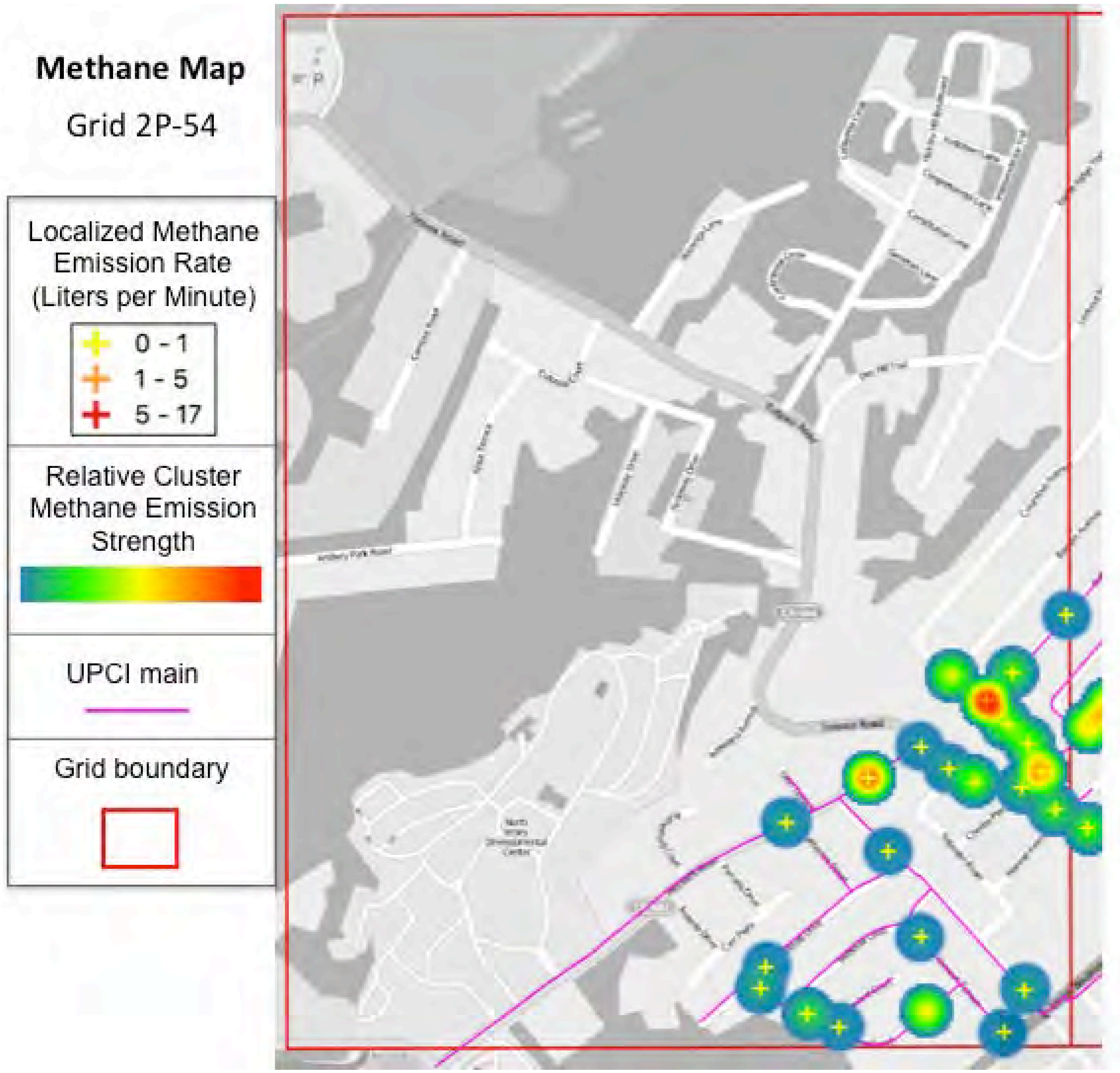
PICARRO


Methane Map
Grid 2P-51
Localized Methane Emission Rate (Liters per Minute)
0 - 1
1 - 5
5 - 17
Relative Cluster Methane Emission Strength
UPCI main
Grid boundary

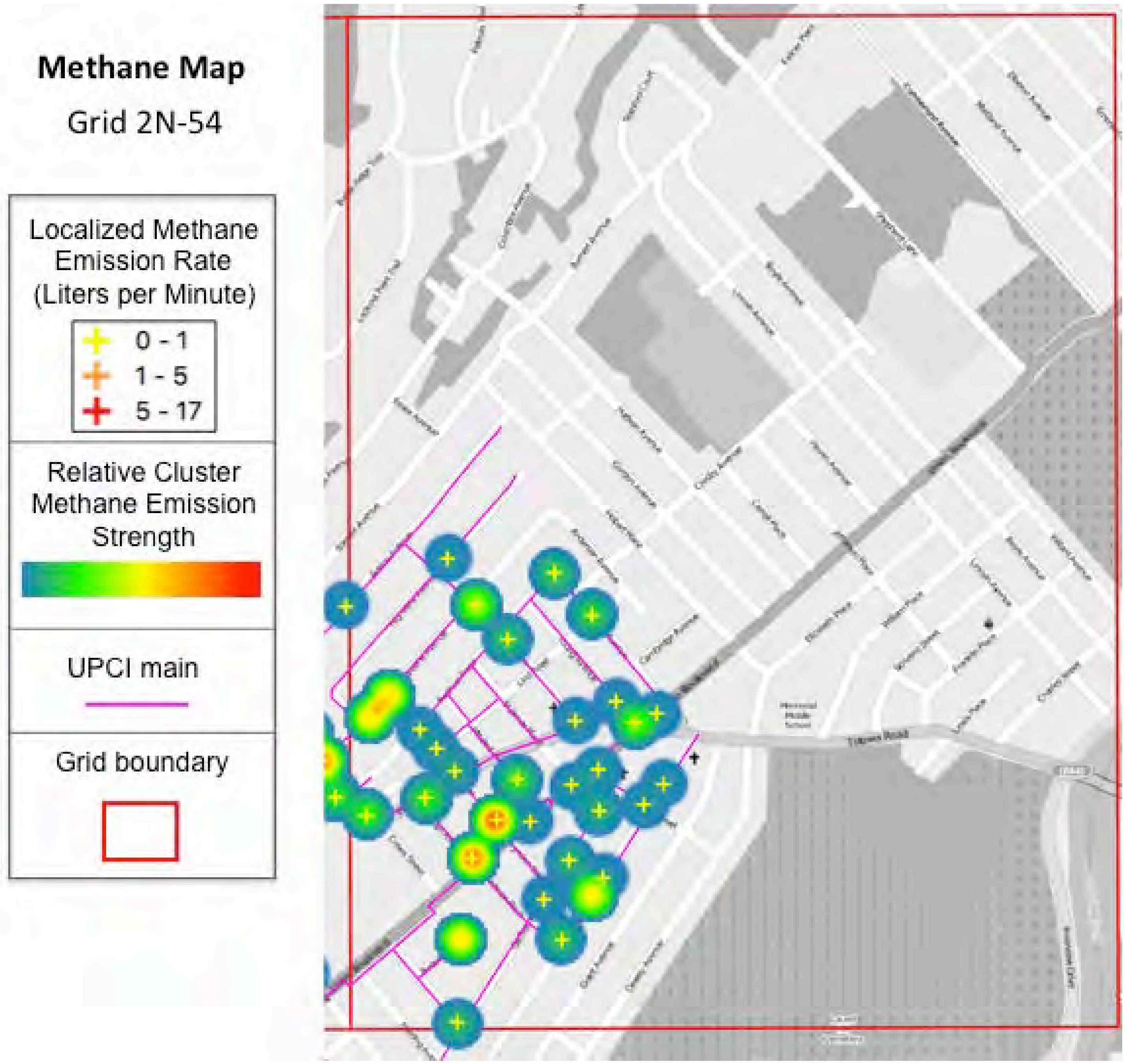
PICARRO


Methane Map
Grid 2L-52
Localized Methane Emission Rate (Liters per Minute)
0 - 1
1 - 5
5 - 17
Relative Cluster Methane Emission Strength
UPCI main
Grid boundary

PICARRO


Methane Map
Grid 2P-54
Localized Methane Emission Rate (Liters per Minute)
0 - 1
1 - 5
5 - 17
Relative Cluster Methane Emission Strength
UPCI main
Grid boundary

PICARRO


Methane Map
Grid 2N-54
Localized Methane Emission Rate (Liters per Minute)
0 - 1
1 - 5
5 - 17
Relative Cluster Methane Emission Strength
UPCI main
Grid boundary

PICARRO

Methane Map

Grid 2K-54

Localized Methane Emission Rate (Liters per Minute)

- 0 - 1
- 1 - 5
- 5 - 17

Relative Cluster Methane Emission Strength

UPCI main

Grid boundary

Methane Map

Grid 2J-54

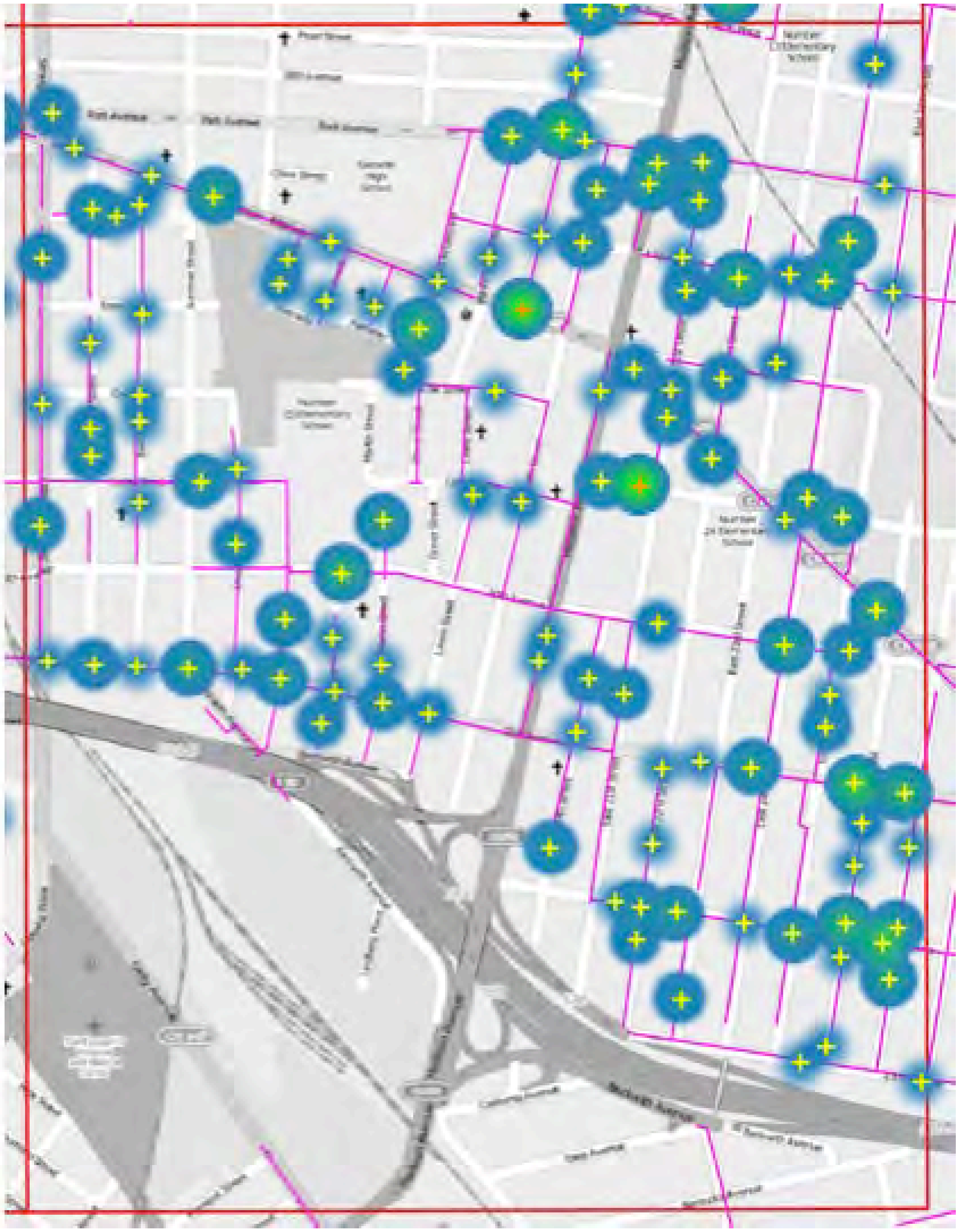
Localized Methane Emission Rate (Liters per Minute)

0 - 1
1 - 5
5 - 17

Relative Cluster Methane Emission Strength

UPCI main

Grid boundary



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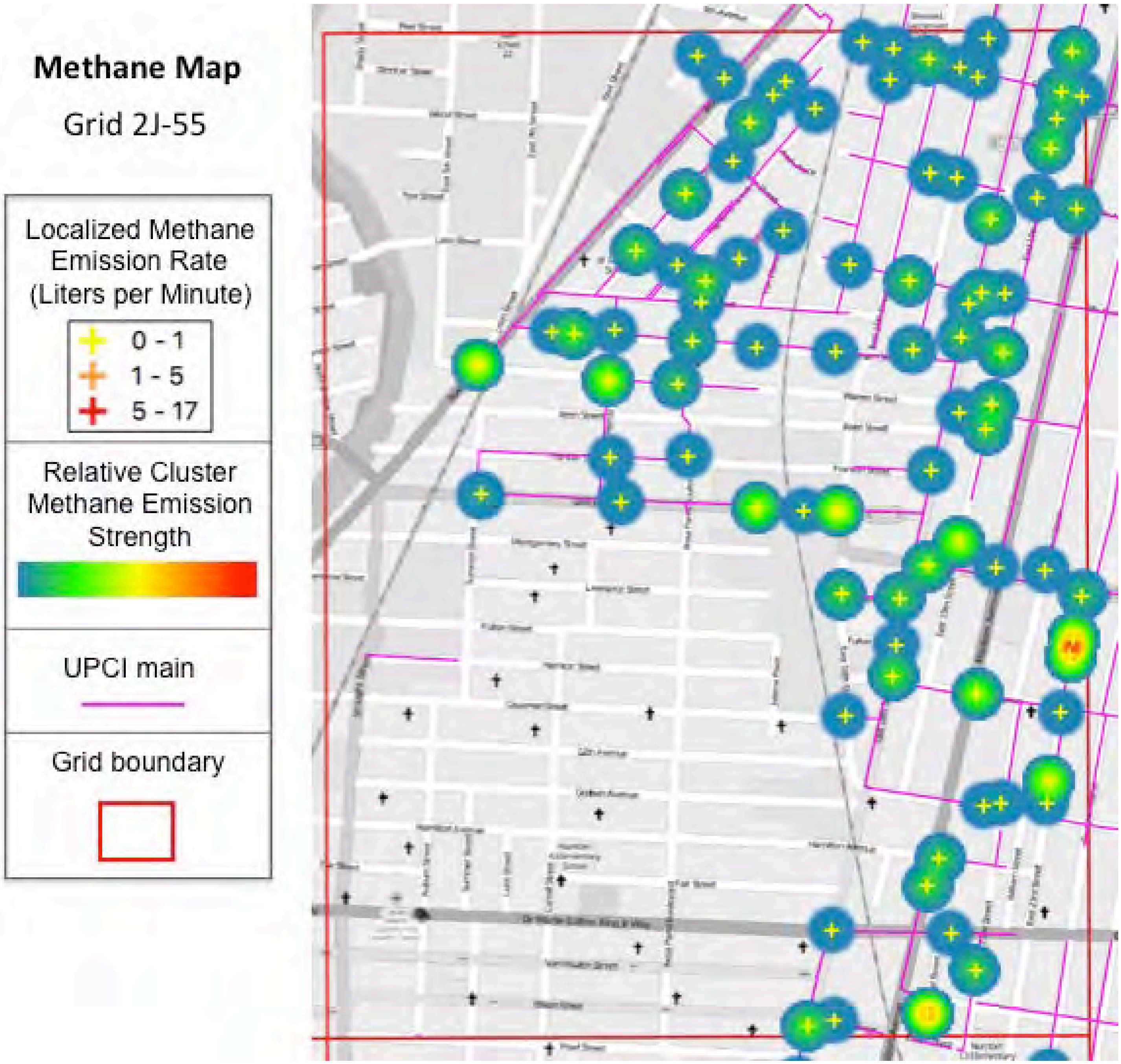
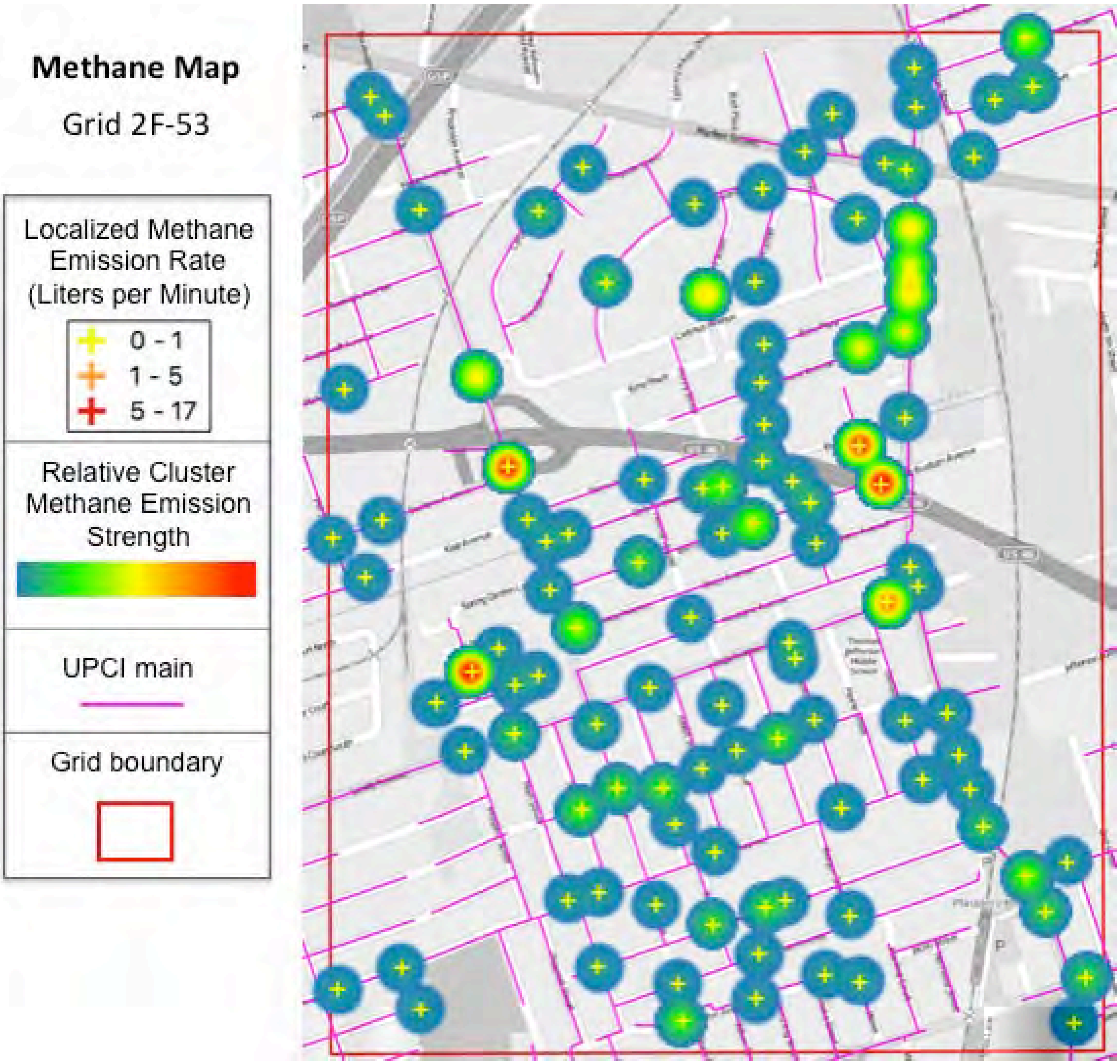
Methane Map

Grid 2J-55




Methane Map
Grid 2F-53
Localized Methane Emission Rate (Liters per Minute)
0 - 1
1 - 5
5 - 17
Relative Cluster Methane Emission Strength
UPCI main
Grid boundary

Methane Map

Grid 1U-51

Localized Methane Emission Rate (Liters per Minute)

- 0 - 1
- 1 - 5
- 5 - 17

Relative Cluster Methane Emission Strength

UPCI main

Grid boundary

PICARRO

Methane Map

Grid 2L-56

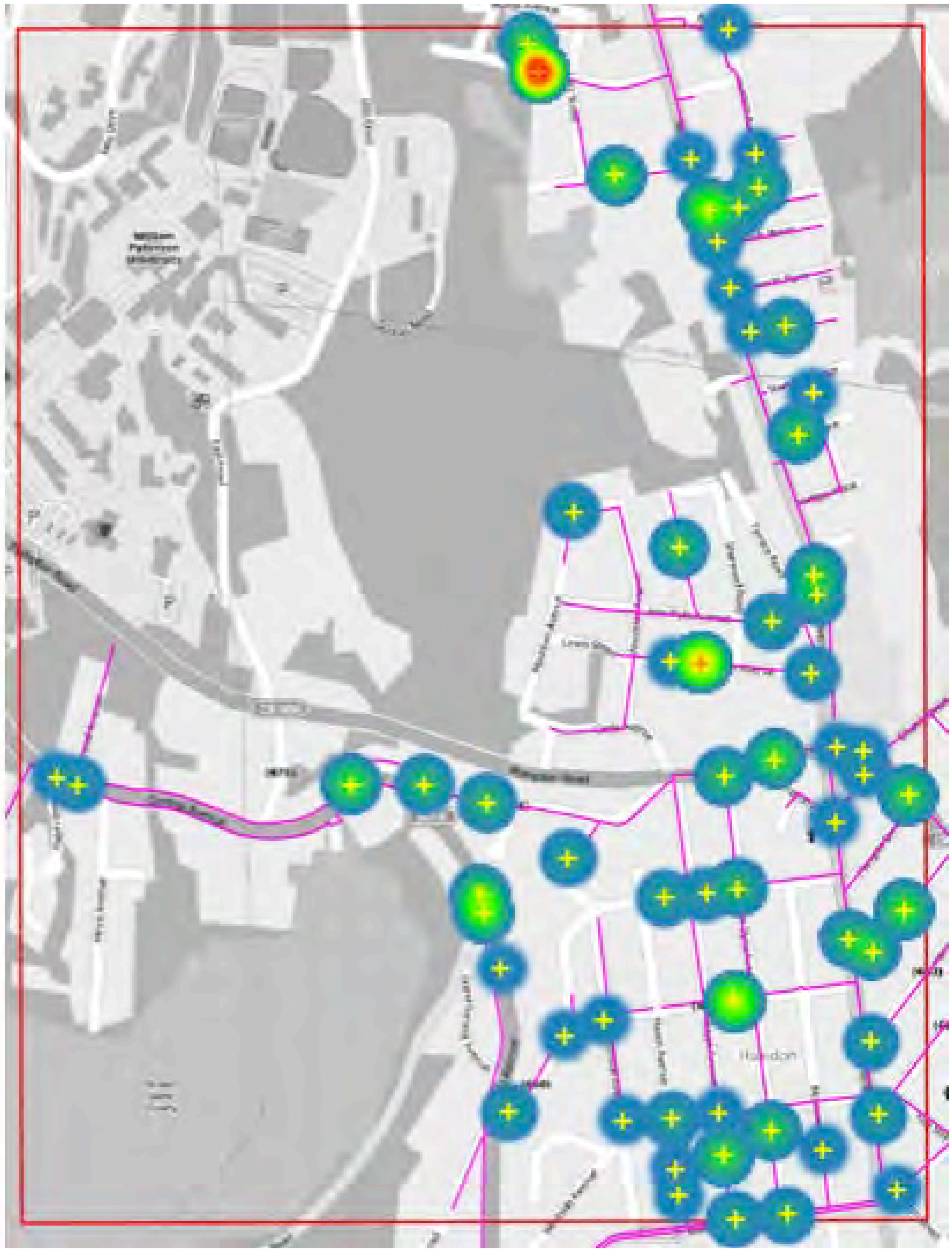
Localized Methane Emission Rate (Liters per Minute)

- 0 - 1
- 1 - 5
- 5 - 17

Relative Cluster Methane Emission Strength

UPCI main

Grid boundary



PICARRO

Methane Map

Grid 2G-57

Localized Methane Emission Rate (Liters per Minute)

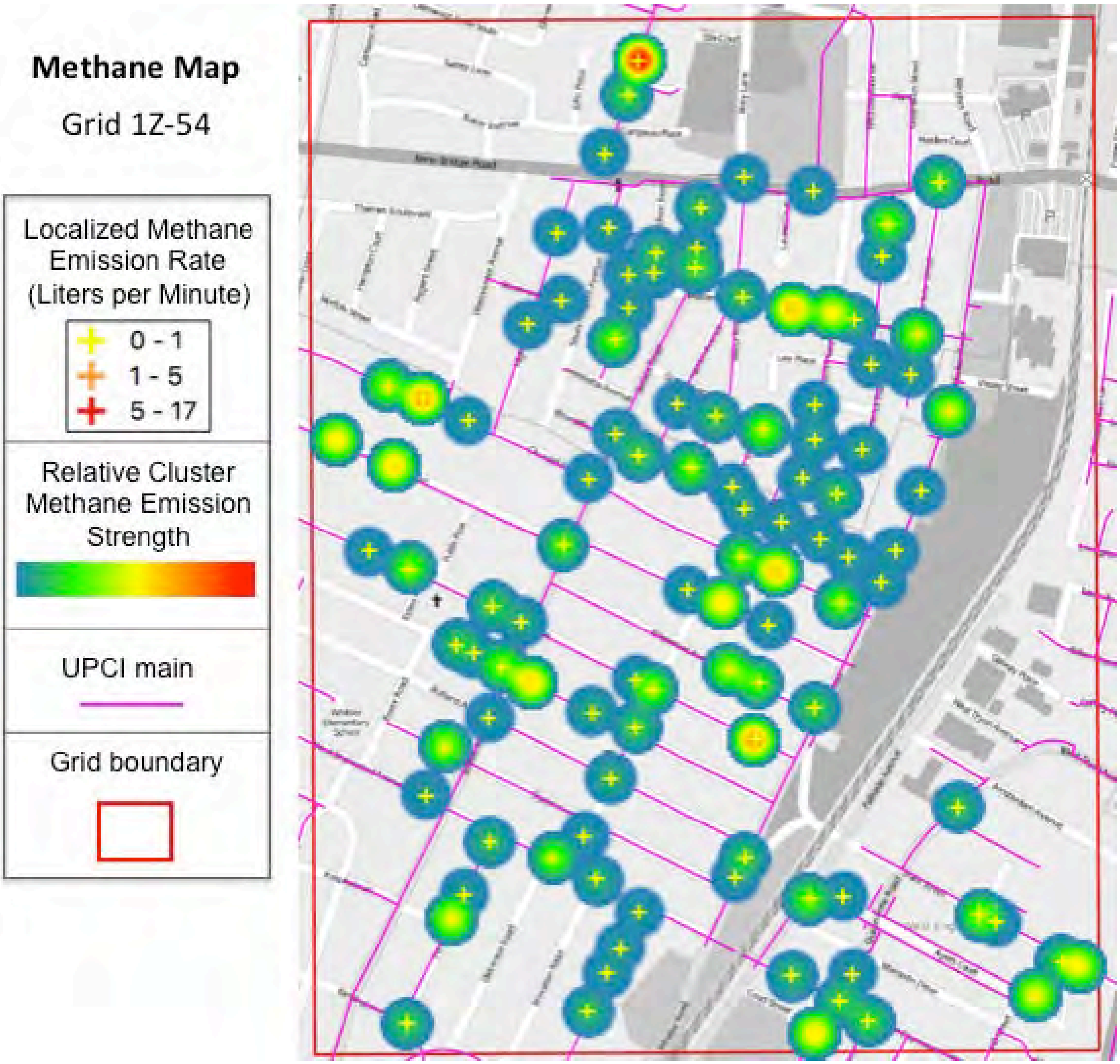
0 - 1
1 - 5
5 - 17

Relative Cluster Methane Emission Strength

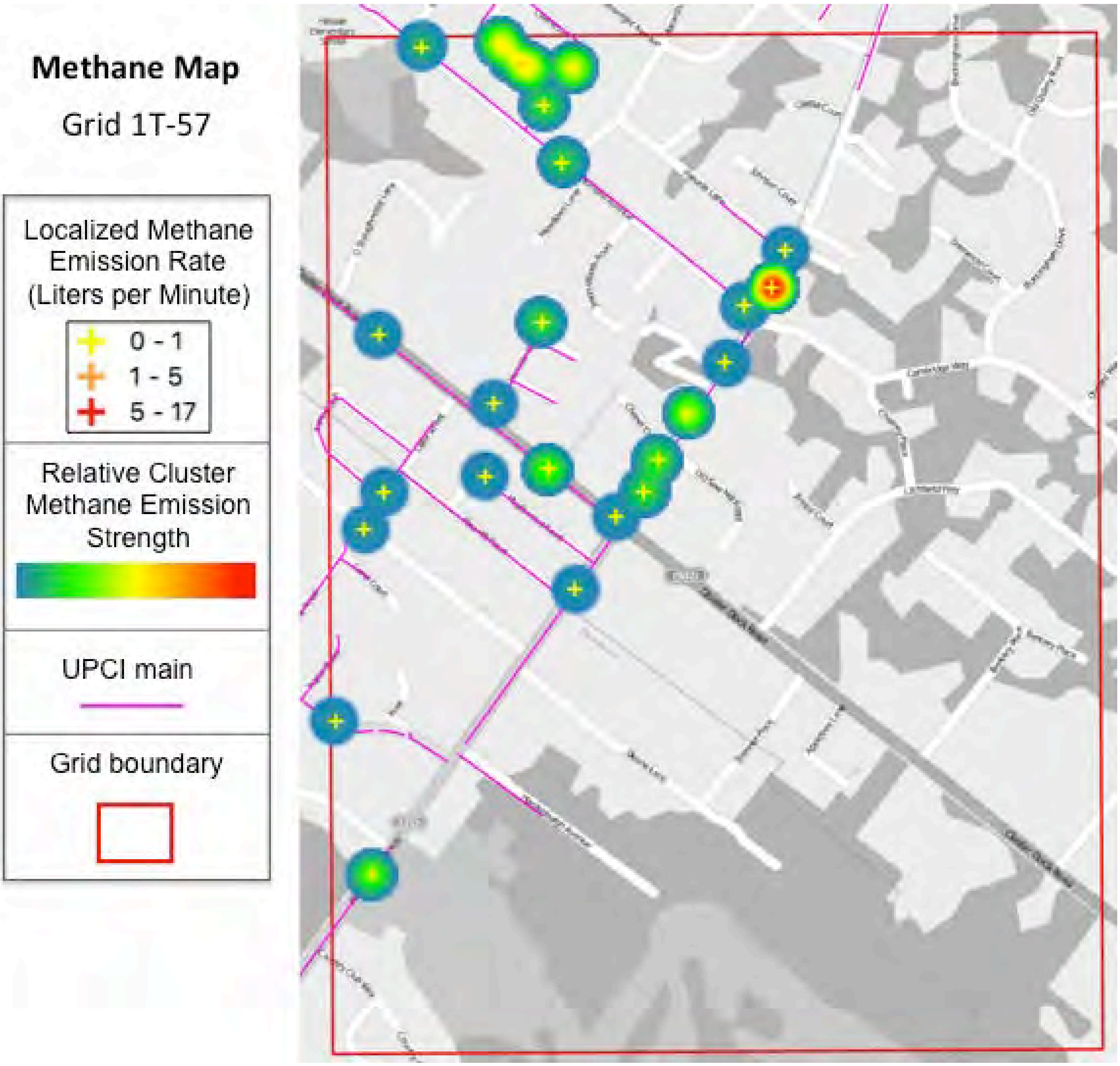
UPCI main

Grid boundary

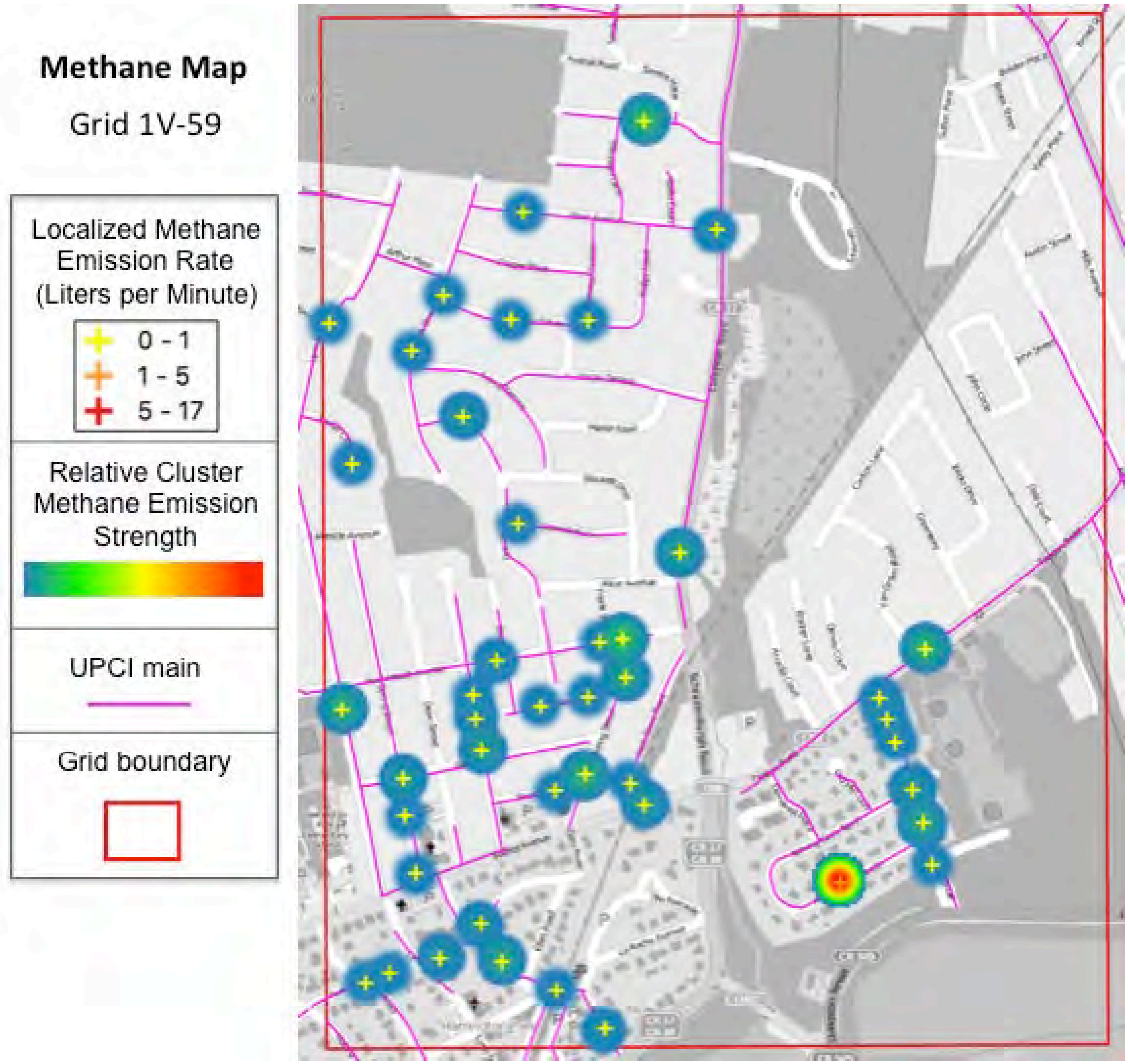
PICARRO


Methane Map
Grid 1Z-54
Localized Methane Emission Rate (Liters per Minute)
0 - 1
1 - 5
5 - 17
Relative Cluster Methane Emission Strength
UPCI main
Grid boundary

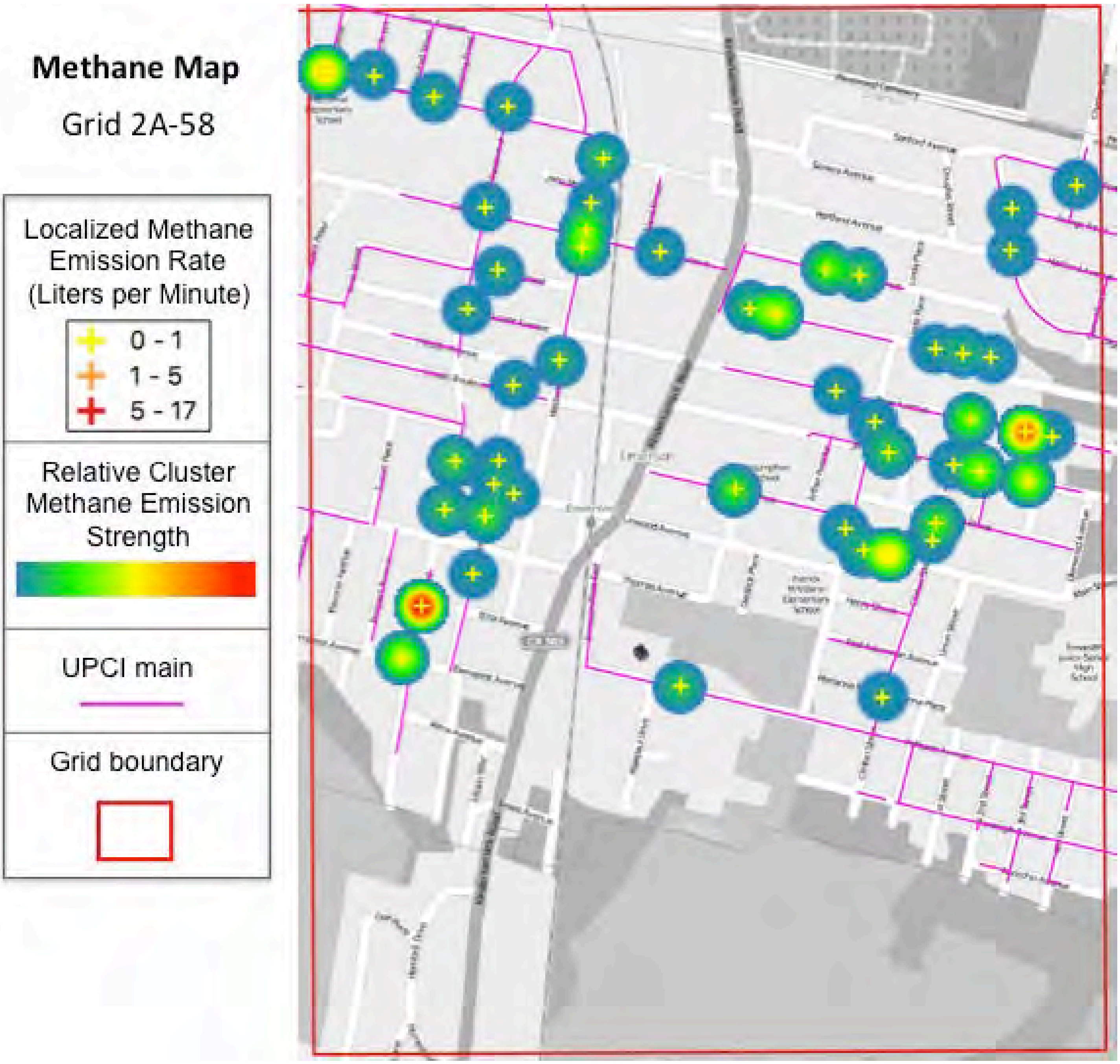
PICARRO


Methane Map
Grid 1T-57
Localized Methane Emission Rate (Liters per Minute)
0 - 1
1 - 5
5 - 17
Relative Cluster Methane Emission Strength
UPCI main
Grid boundary

PICARRO


Methane Map
Grid 1V-59
Localized Methane Emission Rate (Liters per Minute)
0 - 1
1 - 5
5 - 17
Relative Cluster Methane Emission Strength
UPCI main
Grid boundary

PICARRO


Methane Map
Grid 2A-58
Localized Methane Emission Rate (Liters per Minute)
0 - 1
1 - 5
5 - 17
Relative Cluster Methane Emission Strength
UPCI main
Grid boundary

ATTACHMENT D

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Methane Map

Grid 2B-59

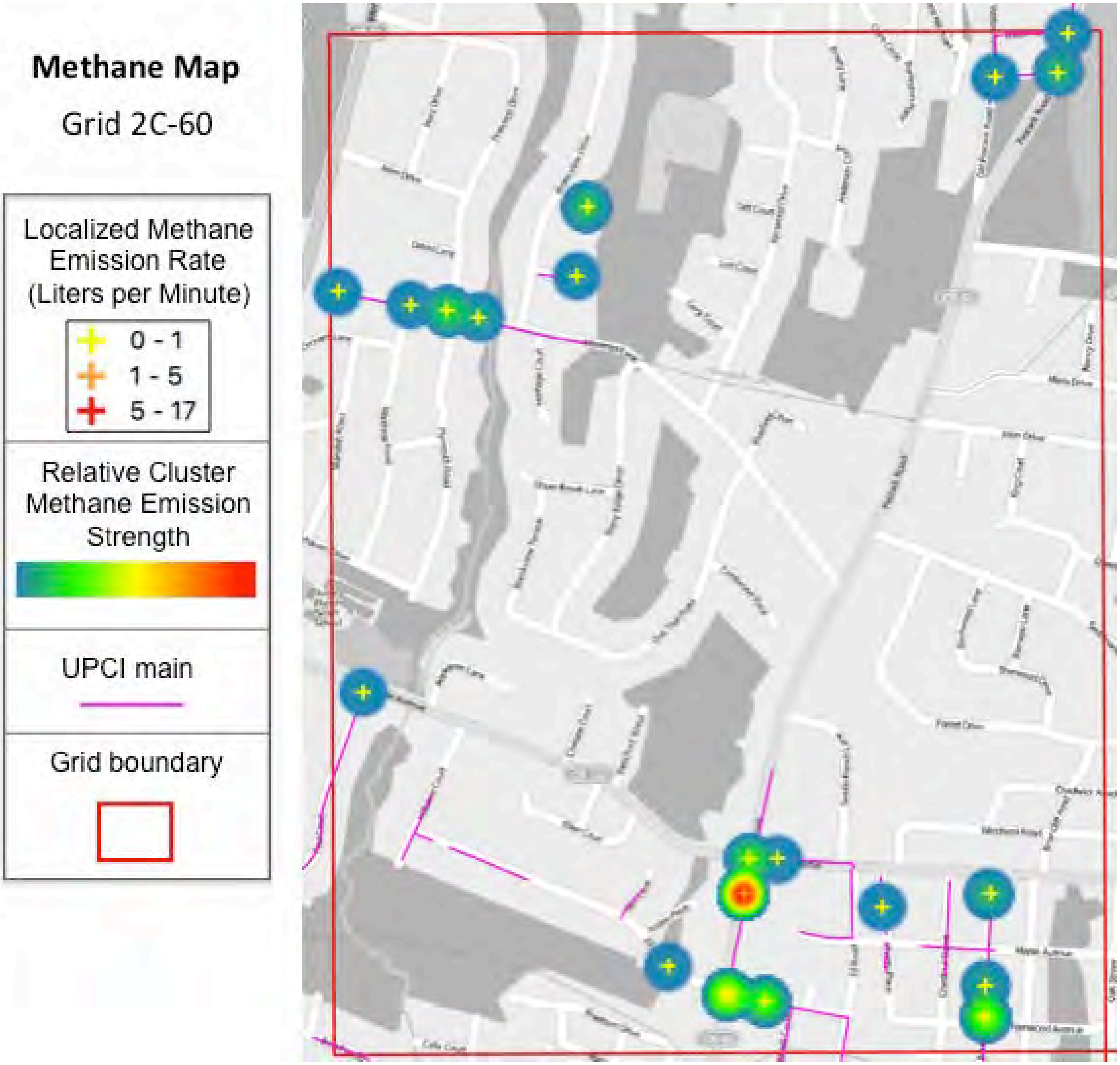
Localized Methane Emission Rate (Liters per Minute)

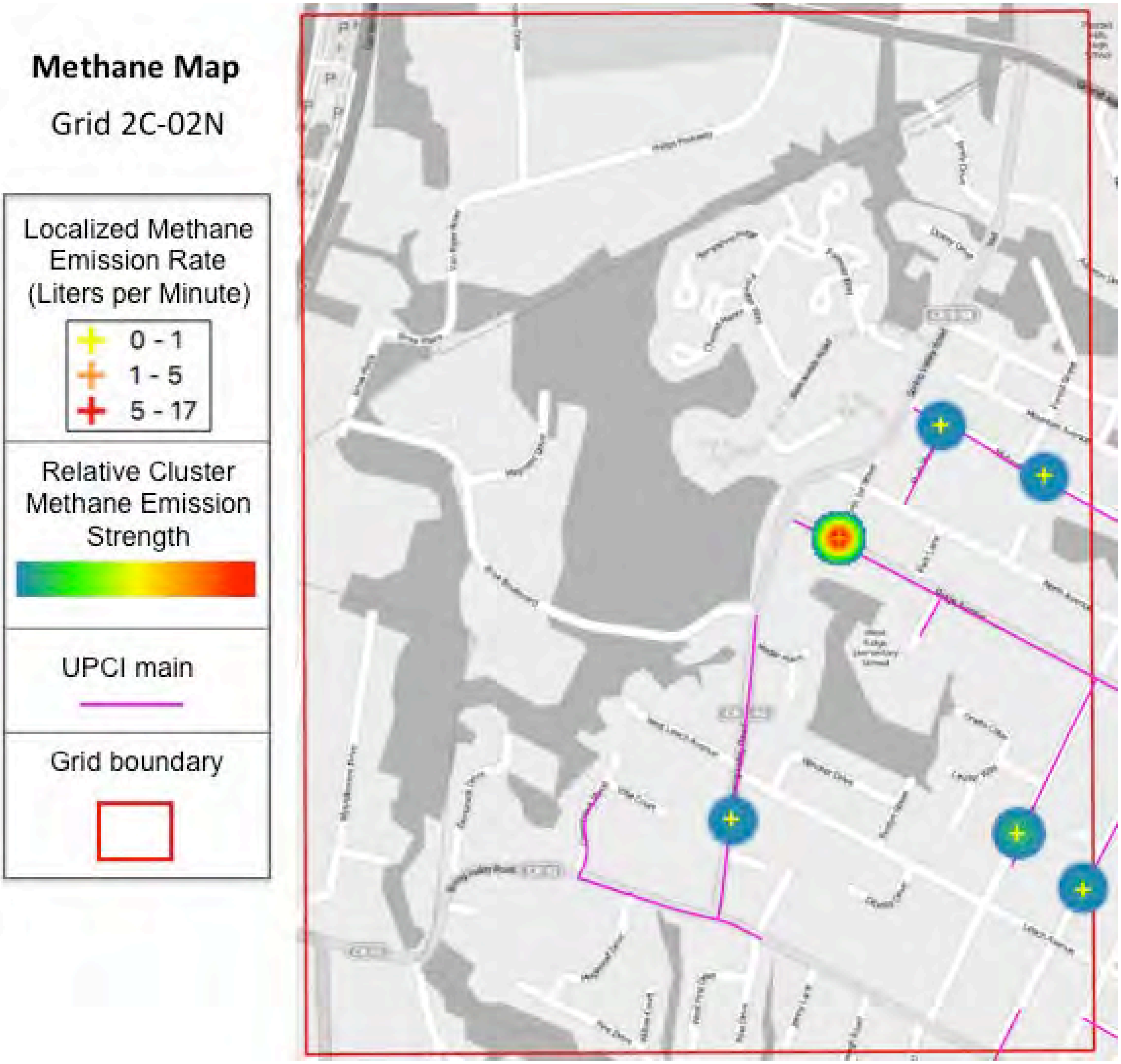
- 0 - 1
- 1 - 5
- 5 - 17

Relative Cluster Methane Emission Strength

UPCI main

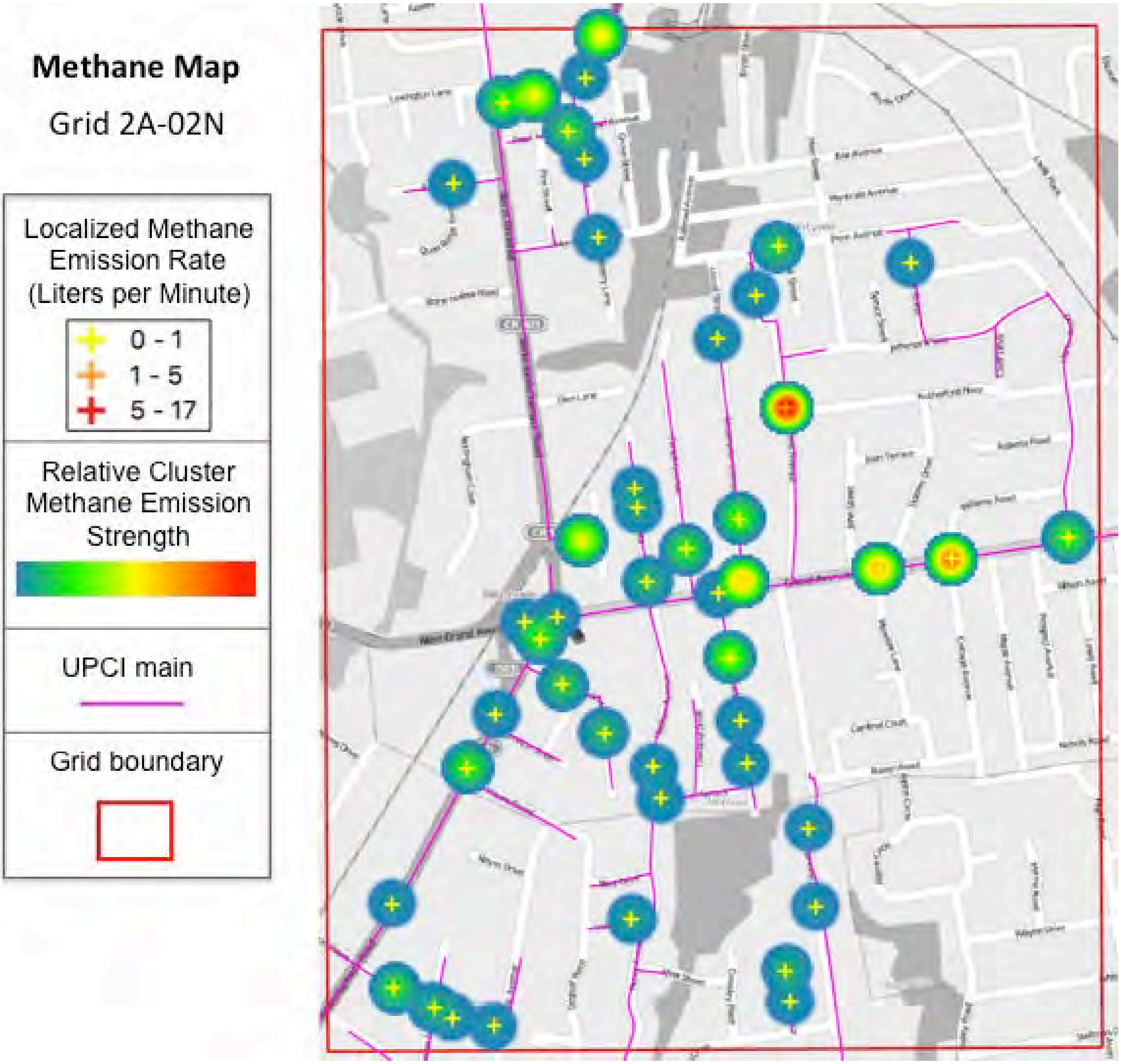
Grid boundary


Methane Map
Grid 2C-60
Localized Methane Emission Rate (Liters per Minute)
0 - 1
1 - 5
5 - 17
Relative Cluster Methane Emission Strength
UPCI main
Grid boundary


Methane Map
Grid 2C-02N
Localized Methane Emission Rate (Liters per Minute)
0 - 1
1 - 5
5 - 17
Relative Cluster Methane Emission Strength
UPCI main
Grid boundary

ATTACHMENT D

PICARRO



GSMP II UPCI Grid Ranking

A grid ranking process has been developed based on the Company's Hazard Risk Index Model. The approach is similar to the hazard ranking method used in GSMP I. PSE&G targets the replacement of its riskiest gas assets through the use of a ranking methodology that prioritizes main segments with the highest risk, through the use of the Hazard Index. The Hazard Index is based on a predictive model constructed from leak history "environmental factors" that include: building setback, number of underground utilities, demographic area (urban, suburban, rural), building types (industrial, commercial, or residential), and asset information (pipe diameter, operating pressure). Through the "weighted leak history" factor, past main breaks are considered and weighted based on how recently they occurred. Each map grid is evaluated by adding the hazard indexes for the individual utilization pressure segments within the grid and dividing them by the total miles of utilization pressure cast iron in the grid, arriving at a hazard index per mile for each map grid. Consistent with the hazard index per mile results, grids are ranked by highest to lowest and then placed into A, B, C and D priority grids categories. Grids with a Hazard Score over 15 are treated as the highest priority (A). B grids have a score between 15 and 10, C grids have a score between 10 and 5 and D grids have a score lower than 5.

Per the GSMP II Stipulation, PSE&G retained the services of Picarro to conduct and complete a methane leak survey of approximately 280 miles of UPCI located within the highest ranked B grids during the Fall of 2018. The 280 miles of main correlated to 44 grids that were surveyed. Consistent with the approach for GSMP I, an "Estimated Flow Rate per Mile (Liters/minute/mile)" was determined for each of the surveyed grids. Once the results for the 44 grids were determined, a discussion between PSE&G and the Environmental Defense Fund (EDF) occurred on Dec 4^{th} 2019 to determine a threshold for accelerating the subset of B grids with significant methane emissions. A value of 4.5 L/min/mi was agreed to verbally at this time. Having not received additional feedback from the EDF, PSE&G moved forward with this value to sub-prioritize the surveyed grids. Per the stipulation, these grids were ranked as the highest priority work after the A grids. Planning discussions with municipalities occurred for all grids accelerated by the methane mapping survey. In a few isolated cases, factors like project feasibility, cost and construction efficiency altered the outlined prioritization and has been documented.

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Exhibit __ (VP-10):

PSE&G Presentation “Replacement Main Prioritization: A Practical Application of Using Risk and Methane Emissions” (May 2, 2019)

Replacement Main Prioritization

A Practical Application of Using Risk and Methane Emissions

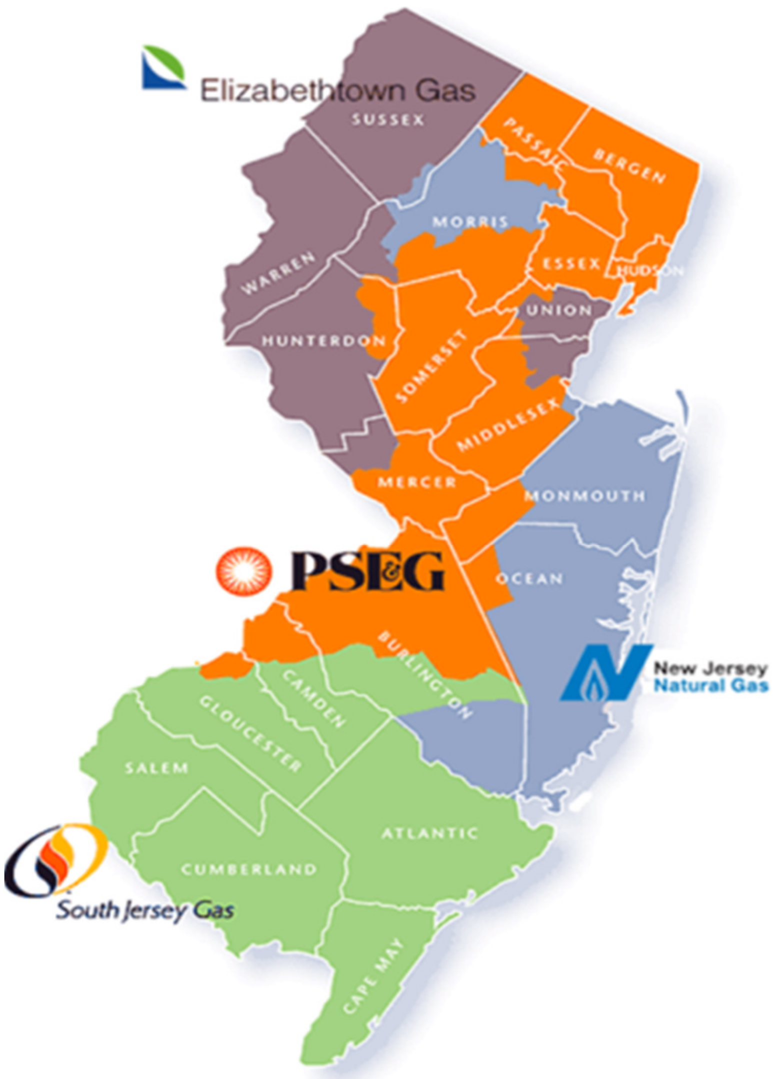
MAY 2, 2019

WADE MILLER, PE- DIRECTOR OF GAS TRANSMISSION & DISTRIBUTION ENGINEERING
ANDREW ARGESKI, PE- GAS PLANNING & DESIGN MANAGER

We have the **energy** to make things work ... for you.

PSEG
We make things work for you.

Getting to know PSE&G



- 6th Highest Gas Utility in US sales
- Serves 10 of the top 15 cities in NJ
- ~2,400 employees
- 12 District Headquarters
- 17,955 miles of gas distribution main
- 57 miles of gas transmission main
- 1.2 million gas services
- 1.8 million gas customers
- Sales volume growth: 1% per year

What is the Gas System Modernization Program (GSMP)?

- Accelerated cast iron and unprotected steel main and service replacement program
- Upgrades legacy low (utilization) pressure systems to medium pressure
- Relocates inside meter sets to outside
- Installs excess flow valve (EFV) safety devices
- Supports DOT focus on replacing the highest risk, most leak prone facilities

Continued replacement at these levels would take 25 years to replace/rehabilitate all the cast iron and unprotected steel

Gas System Modernization Program

- PSE&G currently operates and maintains over 4,400 miles of cast iron and unprotected steel gas distribution main.
- The program provides for investment and clause recovery of Utilization Pressure Cast Iron (UPCI) and Unprotected Steel replacement main, services, and associated uprating of plastic and protected steel in targeted areas
  - GSMP I started in 2016 (3 year term - $900M)
  - GSMP II started in 2019 (5 year term – $1.9B)
- Stipulated Base CapEx spend requirement associated with the program approval
  - Includes High Pressure Cast Iron (HPCI), UPCI, unprotected steel main and service replacement
  - Includes program and stipulated base inside meter set relocations
- Total ~170 miles of main replacement per year in Program and Stipulated Base
- The first two approvals are the beginning phases of a long-term 25 year replacement strategy for cast iron and unprotected steel mains
- Benefits:
  - Methane emission reduction is estimated at 30,000 metric tons of CO2 equivalent per year*
  - Medium pressure system allows usage of high efficiency appliances by customers
  - Includes installation of excess flow valve safety devices where applicable

* EPA SUBPART W METHODOLOGY.

GSMP Stipulation

The replacement of mains in the Program shall follow the prioritization based on the grid based Leak Hazard Indices developed by PSE&G using its Hazard Assessment model.

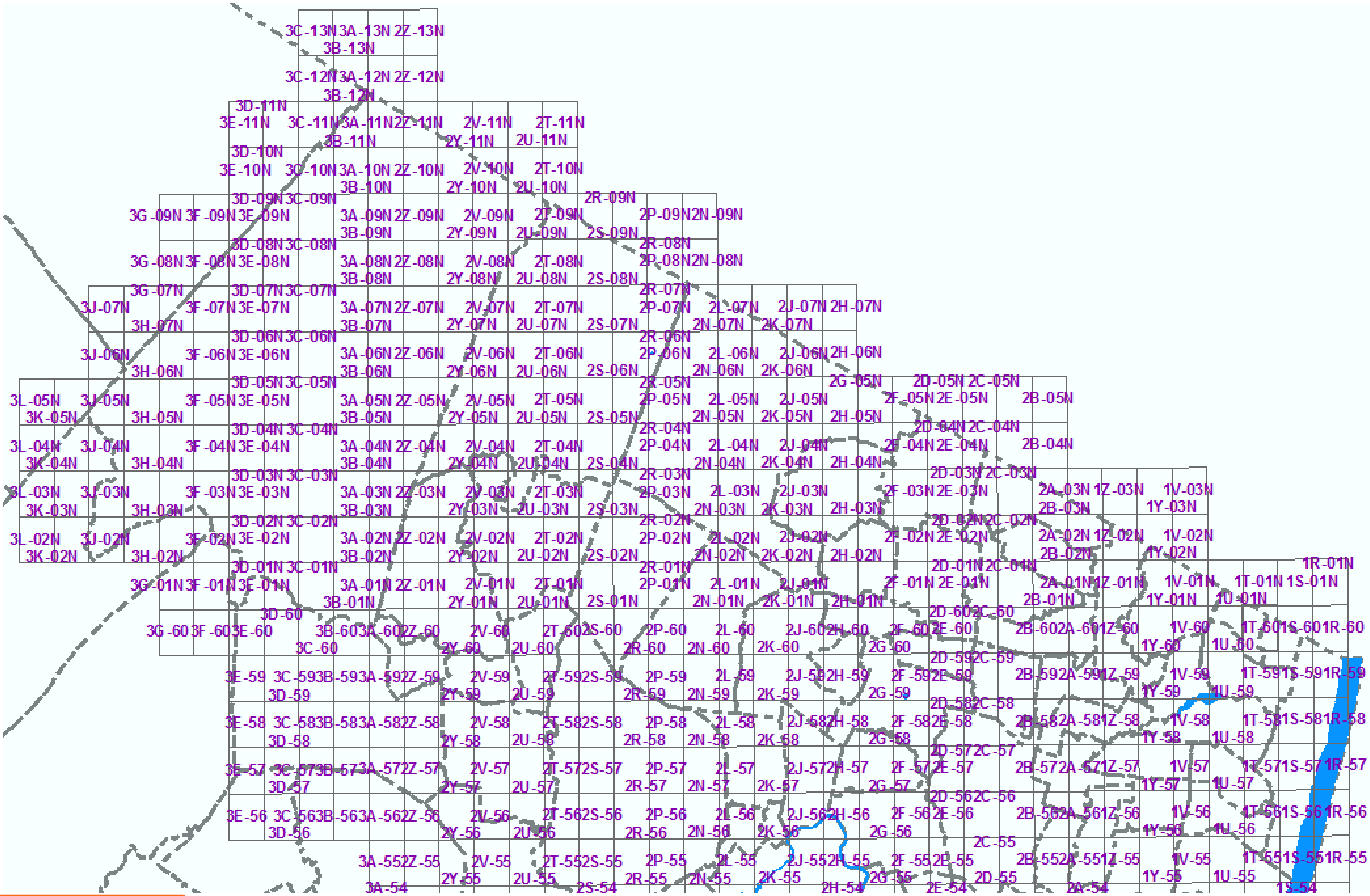
"...Recognizing that considering methane emission flow volume (i.e., emission size) as part of prioritization will reduce the amount of natural gas lost from emissions to the benefit of customers, and reduce the environmental impacts of such emissions, the Signatories agree that for grids with comparable Hazard Index/Mile, available methane emissions survey data estimating flow volumes, as prepared by the Environmental Defense Fund using Program plans, system information and maps provided by PSE&G, will be used, as appropriate, in sub-prioritizing replacement activities…"

Accelerated UP Cast Iron (UPCI) Replacement

- Goal - Replace priority areas most efficiently
  - Highest potential hazard
  - Contiguous area for construction efficiency

- Map grid system utilized
  - 1 square mile area
  - 1 – 20 miles of low pressure cast iron per grid
  - Similar environmental conditions

PSE&G Grid Mapping System



Prioritization of UPCI Replacement Main

- Hazard Index (HI) rankings used to express and compare relative hazard for main segments having a history of breaks.

- Factors used in the calculation
  - Hazard Index = Weighted Break History (WBH) x Environmental Index (E)

  - WBH = The sum of the factors multiplied by the number of annual break repairs for each period (factors higher for recent breaks)

  - Environmental Index evaluates the environmental conditions at the main segment location that may affect the relative hazard of a break and is based upon the following factors
    - Building Density
    - Operating Pressure
    - Building Occupancy
    - Underground Utility
    - Building Set-back
    - Nominal Pipe Size

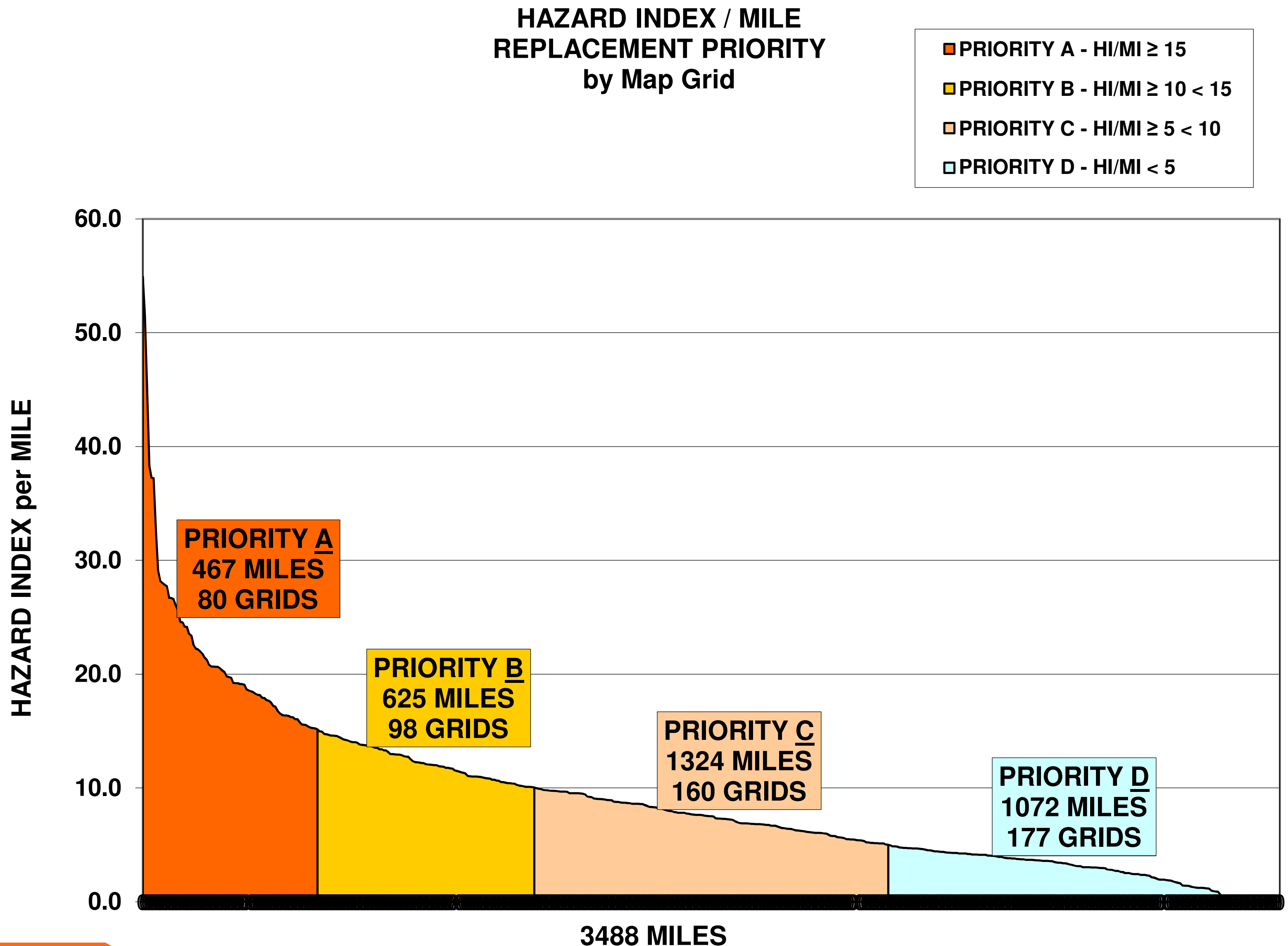
- Mileage is based upon total low pressure cast iron mileage in grid



Prioritization of UPCI Replacement Main (cont'd)

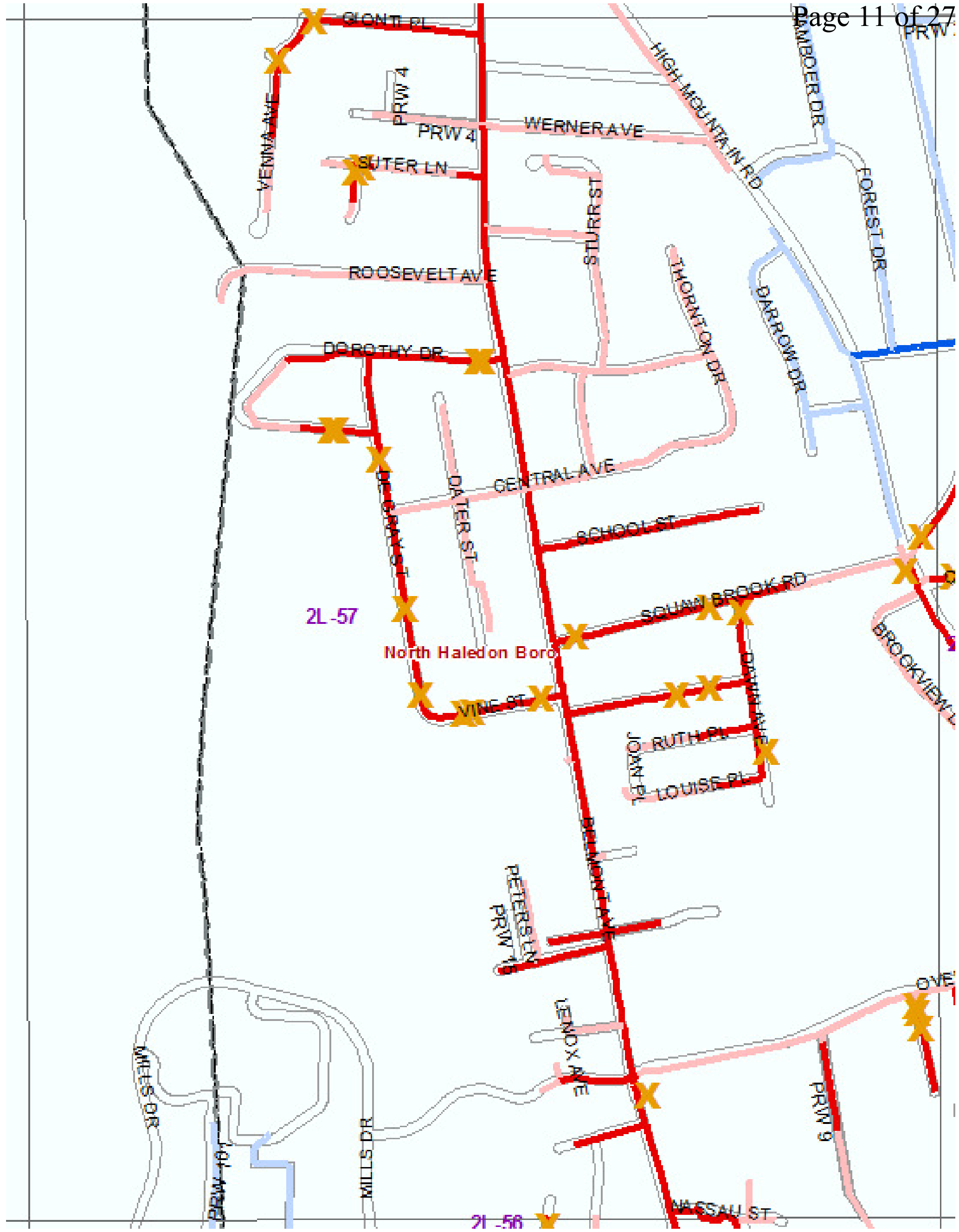
- Mains with break history - Hazard Index
- Individual segments within a grid are summed to obtain total hazard index for the grid
- Miles of UPCI main in grid are summed
- Hazard score divided by miles gives HI/Mi score
- Map Grids ranked by HI/Mi

GSMP I - UP Cast Iron Main Prioritization



Grid 2L-57 (Rank 2)
UP CI = 3.8 miles
HI/MI = 45.4

- UP Cast Iron
- EP Cast Iron
- UP Plastic and Steel
- EP Plastic and Steel
- Regulator
- CI Break



Hazard Index – Grid 2L - 57

District	Street	Municipality	Install Year	Main Size	Main Type	Pressure	Segment Length	B	P	O	U	S	Last Repair Date	Number of Breaks	WBH	BPOU/S	Env Index E	Hazard Index	Wall Map Grid
DGOK	VINE ST	Haledon Boro	1900	6	CI	UP	700	4	1	4	2	1.5	1/8/2014	3	12	21	2.3012	27.615	2L-57
DGOK	DE ROON AVE	Haledon Boro	1900	4	CI	UP	458	8	1	4	3	1	4/4/2012	3	9	96	3.0307	27.2765	2L-57
DGOK	MORNINGSIDE AVE	North Haledon Boro	1953	4	CI	UP	929	8	1	4	3	1	1/28/2013	2	8	96	3.0307	24.2458	2L-57
DGOK	BELMONT AVE	North Haledon Boro	1927	8	CI	UP	460	8	1	15	4	1	11/6/2013	1	5	480	4.5596	22.7982	2L-57
DGOK	DE GRAY ST	Haledon Boro	1955	6	CI	UP	1037	4	1	4	3	1.5	2/14/2013	2	7	32	2.5705	17.9933	2L-57
DGOK	DAWN AVE	Haledon Boro	1951	6	CI	UP	426	8	1	4	3	1	1/14/2011	1	3	96	3.3	9.8999	2L-57
DGOK	GIONTI PL	North Haledon Boro	1928	6	CI	UP	885	4	1	4	2	3	2/11/2014	1	5	11	1.841	9.205	2L-57
DGOK	SQUAW BROOK RD	North Haledon Boro	1937	6	CI	UP	962	4	1	4	3	1	1/12/2009	2	2	48	2.8397	5.6794	2L-57
DGOK	MEADOW PL	North Haledon Boro	1954	4	CI	UP	187	4	1	4	4	1	2/22/2010	1	2	64	2.7615	5.523	2L-57
DGOK	DOROTHY DR	North Haledon Boro	1964	4	CI	UP	276	4	1	4	3	1	3/25/1999	2	2	48	2.5705	5.141	2L-57
DGOK	HIGH MOUNTAIN RD	North Haledon Boro	1900	8	CI	UP	109	2	1	4	3	1.5	12/30/2010	1	2	16	2.3012	4.6025	2L-57
DGOK	SUTER LN	North Haledon Boro	1954	4	CI	UP	93	4	1	4	1	1.5	2/20/2010	1	2	11	1.5718	3.1435	2L-57
DGOK	DAWN AVE	North Haledon Boro	1951	6	CI	UP	267	4	1	4	3	1	12/8/2003	1	1	48	2.8397	2.8397	2L-57
DGOK	DOROTHY DR	North Haledon Boro	1957	6	CI	UP	682	2	1	4	2	3	1/8/2001	2	2	5	1.3807	2.7615	2L-57
DGOK	VENNA AVE	Haledon Boro	1929	6	CI	UP	325	2	1	4	2	3	2/2/2009	1	1	5	1.3807	1.3807	2L-57
																Total Hazard Score		170.1051	
																Total CI Miles in Grid		3.75	
																Hazard Index Per Mile		45.36	

PSEG

Top 20 Hazard Index/Mile

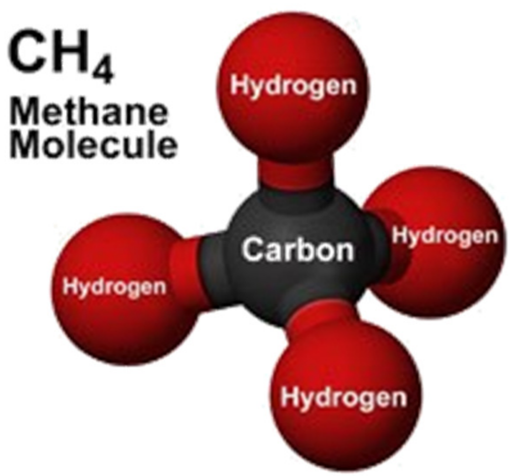
UPCI GRID	UPCI MILES	2014 HAZARD INDEX	HAZARD INDEX/MILE	HI/MILE RANK
2A-48	1.0	55.0970	54.9	1
2L-57	3.7	170.2419	45.4	2
2K-45	5.0	185.4933	37.3	3
2Z-41	1.2	43.9937	37.2	4
2K-44	3.0	109.7977	36.7	5
2B-46	2.9	103.7972	36.2	6
2K-55	11.1	360.4543	32.5	7
2J-51	10.1	294.1113	29.1	8
2D-58	3.1	87.5603	28.2	9
2A-45	2.4	66.1032	28.0	10
2K-57	4.1	115.1842	27.9	11
2L-58	1.7	48.0314	27.7	12
3D-46	2.1	55.6910	26.6	13
3J-50	1.4	37.6969	26.0	14
1Z-47	7.7	200.3936	25.9	15
3C-25	1.4	35.9431	25.6	16
2H-50	6.6	162.3633	24.8	17
2L-51	8.1	194.9827	24.2	18
2H-45	3.6	87.6968	24.2	19
2L-43	7.1	167.2065	23.6	20

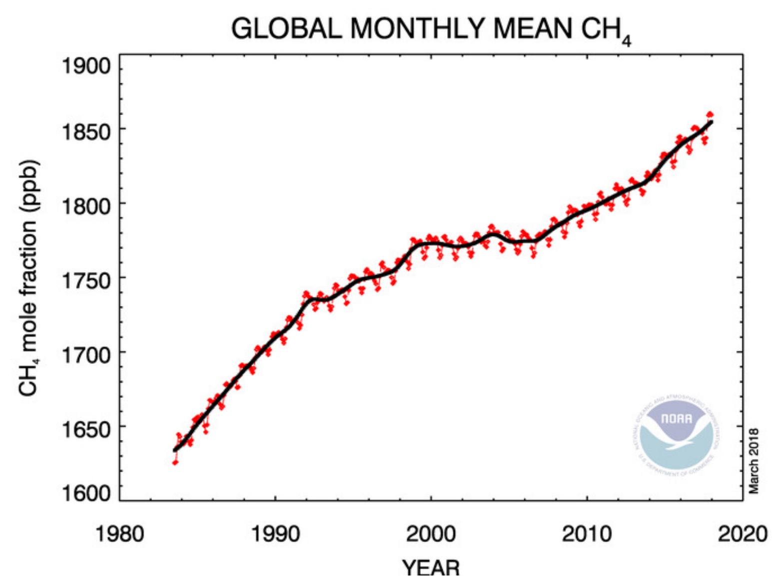
Methane as a Greenhouse Gas

- Methane has 84 times the warming effect of carbon dioxide over a 20 year period
- EDF estimates that about 25% of the manmade global warming we're experiencing today is caused by methane emissions

Typical Composition of Natural Gas

Methane	CH_4	70-90%
Ethane	C_2H_6	0-20%
Propane	C_3H_8	
Butane	C_4H_{10}	
Carbon Dioxide	CO_2	0-8%
Oxygen	O_2	0-0.2%
Nitrogen	N_2	0-5%
Hydrogen sulphide	H_2S	0-5%
Rare gases	A, He, Ne, Xe	trace





Working with the EDF

- In advance of GSMP I, PSE&G engaged the Environmental Defense Fund (EDF) to quantify methane emissions in our service territory to consider in the prioritization of the work
- Mapping was performed over a six month period
- Study was done at no cost to PSE&G
- PSE&G followed the EDF equipment with its own optical methane leakmobile to compare data

EDF
ENVIRONMENTAL DEFENSE FUND®
Finding the ways that work

EDF Overview - Continued

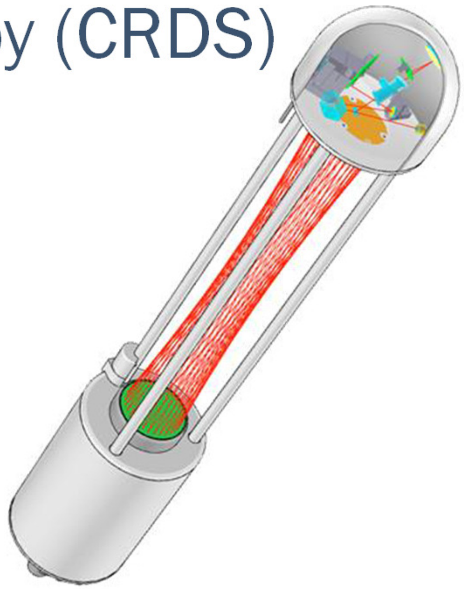
- The EDF partnered with Google and Colorado State University on a nationwide program to detect and map methane leaks from natural gas distribution systems
- A Google street-view car, equipped with state of the art methane and meteorological sensors, was driven repeatedly along streets with natural gas pipelines to map emissions
- Urban areas have been mapped across the country (Birmingham, Boston, Burlington, Chicago, Dallas, Indianapolis, Jacksonville, Los Angeles, Mesa, Pittsburgh, Staten Island, and Syracuse)
- The same technology used to map these cities was also used for the PSE&G project

Google

Colorado State University

What Technology Was Used?

- Advanced GPS technology and anemometer
- Open path, Cavity Ring-Down Spectroscopy (CRDS) LiCor analyzer



- High data collection rate
- No pumps (closed path CRDS)
- The longer the laser path, the better the sensitivity in detecting molecular signatures
- Equipment uses a series of mirrors within the sample cavity to reflect the laser path from a distance of 25 cm to over 20 km

PSEG

Methane Quantification Data

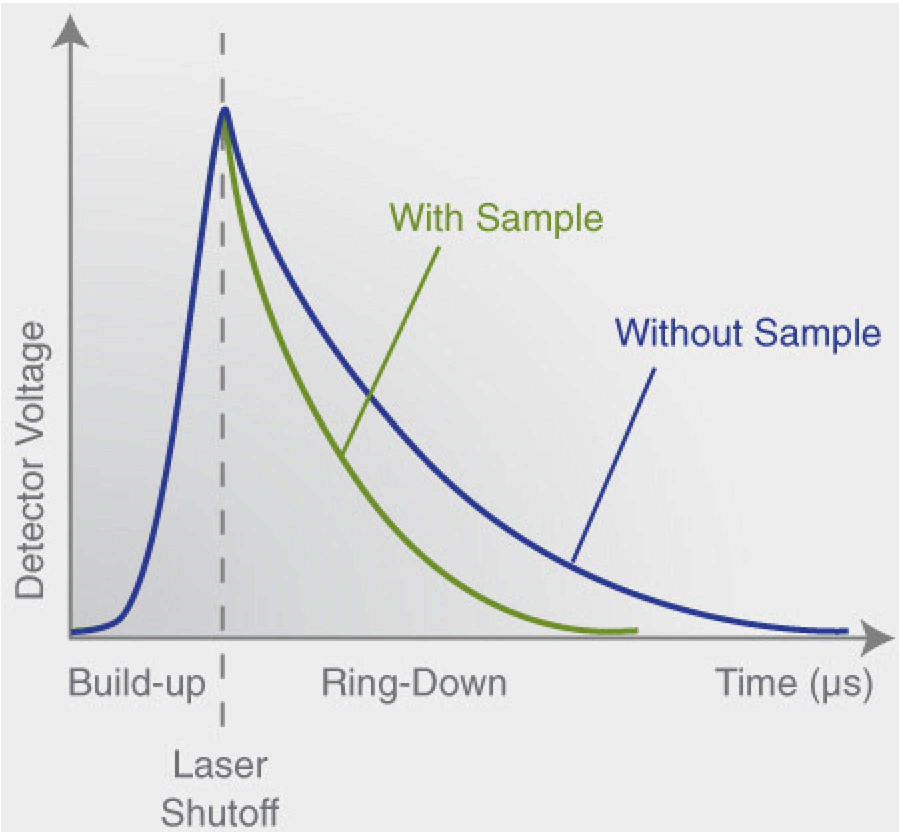


Fig 1. Ring Down Graph. Adapted from Picarro. Retrieved from Picarro.com

- Different gases absorb light (laser) at specific rates
- Normal atmospheric air has a certain decay pattern as the laser fades inside the sample chamber (blue graph)
- When a gas like methane is in the sample, it absorbs light at a different decay rate than the control (green graph)
- The laser wavelength and difference in decay rates is used to quantify methane by analyzing the sample data stream through a series of algorithms
- Wind and precipitation are factors in sampling

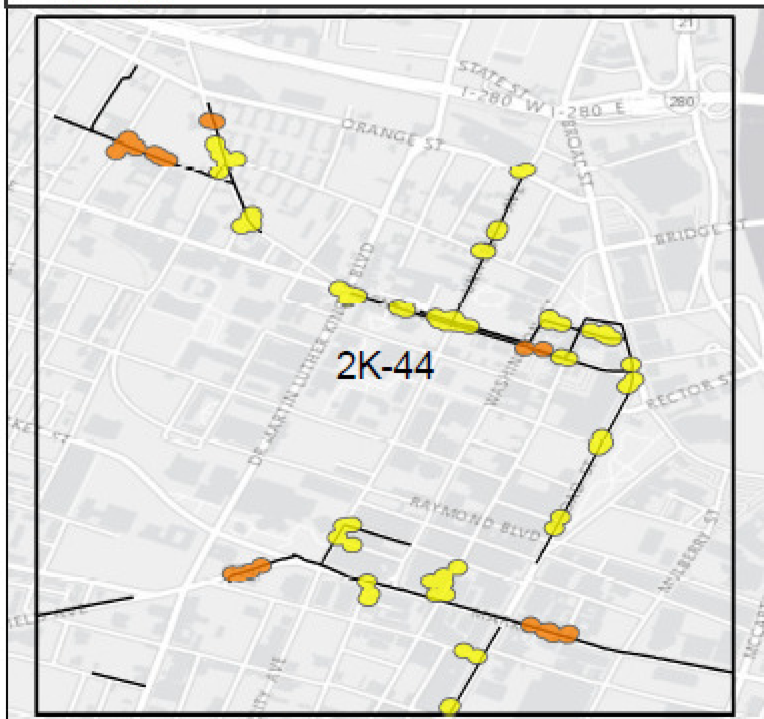
Readings vs Indications

Overlap of UPCI Pipes and Observed Data from EDF Methane Mapping

New Jersey: Observed Readings

Clusters of readings that contribute to one verified leak of the following size:

- 700 to 9,000 liters/day
- 9,000 to 60,000 liters/day
- More than 60,000 liters/day
- PSEG UPCI Pipes
- PSEG Map Grid

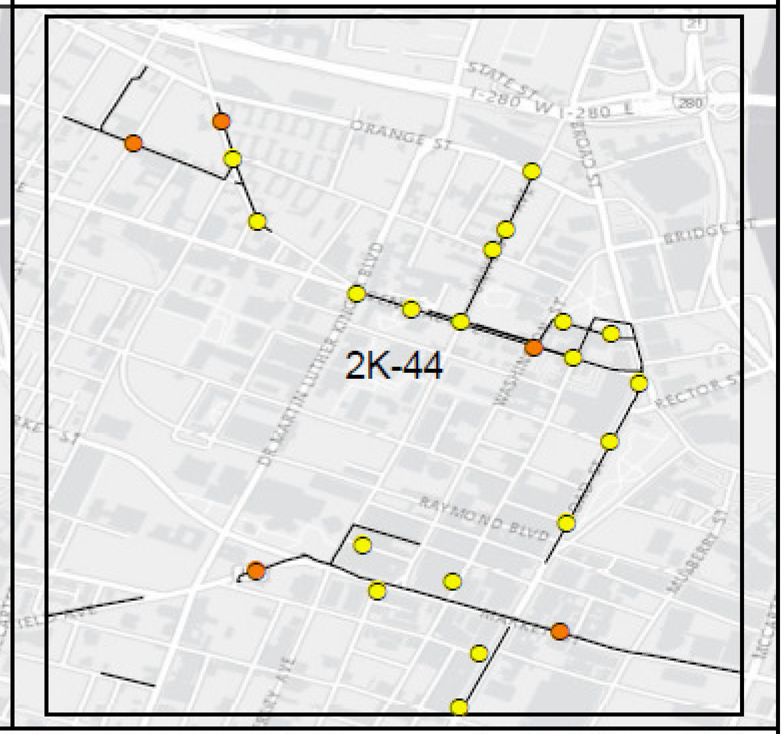


Overlap of UPCI Pipes and Verified Leaks from EDF Methane Mapping

New Jersey: Verified Leaks

- 700 to 9,000 liters/day
- 9,000 to 60,000 liters/day
- More than 60,000 liters/day
- PSEG UPCI Pipes
- PSEG Map Grid

Estimated Total Flow Rate: 119 (+/- 15*) L/min
Number of Verified Leaks: 24
Miles of UPCI: 3.4 miles
Flow Rate/Mile UPCI: 34.8 (+/- 4.3*) L/min/mile
Rank:4
*** Represents 95% confidence of true leak rate**



These maps only show readings that potentially overlap with utility UPCI pipes. Other recorded EDF data is not represented.

0 500 1,000 2,000 Feet

PSEG

Using the Results in GSMP I

- Hazard Index per Mile (HI/Mi) still primary risk ranking tool
- Any grid with HI/Mi > 25 is highest priority
- Where HI/Mi is comparable (< 25), EDF data used to help **sub-prioritize** by leak rate of liters per minute per mile of UPCI pipe in the grid (L/Min/Mi)
  - Grids with outlying leak rates of >10 L/Min/Mi take highest priority
  - Grids with leak rates of <10 L/Min/Mi as well as non-surveyed grids take secondary priority
- Grids are evaluated for construction efficiencies and logistics as well as permitting and municipality conflicts prior to setting the final prioritization
- Results reviewed with EDF and submitted to the NJ Board of Public Utilities

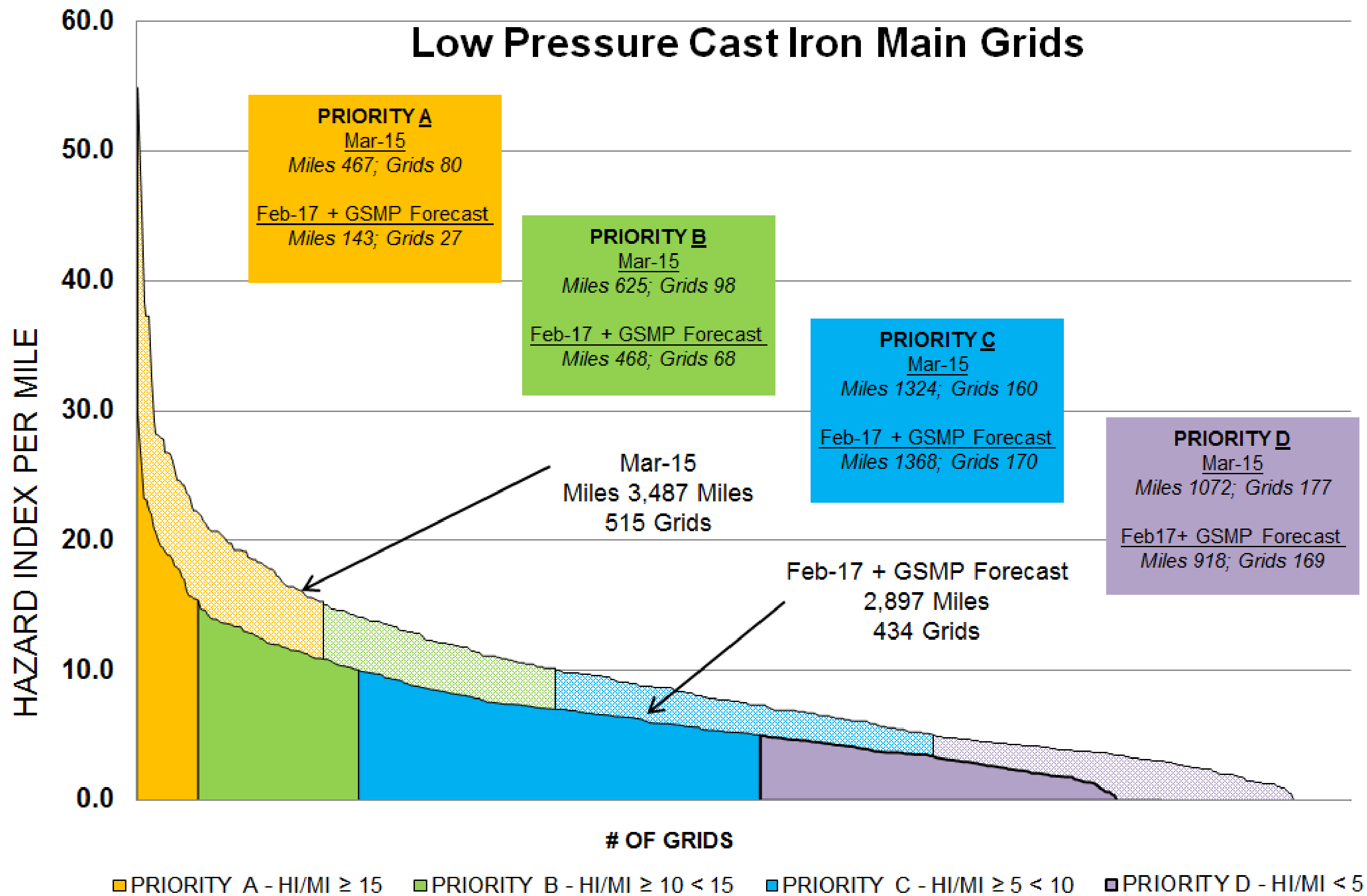
Reduction in Emissions

- Outlier grids (>10 L/min/mi) were looked to be moved up in schedule where possible
- Mains retired earlier than originally planned stop emitting methane faster
- By accelerating high emissions grids, PSE&G was able to reduce total grid emissions by 83% early in the program.
- To achieve the same emissions reductions, 35% less main abandonments were needed vs if PSE&G followed strictly by hazard ranking.
- The accelerated grids the company prioritized for upgrades accounted for more than 37% of the emissions but only 9% of the mileage on which leak rates were measured.

Continuing the Program into GSMP II

- GSMP II filed in 2017 and approved in Spring 2018 as a five year extension
- Hazard Index and methane mapping to be used again to prioritize grids
- Picarro was chosen to map 44 “B Grids” of similar HI/mi that covered the 280 miles agreed to in the stipulation

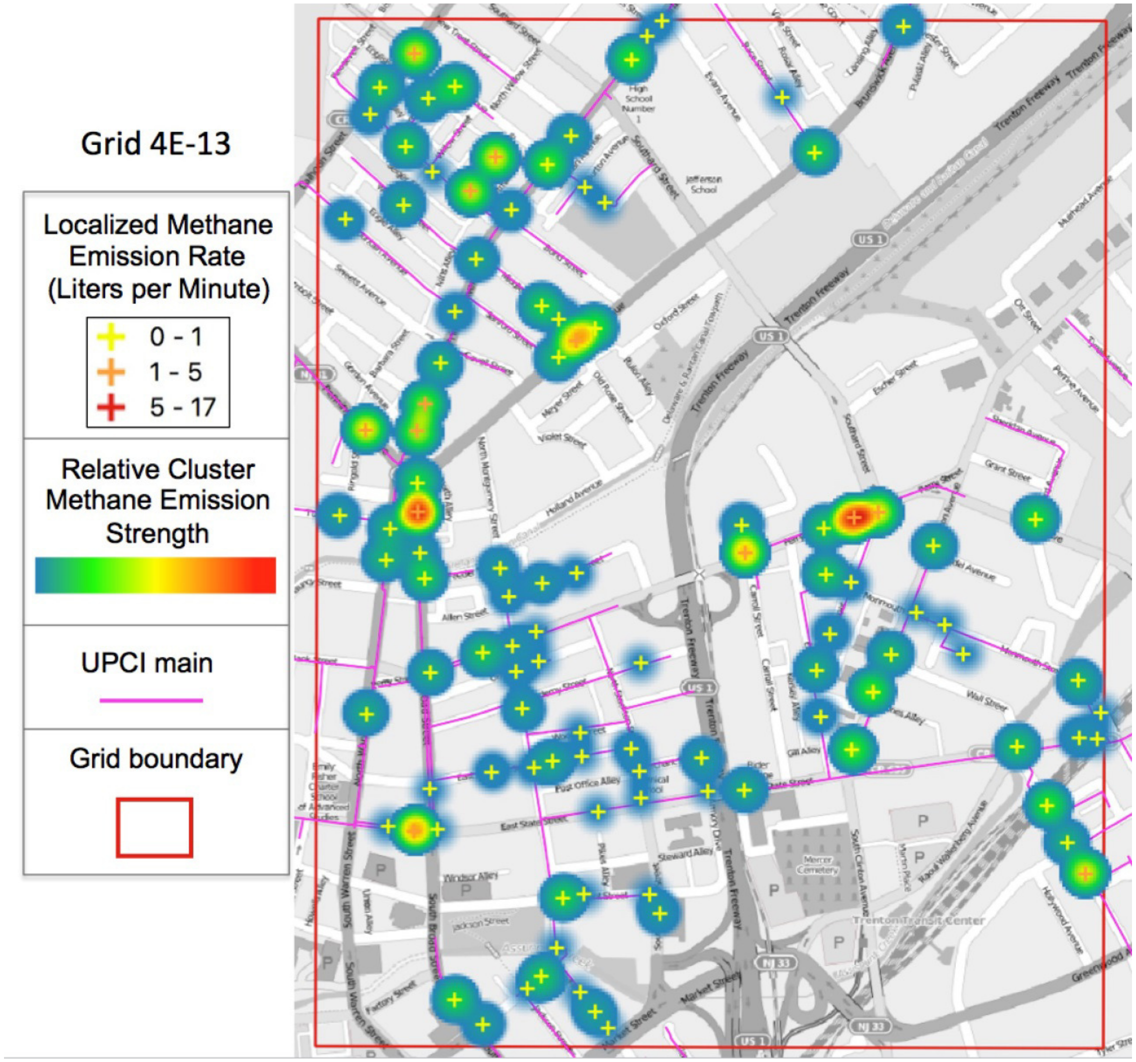
Reduction in Risk and Methane Mapping



Continuing to address the highest hazard main segments

Methane Quantification Survey

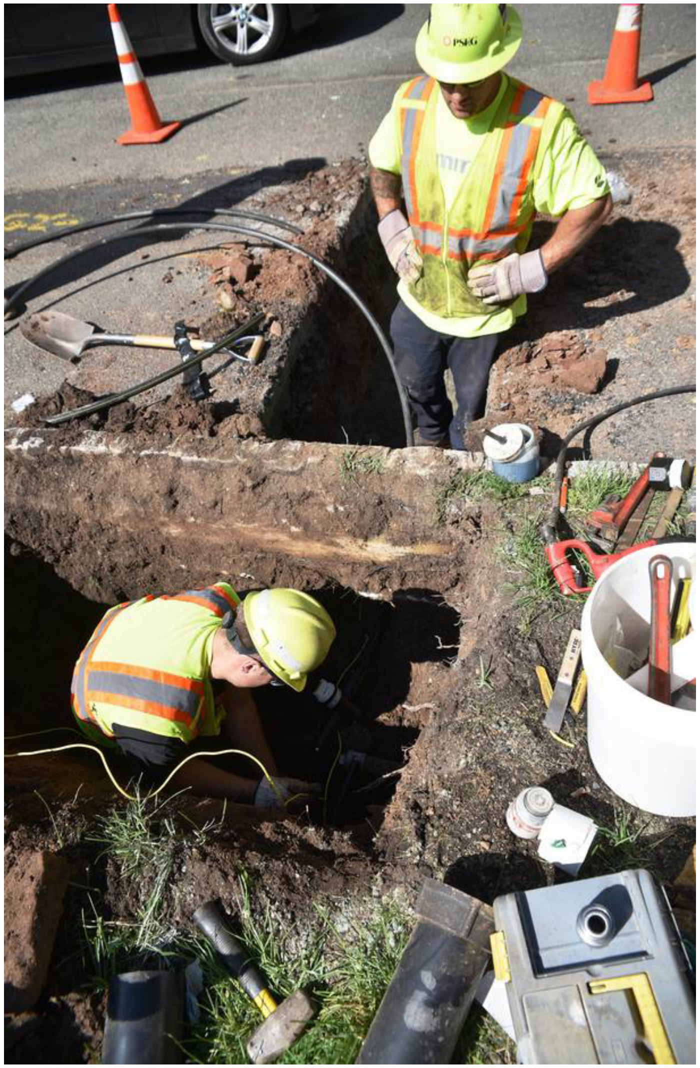
- Areas require 3 passes on each side of the street for proper sampling (95% statistical confidence interval)
- Indications are run through an algorithm with wind, vehicle speed, ethane content and other factors, leak rates are determined
- Heat maps can show areas of high emissions and calculated leak rates



Using GSMP II Results

- Discussion with EDF after data collected to set prioritization
- Threshold of 4.5 L/min/mi used for accelerating grids that were surveyed (down from 10 L/min/mi in GSMP I)
- 6 grids accelerated
- If retired sooner than "as is" plan, they account for 41% of the methane loss in only 16% of the grids surveyed
- Construction beginning in Spring of 2019

Key Takeaways



- Hazard Ranking and safety are highest priority
  - Hazard Rank and Leak Volume do not necessarily correlate
- Methane Emissions sub prioritization useful for areas of relatively equal hazard
  - Better for the environment
  - Less chance of non-hazardous leaks getting worse
  - Fewer potential customer calls/complaints
- Other LDC’s and PUC’s continue to discuss best applications for the technology's use

Questions?