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Urban Growth Impacts on High Consequence Area and Class Location Changes Using Orthoimagery and LiDAR Data Collection

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Abstract

Urban growth can have major impacts to small or large utility companies when attempting to ensure the safety of its customers. Segments of gas pipelines can be classified as High Consequence Area (HCA). Buildings near these HCA segments of pipeline can be at risk from the pipeline. New buildings and infrastructure can change pipeline segments designated as HCA. A Class Location structure is a unit or dwelling which has a class value (class 1-4) assigned to it based on the type of structure or dwelling, structure use, number of human occupancies, and days the structure or dwelling is occupied. LiDAR and remote sensing data collection can help utilities survey urban growth that may impact gas pipeline system. The use of web application and maps on mobile devices can collect and monitor HCA and Class Location changes from the field in real time. When field crews are surveying these HCA segments the data collected can be helpful to risk management groups to prioritize future planning and maintenance in the gas pipeline system. The project ensures all stakeholders have a useful tool to perform their day-to-day work and assists senior level employees in seeing how LiDAR and remote sensing mitigate risk and potential hazards. Interpreting the effects of urban growth on HCA and Class Location changes to Gas Pipeline System at Pacific Gas and Electric Co will further advance the company's use of ArcGIS Online capabilities such as sharing data and key information related to pipeline integrity quickly to multiple stakeholders. The project ensures all key stakeholders have a useful tool to perform their day-to-day work and senior level employees have the access to see how daily operations work to mitigate risk. The goal of this project is to determine the Class Location and HCA change differences between the Bay Area and Sacramento Regions, as there has been more construction in these locations which could impact gas transmission pipeline maintenance. Pacific Gas and Electric wants a better understanding for where the most changes might occur. Knowing potential impacts early on could benefit crews, engineers, and leak survey operations in how they prepare and plan for preventive maintenance in relation to HCA and Class Location changes.

Introduction

Urban growth, the rapid expansion of the geographic extent of cities and towns, is often characterized by low-density residential housing, single-use zoning, and increased reliance on the private automobile for transportation (Wilson et al., 2018) It has made a significant impact to Pacific Gas and Electric Company assessment of HCA segments of pipeline that can be at risk to the general population if these aren't maintained properly. Furthermore, class location of buildings and places of gathering along sections of HCA pipe can also have an impact on pipeline maintenance. Human impact has driven the need for Pacific Gas and Electric to take action to mitigate urban growth impacts. As the demand for housing continues to rise in California, the threats or risks to Pacific Gas and Electric's gas pipeline system increase. Gas transmission pipelines experience class change due to urban growth and land use changes such as the creation of a new public park or the expansion of a subdivision (Tran et al., 2018). Pipeline integrity teams must ensure pipelines are properly classified and then upgrade sections where classification levels have increased (Leis et al., 1994).

The Pipeline and Hazardous Materials Safety Administration also known as PHMSA, was created in 2004 by the U.S. Department of Transportation. The agency is responsible for developing and enforcing regulations for the safe, reliable, and environmentally sound operation of the US's 2.6-million-mile pipeline system. The agencies mission statement is “to protect people and the environment by advancing the safe transportation of energy and other hazardous materials that are essential to our daily lives” (Brown, 2012). PHMSA establishes national policy, sets and enforces standards, educates and conducts research to prevent incidents (NTSB, 2014). Pacific Gas and Electric prepares the public and first responders to reduce consequences if an incident occurs. Pacific Gas and Electric enforces the rules and regulations to uphold safety standards for all customers that it serves (NTSB, 2014). HCA and Class Location is just one of the requirements with which Pacific Gas and Electric must comply with to ensure safety and potential risks of fines.

Unfortunately, there have been instances where HCA pipeline segments weren’t properly attributed as HCA leading to inadequate maintenance in certain sections of the gas pipeline system. This can increase the potential risks of hazardous events occurring. On May 4th 2009, an incident occurred where an 18-inch-diameter interstate natural gas transmission pipeline, operated and owned by Florida Gas Transmission Company, ruptured in a sparsely populated area approximately six miles south of Palm City, Florida. The ruptured section was in a Class 1 location with no HCA identified sites. Therefore, this was not included in Florida Gas Transmission Company IM (Integrity Management) program. However, the post-accident review of the area by PHMSA determined that a neighboring high school qualified as an HCA identified site (NTSB, 2014). Because the potential impact radius intersected three semi-open structures at the nearby high school, the ruptured section should have been included in the Florida Gas Transmission Company IM program (NTSB, 2014).

Another instance occurred on September 9th, 2010 in San Bruno, CA, where a 30-inch diameter segment of a natural gas transmission pipeline, owned and operated by the Pacific Gas and Electric Company (PG&E), ruptured in a residential area. Although the ruptured pipeline was determined to be an HCA pipeline segment and was covered by PG&E’s IM program, the NTSB (National Transportation Safety Board) determined there was a poorly welded pipeline (NTSB, 2014). The segment ultimately ruptured during a pressure increase during a poorly planned maintenance session to address electrical problems. This caused major improvements in PG&E’s IM program to address the failures and lack of proper risk assessment.

In Sissonville, West Virginia, on December 11th, 2012, a 20-inch diameter natural gas transmission pipeline, owned and operated by the Columbia Gas Transmission Corporation, ruptured near Interstate 77 in a sparsely populated area. The ruptured pipeline was not an HCA pipeline segment, so this was not covered in Columbia Gas IM program (NTSB, 2014). Upon investigation, it was determined the ruptured segment was interconnected in a system that included two adjacent HCA pipelines. All three pipelines were protected against external corrosion threats using external coating and cathodic protection (NTSB, 2014). Improper records and maintenance and the improper maintenance of adjacent pipelines were to blame for this segment rupture.

The previous examples are just some of the instances where the misclassification of the ruptured section highlighted one of the core elements of an IM program in properly maintaining and determining HCA identification. **Figure 1** (NTSB, 2014) describes how utilities should design their integrity management program. PHMSA describes these policies as "A documented set of policies, processes, and procedures that are implemented to ensure the integrity of a pipeline” (NTSB, 2014). An Integrity Management program needs to include processes for determining which pipeline segments could affect a High Consequence Area (HCA). One process for continual integrity assessment and evaluation and an analytical process that integrates all available information about pipeline integrity and the consequences of a failure. The processes will help determine repair criteria to address issues identified by the integrity assessment method and data analysis (the rule provides minimum repair criteria for certain higher risk features identified through internal inspection). Another process should be designed to identify and evaluate preventive and mitigative measures to protect HCAs to measure the integrity management program's effectiveness. Lastly, a process for review of integrity assessment results and data analysis by a qualified individual." (Reference 49CFR 195.452, NTSB, 2014).

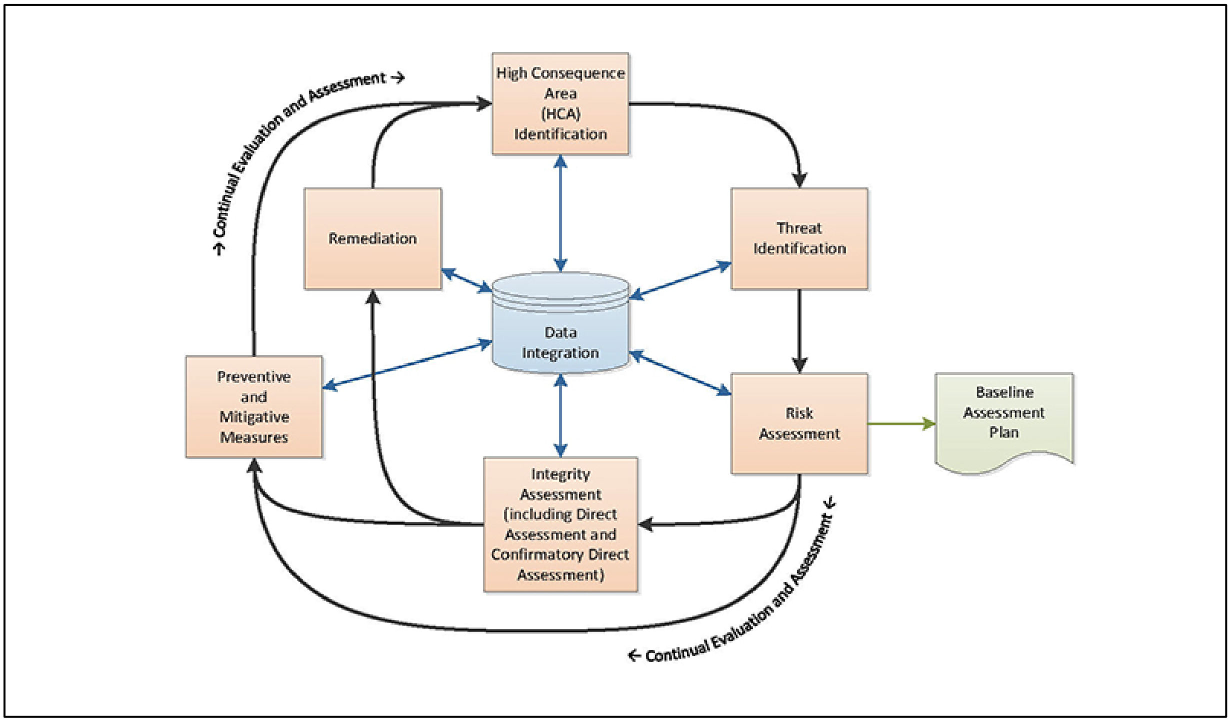

Figure 1. Chart of Continual Evaluation and Assessment for HCA Identification in an Integrity Management Program of Gas Transmission Pipelines. (Photo credit: Integrity Management of Gas Transmission Pipelines in High Consequence Areas (NTSB, 2014))

Class Location

A Class Location unit is defined as an area that extends roughly 660 feet on either side of the centerline of any continuous 1-mile length of pipeline (NTSB, 2014). Each separate dwelling unit in a multiple dwelling unit building is counted as a separate building intended for human occupancy. Building or structures are assigned one of 4 class location values, Class 1 to 4.

A Class 1 location is either an offshore area or any building that has 10 or fewer buildings intended for human occupancy (Porter et al., 2014). A Class 2 location is any building that has 11 to 45 buildings intended for human occupancy. A Class 3 location is either any building that has 46 or more buildings intended for human occupancy or an area where the pipeline lies within 100 yards (91 meters) of a common gathering place, which is described as small park, playground, or any well-defined outdoor area (i.e. a playground, recreation area, outdoor theater, or other place of public assembly) that is occupied by 20 or more persons on at least 5 days a week for 10 weeks in any 12-month period. (The days and weeks need not be consecutive.) (Yuan et al., 2005). A Class 4 location is any class location unit where "buildings with four or more stories above ground" (Wilson et al., 2019).

Pipelines experience class location change due to urban growth and land use changes such as the creation of a new public park or the expansion of a subdivision. Class Location changes are currently updated annually but hopefully in the future this could become a quarterly review. Pipeline integrity teams must ensure pipelines are properly classified and then upgrade sections where classification levels have increased.

High Consequence Areas (HCA)

The U.S. Department of Transportation defines a High Consequence Area (HCA) as "A location that is specially defined in pipeline safety regulations as an area where pipeline releases could have greater consequences to health and safety or the environment. For oil pipelines, HCAs include high population areas, other population areas, commercially navigable waterways and areas unusually sensitive to environmental damage. Regulations require a pipeline operator to take specific steps to ensure the integrity of a pipeline for which a release could affect an HCA and, thereby, the protection of the HCA." (NTSB, 2014).

HCAs are within 660 feet (200 meters) of a segment of pipeline which passes through developed areas where people live in an urban or suburban setting, or where they frequently gather, like a school or shopping center (NTSB, 2014). Gas pipelines within an HCA are required to have extra safety features or extra precautions in place. Although HCAs are commonly assumed to run through areas with a high population density, that is not the full picture of how HCAs are designated (Karantzalos et al., 2015). There is a detailed process that gas utilities must follow to determine where an HCA is located.

A critical component in determining an HCA is the potential impact radius (PIR). PIR means the radius of a circle within which the potential failure of a pipeline could have significant impact on people or property, shown in **Figure 2** below.

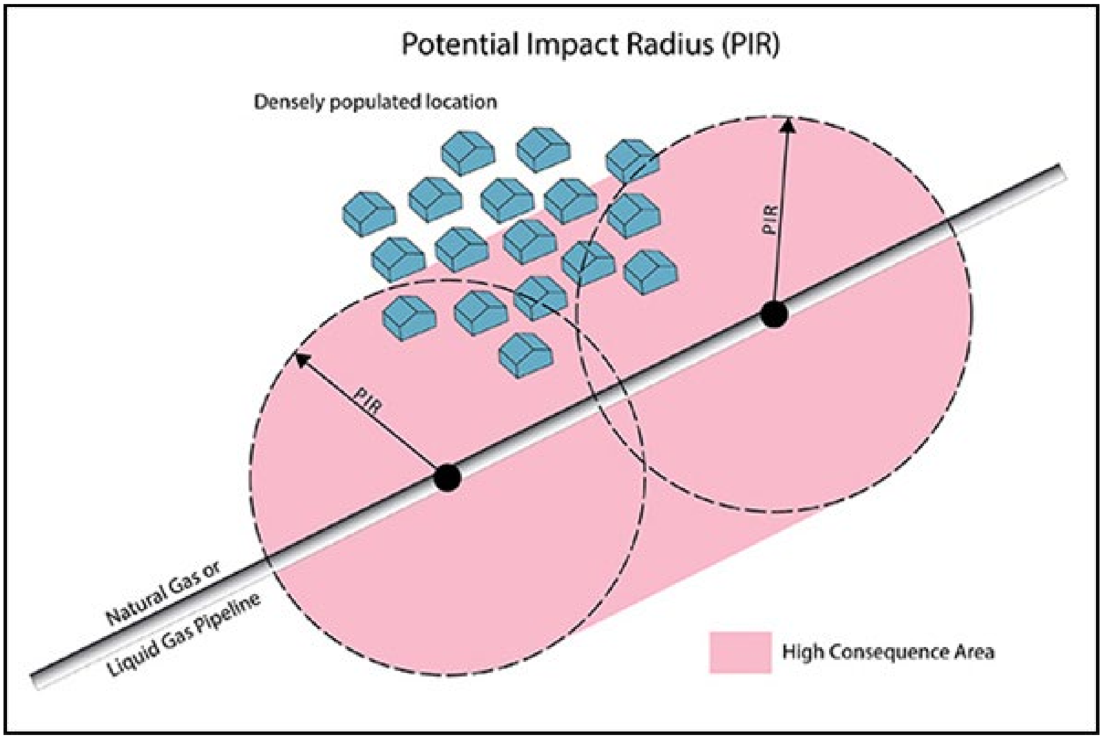

Figure 2. The extent of the potential impact radius (PIR) from the pipeline depends on the contents and pressure within pipeline. If the PIR contains a densely populated area or other designated feature such as a school, then an HCA is established, as shown in shaded area. (Photo Credit: PHMSA, Cohesive Solutions, 2019).

The descriptions that are used to determine HCA are established by one of two methods listed in Title 49 § 192.903: A Class 3 or Class 4 location or any area in a Class 1 or 2 location where "the potential impact radius is greater than 660 feet (200 meters), and the area within a potential impact circle contains 20 or more buildings intended for human occupancy" and any area in a Class 1 or Class 2 location where the PIR contains an identified site (NTSB, 2014). The second method of identifying an HCA area, is "an area within a PIR containing either an identified site, or 20 or more buildings intended for human occupancy, with some exceptions" (NTSB, 2014).

When utilities can properly identify locations where a pipeline failure might impact an HCA this will reduce the risk of damage from failure and better serve the community. Gas utilities must be responsible for repairing identified pipeline defects, conducting a risk analysis to identify the most significant pipeline threats, regularly evaluating all information about the pipeline including threats, and evaluating the effectiveness of the IM program to find ways to improve (Stephens, 2002).

Orthoimagery and LiDAR

Orthoimagery and LiDAR data collection can be a powerful tool to detect human or environmental activity that can impact Pacific Gas and Electric Co. assets. Change detection is described as follows; “The surface of the earth changes continuously due to the natural phenomena or human activities. The process of identifying the changes which has occurred over time on the earth surface is called change detection. Change detection of earth’s surface is carried out effectively in the field of remote sensing using various techniques.” (Mishra et al., 2017). Remote sensing and LiDAR data collection can help stakeholders at Pacific Gas and Electric Co. identify new risks such as construction of new buildings or outdoor areas near areas not previously identified as HCA and determine if segments of gas pipeline need to be attributed to an HCA designation (Bouziani et al., 2010).

The advantages of using LiDAR and remote sensing data collections to help conduct surveys are: quick collection, high accuracy, and high sample density (Akbulut et al., 2018). The high sample density improves results for certain applications, such as the collection of LiDAR data in a densely vegetated area, where photogrammetry fails to reveal the accurate terrain or built surface due to dense canopy cover (Akbulut et al., 2018). LiDAR uses an active illumination sensor and can be collected day or night when compared to traditional photogrammetric techniques and can be easily integrated with other data sources (Ishimaru et al., 2012). In **Figure 3**, we can see two sets of orthoimages showing changes along the pipeline right of way where a building did not exist in March 2013 but now does in November 2014. In this project I will be processing LiDAR data collection to create orthophotographic imagery similar to **Figure 3** to help see changes or a new risk in the right of way of the gas transmission pipe for Pacific Gas and Electric Co.

Figure 3. Airborne data collection alerting a utility company that there is a warehouse in the impact area of the gas pipeline. (Brown, 2012)

Figures 4 and 5, are examples of where LiDAR and Remote Sensing collection which has been processed into ortho images can be useful in helping Pacific Gas and Electric Co notices building changes near gas assets and are aware of any potential changes to HCA and Class Location in these areas.

Figure 4. Image on left shows one single family home on a large property. Image on Right shows previous location now has 11 new homes where previously there was only one. (Photo Credits: Enview and Pacific Gas & Electric)

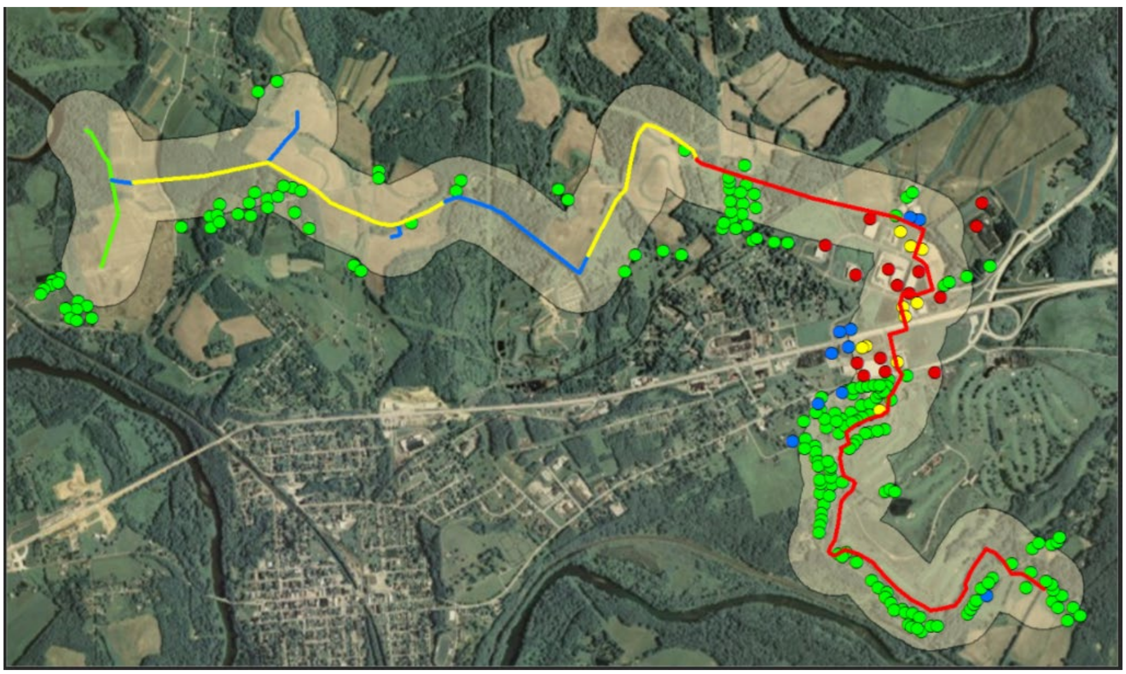

Figure 5. Map showing PIR buffer, containing color coded Gas Transmission Pipeline indicating which HCA line segments are Class 1 (Green), Class 2 (Blue), Class 3 (Yellow), and Class 4 (Red) sections. Class 4 locations of building or dwellings (points) are shown in Red, Class 3 in Yellow, Class 2 in Blue, and Class 1 in green.

Project Study Area

The study area for this project is the Bay Area region in California. There has been an increase in construction, such as new housing developments occurring in these locations. The increase of population in these areas or moving to the other can increase risk and safety Pacific Gas and Electric must take into account as urban growth is happening in these areas. **Figure 6** shown below, indicate the vicinity of the project area and counties that will be used to investigate urban growth impacts on HCA and Class Location changes. **Figure 6** shows the Bay Area region which consists of nine counties: Sonoma, Napa, Marin, Solano, Contra Costa, Alameda, San Francisco, San Mateo, and Santa Clara. These areas contain majority of the Bay Area population and areas of interest to Pacific Gas and Electric Co (PG&E) as there are numerous construction projects near gas pipelines.

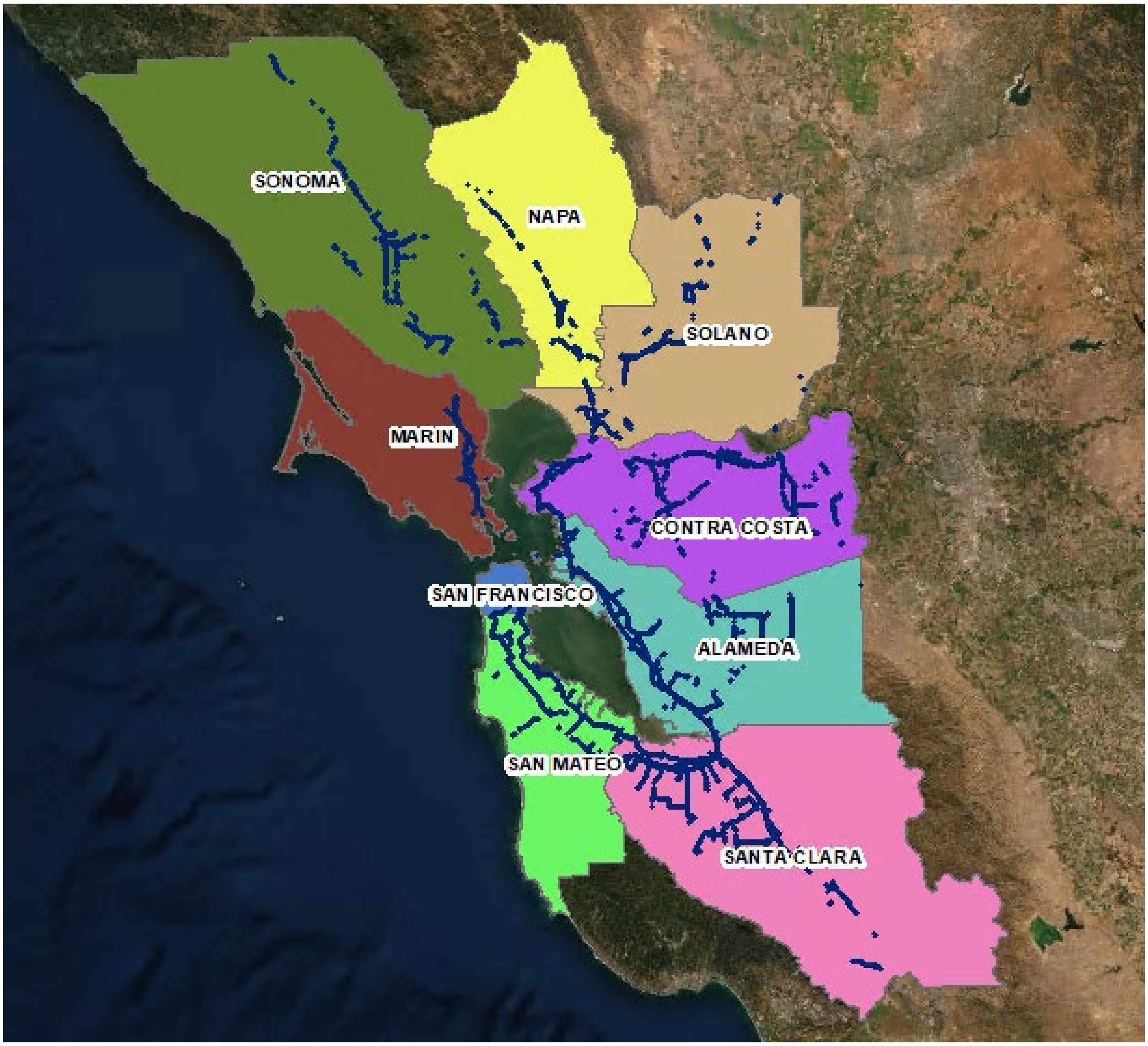

Figure 6. Bay Area Region study area. Blue Lines represent the Gas Transmission Pipelines classified as HCA pipelines in the Bay Area Region.

Methodology

The methodology for this project (**see Figure 7**) was to create orthophotographic imagery using acquired LiDAR, overlaying our Structures layer, and creating a PIR buffer to help identify HCA and Class Location changes to existing, removed, or new structures and update our Gas Transmission Pipeline layer.

Figure 7, begins with data collection (see **Figure 7** (b)) via fixed winged aircraft equipped with a LiDAR sensor to fly over our gas transmission pipeline in the Bay Area and Sacramento regions. The fixed winged aircraft uses the previous year's PIR buffer for the coverage area along the gas pipeline in the study area. Once data is received, LiDAR processing, point cloud generation, and ground filtering techniques (see **Figure 7** (c-d)) were applied to remove unwanted discrepancies to create the orthoimagery, DEM, DSM, and TIN models for potential other uses for other stakeholders in the company.

A segmentation process is first initialized by a region growing method from an automatically selected ground seed (see **Figure 7** (c)). Then the method adds neighbor points based on three mathematical measurements of the points to the mathematical plane represented by points in a segment and eventually separates LiDAR point clouds into segments that are corresponding to surface objects (Tran et al., 2018). The second stage utilizes those segments as basic elements for a least-square linear interpolation by incorporating an adaptive weight function to minimize the weights for segments from non-ground objects (Yuan et al., 2005).

One of the ground filtering techniques (see **Figure 7** (d)) applied were segmentation and clustering. These are popular techniques for land-use and land-cover classification, and researchers have been trying to implement this approach to separate discrete LiDAR point clouds (Tran et al., 2018). For example, Tran et al. (2018) performed a clustering classification to separate ground features into four types using point position information, elevation difference to neighbors, and parameter description from the point to its tangent plane.

Once the ground filtering (see **Figure 7** (d)) had taken place, we were able to identify and create a new building layer from our data collection and make mosaiced orthophotos to use for our analysis. Identifying HCAs (see **Figure 7** (f)) consists of using the previous year's information and comparing to our new collection to determine whether the class location has changes on existing buildings and updates to the PIR buffer. New buildings will need to have a class location assigned to them based on the criteria mentioned previously (see HCA and Class Location sections (**Figure 7** (i-s))).

The process of updating the HCA and Class Location structure layer (**Figure 7** (u-z)), begins with utilizing previous years imagery for example 2015-2020 imagery was used to validate additions and removals of structures that were previously not an HCA structure or the structure was already an HCA structure. I also used the existing Care Facility layer to help identify where our previous Care Facilities were to ensure these types of HCA structures still were a Care Facility or not when updating the new structure collection. All critical fields such as building type, HCA (Y/N), building count, number of occupancies, Class (1, 2, 3, 4), date entered, and building description were updated when reviewing each year's data collection. Once QA/QC of the new structure updates were completed, the structure identified as "HCA = Yes" would then be uploaded into the master database layer containing existing HCA structures. From here, I was able to create a new HCA and Class Location pipeline and structure layer to be used by the company and further analysis in this study. (see **Figure 7** (f and h)). These new layers were then able to be used to create dashboards and metrics as needed for various stakeholders in Pacific Gas and Electric Company.

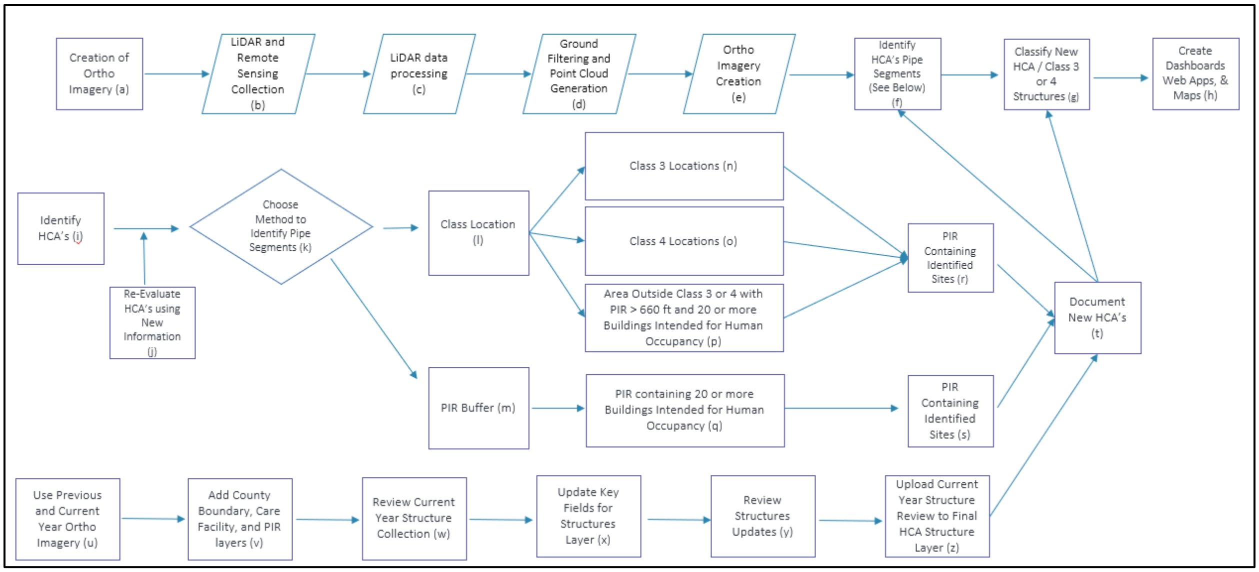

Figure 7. Project Workflow

Results and Discussion

The HCA and Class Location changes from 2015-2020 from the nine counties in the Bay Region have shown signs of urban growth areas where gas transmission pipeline segments were already HCA and new pipeline segments were added throughout this timeframe. HCA structure counts show an increase throughout the study period in each county. New structures being built or existing building with increased occupancy have affected the increase in HCA pipeline and HCA structures in the Bay Area region. **Figures 8-25** show for each county the miles of HCA pipeline and structure changes throughout the study period 2015-2020. Below is a county-by-county analysis.

Alameda County:

In Alameda County, the mileage of HCA pipeline increased by around 1.25 miles combined in the years 2015 to 2016 but there was an increase of 26.5 miles in 2017 (**Figure 8**). This observation coincides with the structure count increase shown in **Figure 9** as we can see that 170 and 187 new HCA structures were added in 2015 and 2016. In 2017, there was an increase in mileage of HCA pipeline which was expected from the new construction that had been completed in 2015 and 2016. Most of the locations in this time frame were new warehouses, apartments, and transportation infrastructure updates to the local transit system such as widening of roads, expansion of existing rail stations, and parking structures in Alameda County. Another indicator of urban growth occurring in the county was see in late 2019 and 2020. There was an increase in HCA pipeline of around 3 miles in 2019 but in 2020 the mileage of HCA pipeline increased by 10 miles. The increase in the later years of the study period for this project were due to a new section of a hospital and transit center being completed in Oakland. There were also newer condos and townhomes built near Oakland and in Dublin which account for majority of the increase in miles and HCA structures during 2019 and 2020.

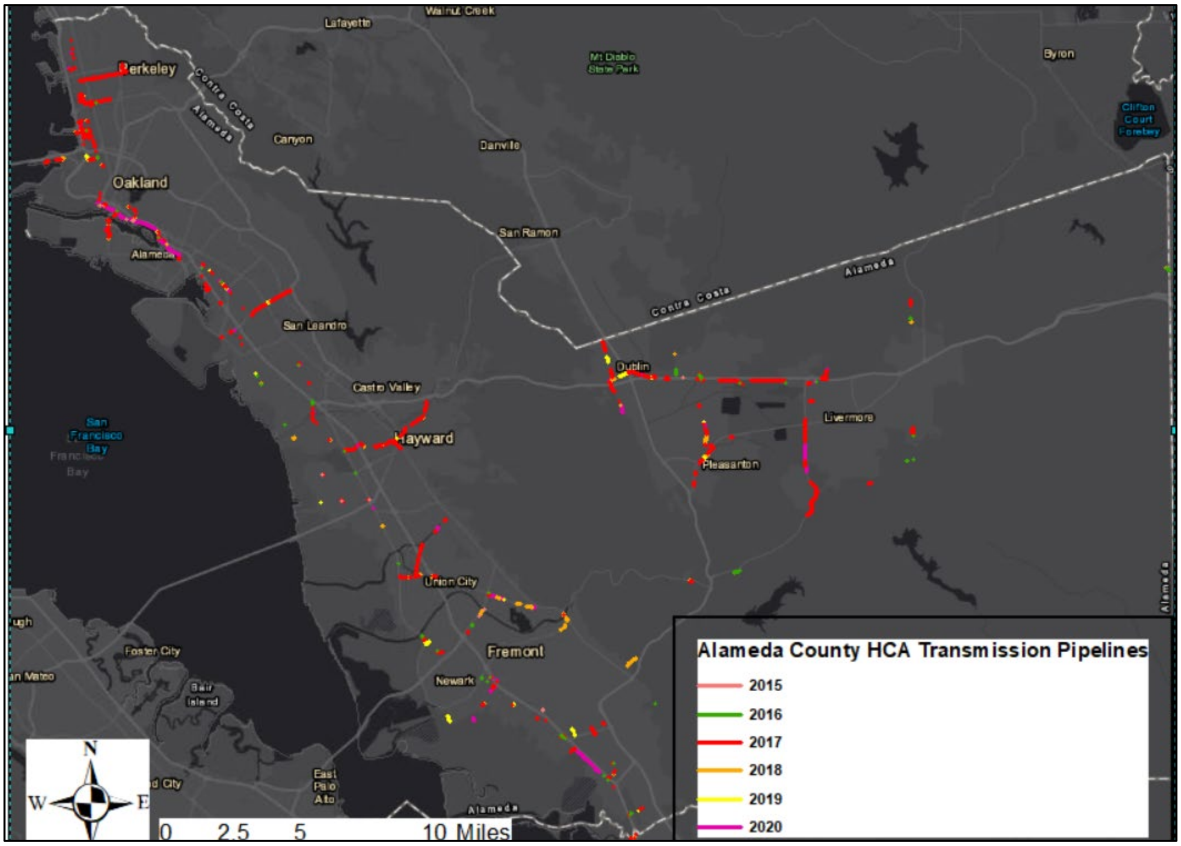

Figure 8. Alameda County HCA Gas Transmission Pipelines. Colors show year by year HCA pipeline segment additions from 2015-2020 in Alameda County. 2015 HCA pipeline segments are shown in pink. 2016 HCA pipeline segments are shown in green. 2017 HCA pipeline segments are shown in red. 2018 HCA pipeline segments are shown in orange. 2019 HCA pipeline segments are shown in yellow. 2020 HCA pipeline segments are shown in purple.

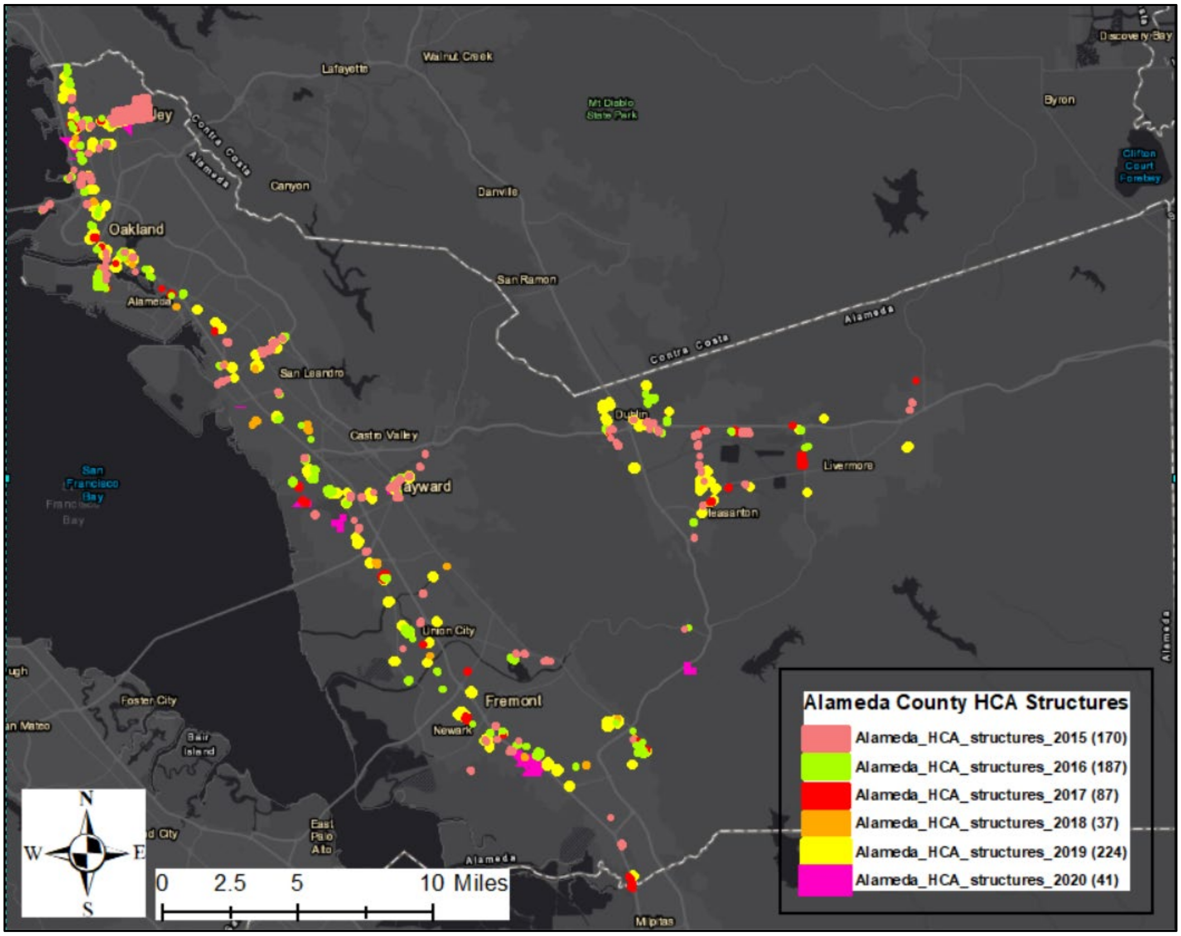

Figure 9. Alameda County HCA structures. Colors show year by year HCA structure additions from 2015-2020 in Alameda County. 2015 HCA structures are shown in pink. 2016 HCA structures are shown in green. 2017 HCA structures are shown in red. 2018 HCA structures are shown in orange. 2019 HCA structures are shown in yellow. 2020 HCA structures are shown in purple. Number of HCA structure additions by year are shown in paratheses in the legend.

Contra Costa County:

Contra Costa County showed a similar pattern seen in Alameda County where in 2015 and 2016 there was a minor increase in HCA pipeline mileage added to the existing amount but then in 2017, an increase of 25 miles of HCA pipeline (see **Figure 10**). The HCA structure increased during this time as well (**Figure 11**). We saw an addition of 778 HCA structures due to new additions to public transit, outdoor gathering areas such as updates to trails and parks. In the eastern portion of Contra Costa County, the jump in structures in 2016 is due new homes and a golf course under construction in the Brentwood area. The second spike in HCA structures in our database is shown in 2019. The factors behind the increase were new townhomes being built throughout the county. There were also a number of new businesses opening in existing or new shopping centers which accounted for the increase in HCA structures in Contra Costa County.

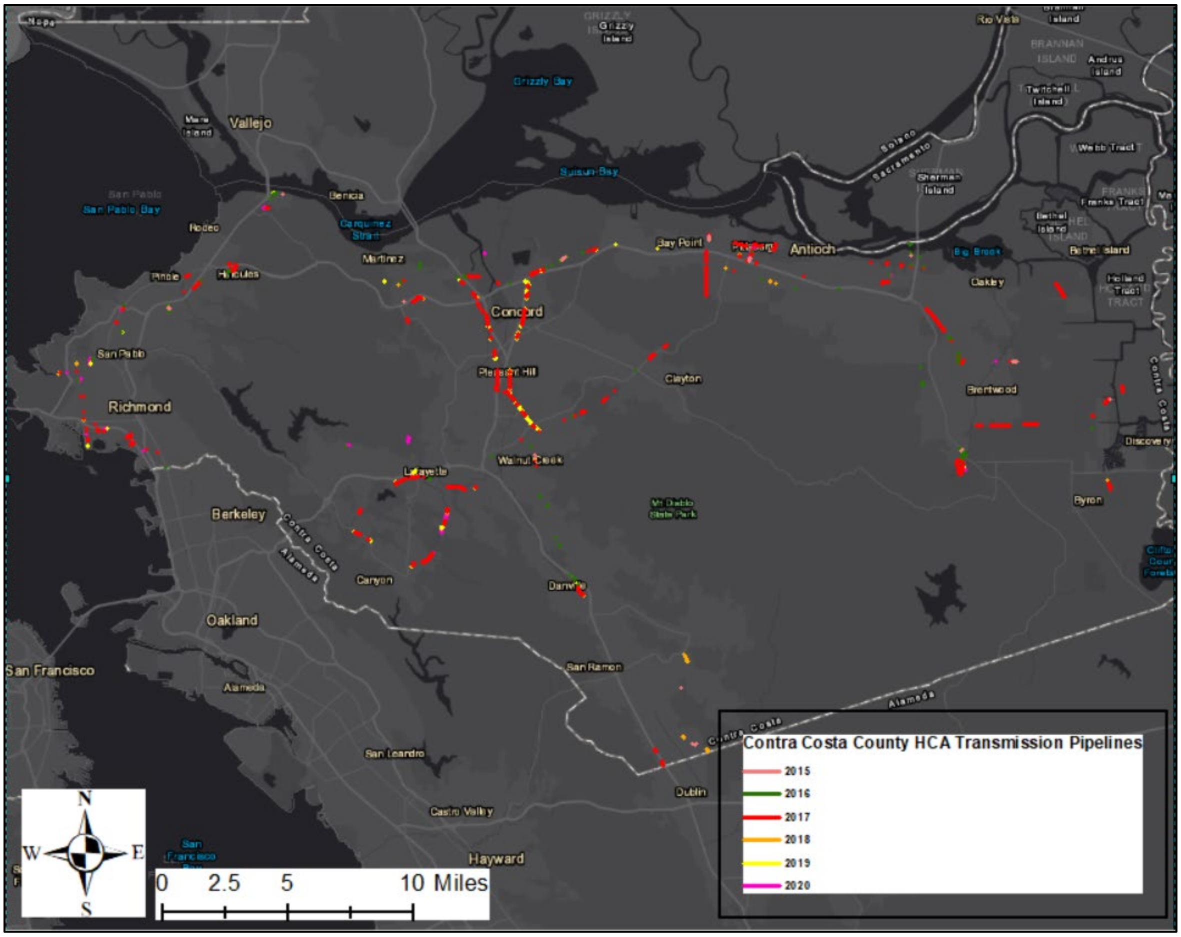

Figure 10. Contra Costa County HCA Gas Transmission Pipelines. Colors show year by year HCA pipeline segment additions from 2015-2020 in Contra Costa County. 2015 HCA pipeline segments are shown in pink. 2016 HCA pipeline segments are shown in green. 2017 HCA pipeline segments are shown in red. 2018 HCA pipeline segments are shown in orange. 2019 HCA pipeline segments are shown in yellow. 2020 HCA pipeline segments are shown in purple.

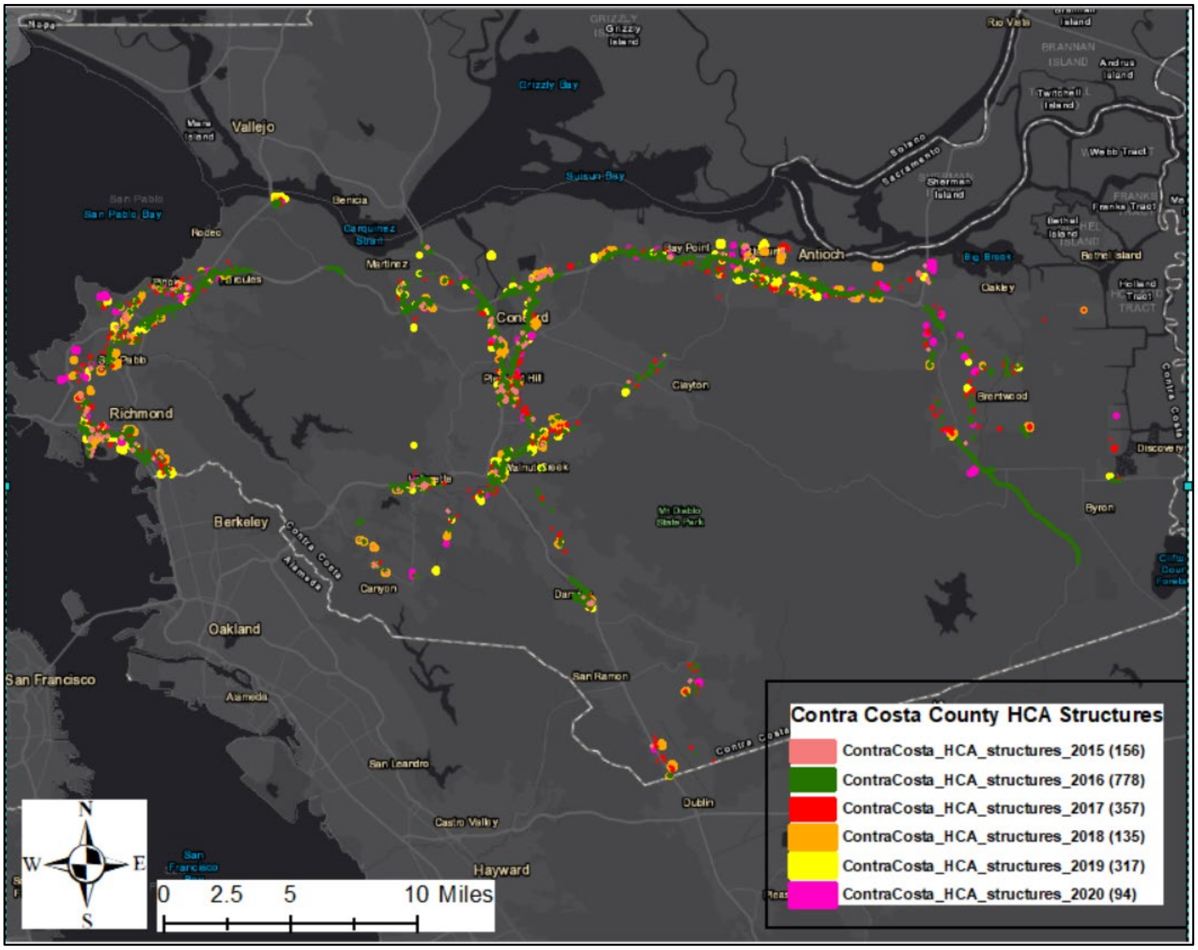

Figure 11. Contra Costa County HCA structures. Colors show year by year HCA structure additions from 2015-2020 in Contra Costa County. 2015 HCA structures are shown in pink. 2016 HCA structures are shown in green. 2017 HCA structures are shown in red. 2018 HCA structures are shown in orange. 2019 HCA structures are shown in yellow. 2020 HCA structures are shown in purple. Number of HCA structure additions by year are shown in paratheses in the legend.

Marin County:

Marin County signs of urban growth were noticeable in the 2017 timeframe with the mileage of HCA pipeline segments increasing by 11 miles that year (**Figure 12**). From 2018 to 2020, the HCA pipeline miles increase by a total of 7 miles. Coincidently, the HCA structures also began to increase in the same timeframe as HCA pipeline increases. The factors behind the increase in these years were due to expansion of roads and new pipeline being installed to provide for business that were opening in the area. We can also see from **Figure 13** the HCA structure count increased by 329 in 2019, in part due to the road and pipeline projects being completed first then the new businesses, expansion of the transit center in San Rafael, and new apartment buildings.

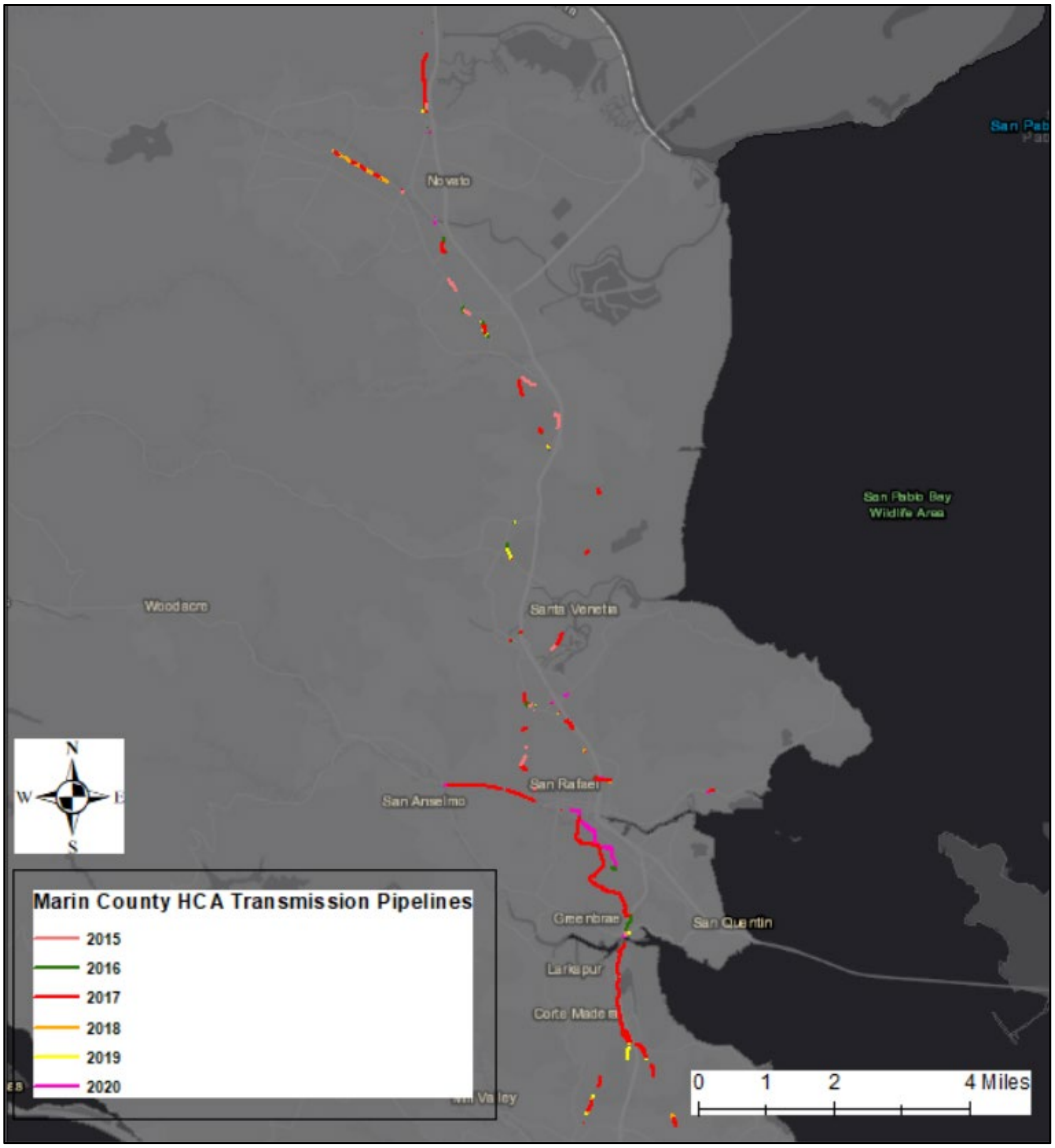

Figure 12. Marin County HCA Gas Transmission Pipelines. Colors show year by year HCA pipeline segment additions from 2015-2020 in Marin County. 2015 HCA pipeline segments are shown in pink. 2016 HCA pipeline segments are shown in green. 2017 HCA pipeline segments are shown in red. 2018 HCA pipeline segments are shown in orange. 2019 HCA pipeline segments are shown in yellow. 2020 HCA pipeline segments are shown in purple.

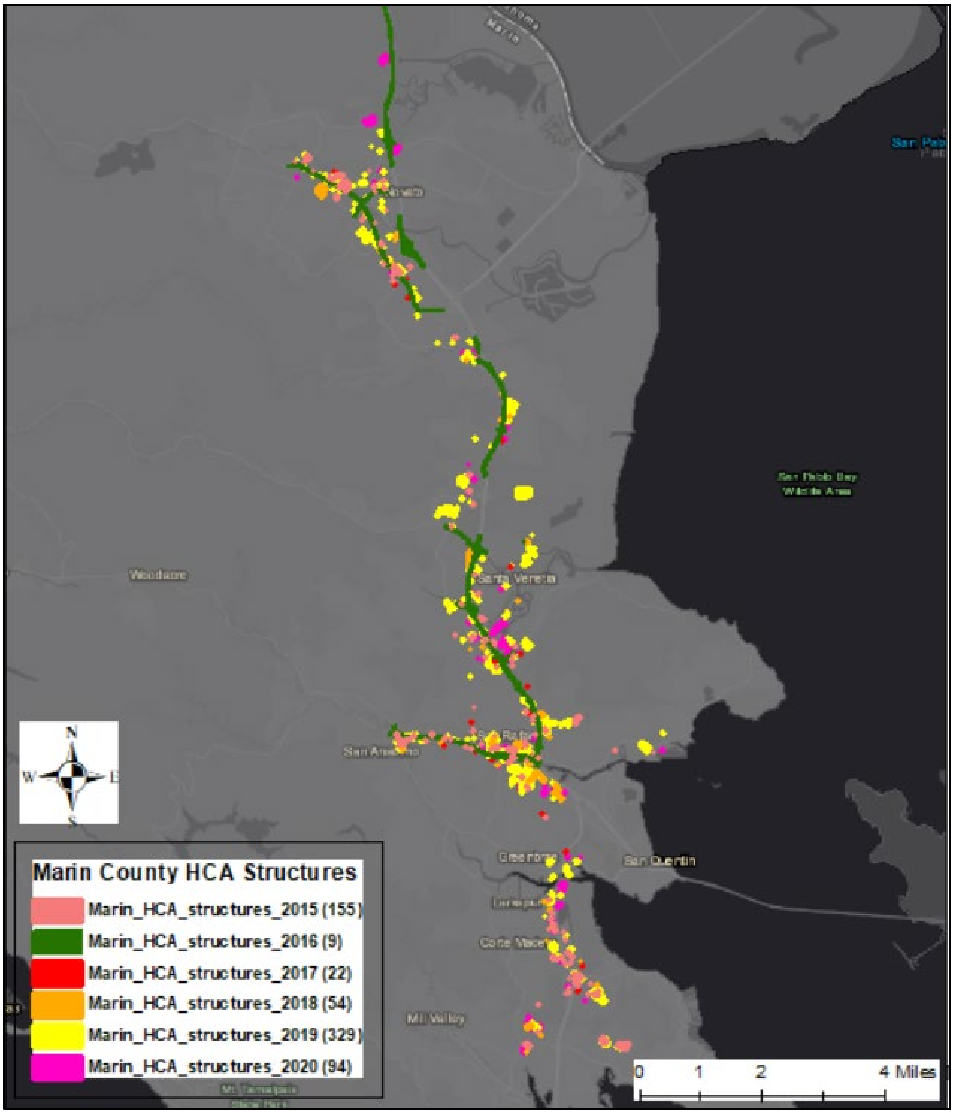

Figure 13. Marin County HCA structures. Colors show year by year HCA structure additions from 2015-2020 in Marin County. 2015 HCA structures are shown in pink. 2016 HCA structures are shown in green. 2017 HCA structures are shown in red. 2018 HCA structures are shown in orange. 2019 HCA structures are shown in yellow. 2020 HCA structures are shown in purple. Number of HCA structure additions by year are shown in paratheses in the legend.

Napa County:

Napa County was affected by wildfires during the project study period, which is noticeable in the small increase in HCA pipeline segment mileage added. Also, new HCA structures were built or existing areas increased the number of HCA structures in the county. The mileage throughout the study period was only a total of 9 miles being added in Napa County (**Figure 14**). In **Figure 15**, we can see post 2017 wildfires impacted the area, with homes and wineries being rebuilt in 2018. In 2019, more apartment complexes, business, and improvements to the downtown Napa area were the key factors of the HCA structure count increasing by 453 in Napa County. Overall, we can see here how a wildfire impacted a slow increase in HCA structures over time as the area recovered.

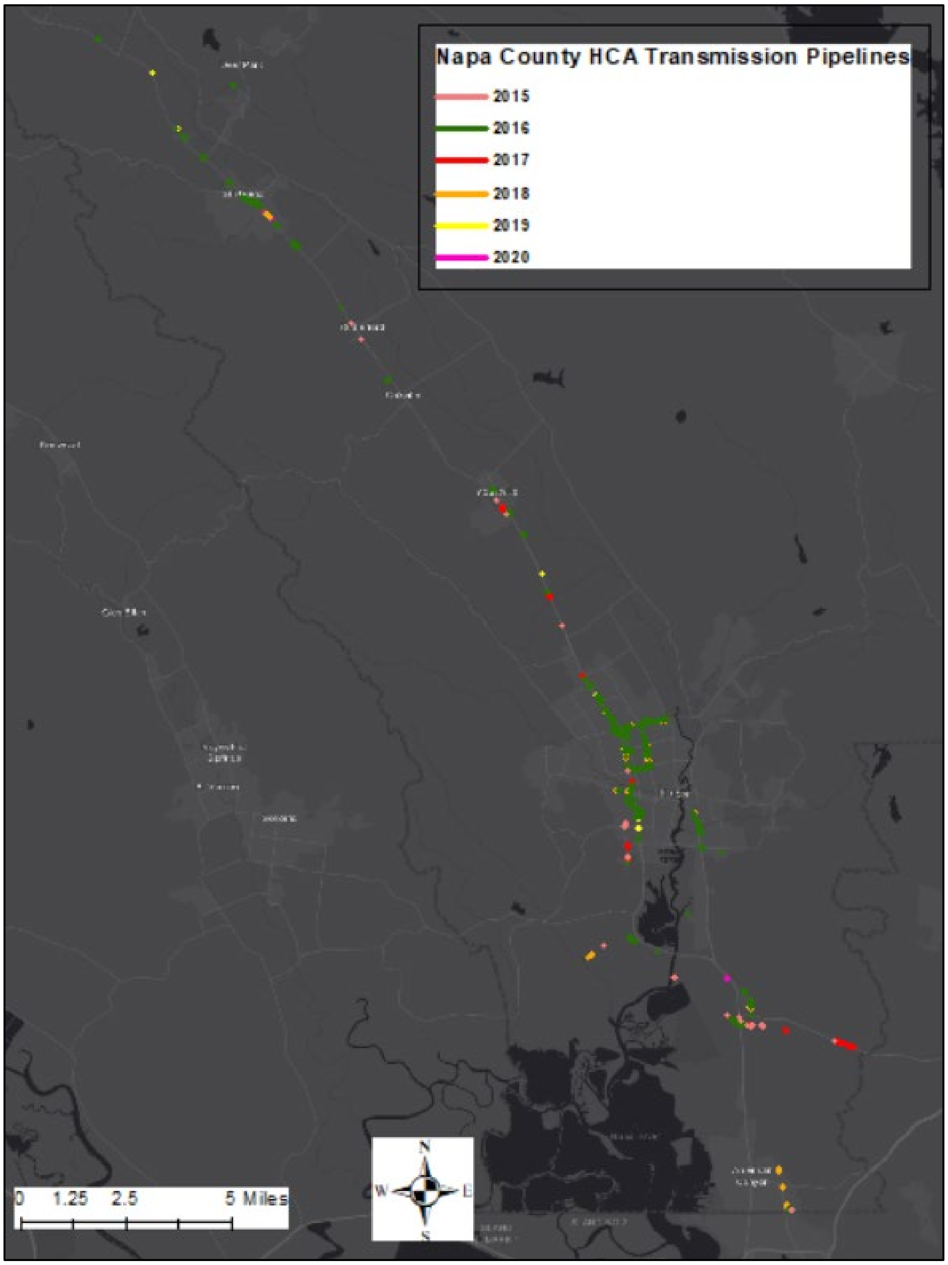

Figure 14. Napa County HCA Gas Transmission Pipelines. Colors show year by year HCA pipeline segment additions from 2015-2020 in Napa County. 2015 HCA pipeline segments are shown in pink. 2016 HCA pipeline segments are shown in green. 2017 HCA pipeline segments are shown in red. 2018 HCA pipeline segments are shown in orange. 2019 HCA pipeline segments are shown in yellow. 2020 HCA pipeline segments are shown in purple.

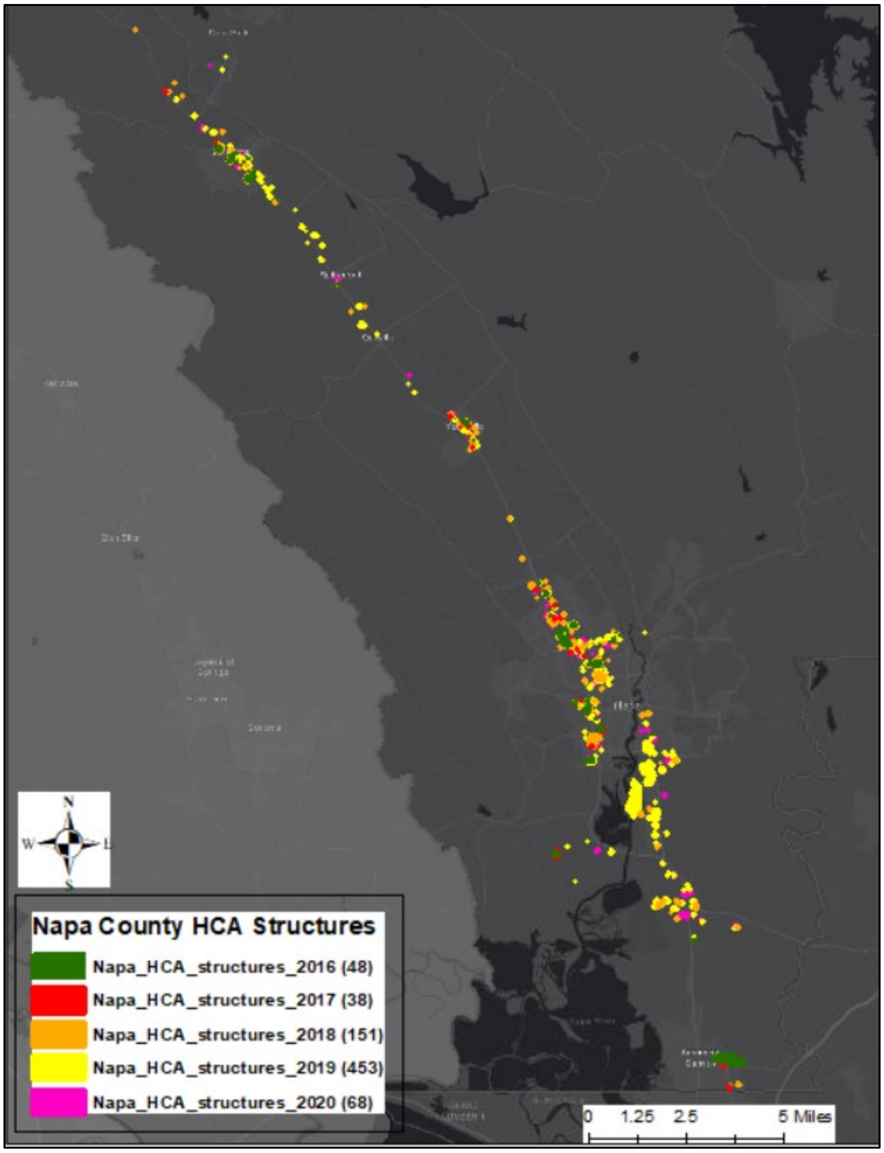

Figure 15. Napa County HCA structures. Colors show year by year HCA structure additions from 2015-2020 in Napa County. 2015 HCA structures are shown in pink. 2016 HCA structures are shown in green. 2017 HCA structures are shown in red. 2018 HCA structures are shown in orange. 2019 HCA structures are shown in yellow. 2020 HCA structures are shown in purple. Number of HCA structure additions by year are shown in paratheses in the legend.

San Francisco County:

In San Francisco there was an addition of 2.6 HCA miles of transmission pipeline was due to a new segment of pipeline being installed shown in purple in **Figure 16**. The increase in HCA structures (see **Figure 17**) in 2019 and 2020 was in part to the Chase Center development and opening in the area.

The new arena drove an influx of new condos being built and abandoned lots or buildings being developed, causing the increase in HCA structures for the county.

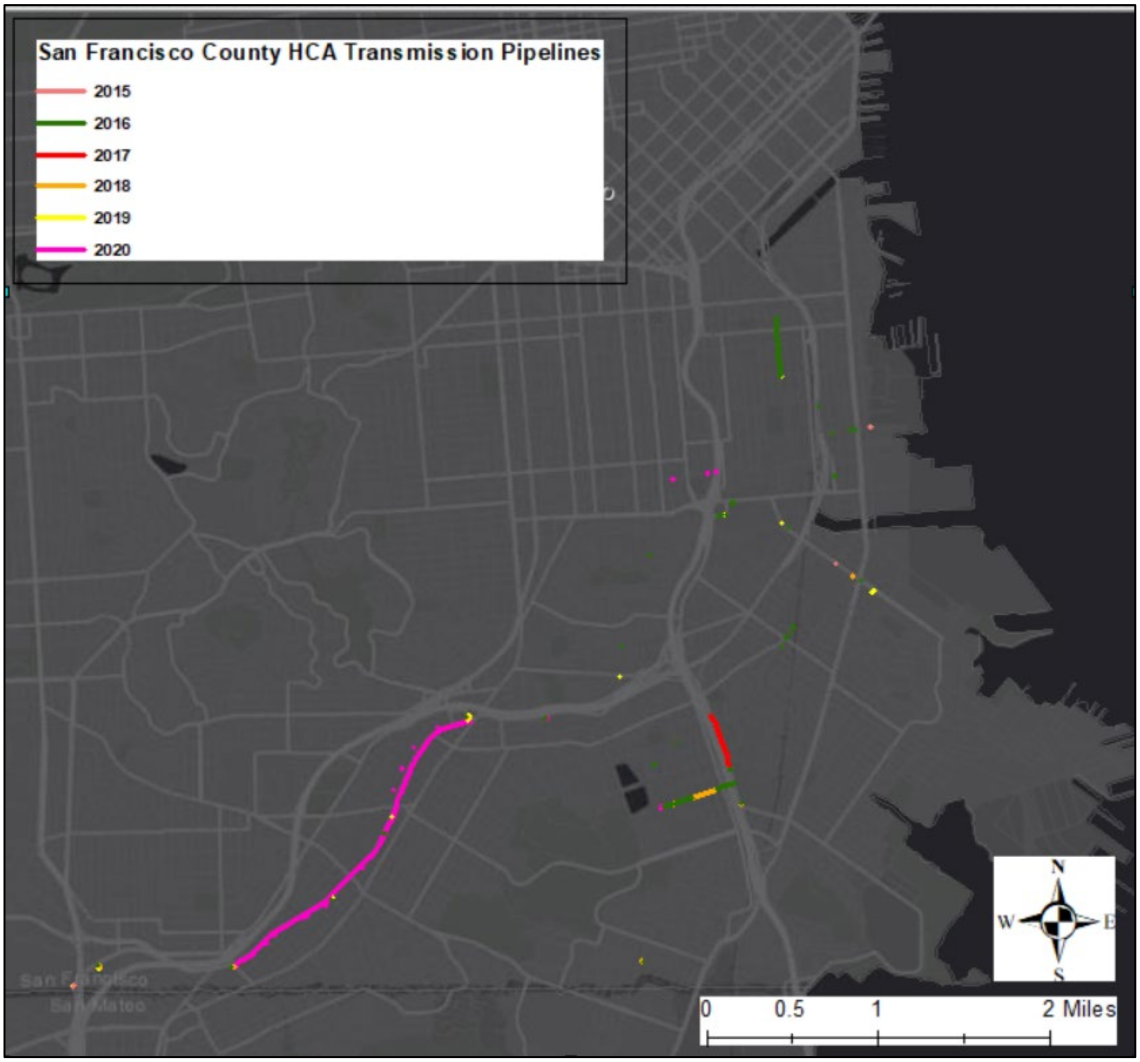

Figure 16. San Francisco County HCA Gas Transmission Pipelines. Colors show year by year HCA pipeline segment additions from 2015-2020 in San Francisco County. 2015 HCA pipeline segments are shown in pink. 2016 HCA pipeline segments are shown in green. 2017 HCA pipeline segments are shown in red. 2018 HCA pipeline segments are shown in orange. 2019 HCA pipeline segments are shown in yellow. 2020 HCA pipeline segments are shown in purple.

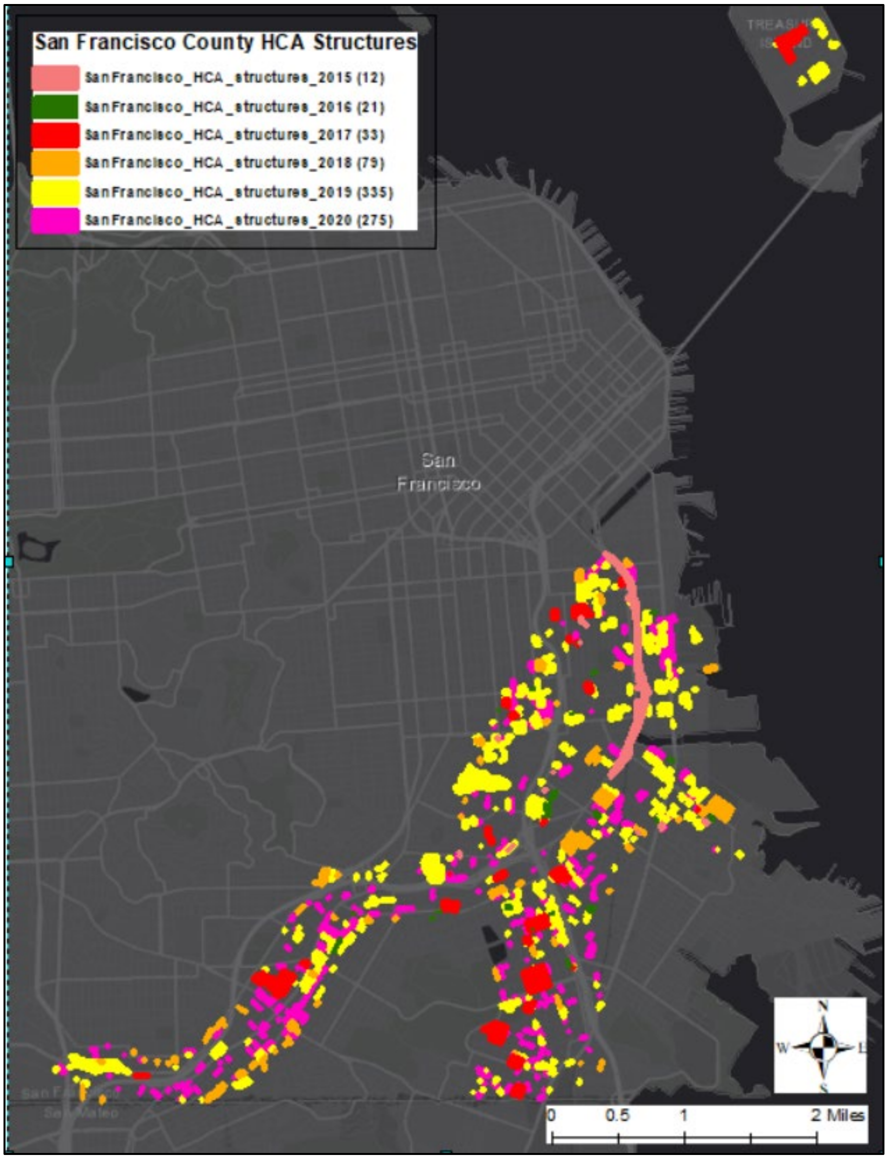

Figure 17. San Francisco County HCA structures. Colors show year by year HCA structure additions from 2015-2020 in San Francisco County. 2015 HCA structures are shown in pink. 2016 HCA structures are shown in green. 2017 HCA structures are shown in red. 2018 HCA structures are shown in orange. 2019 HCA structures are shown in yellow. 2020 HCA structures are shown in purple. Number of HCA structure additions by year are shown in paratheses in the legend.

San Mateo County:

San Mateo County has had minor increases in HCA pipeline segment since 2016. In the years 2017 to 2020 the HCA pipeline mileage increased by 6 miles as we can see in **Figure 18.** In 2016**,** there was increase of 23 miles. In **Figure 19** we can see a fair amount of increase in HCA structures but with 2019 seeing the most drastic increase with 943. The reason for the increase in HCA pipeline segments was the same as for San Francisco County, with a number new transmission pipeline being installed. The HCA structures had a major jump in 2019 due to numerous additions to existing shopping centers, offices, condos, apartments, and outdoor gathering areas being added to areas where existing HCA pipeline segments were already in place throughout the county.

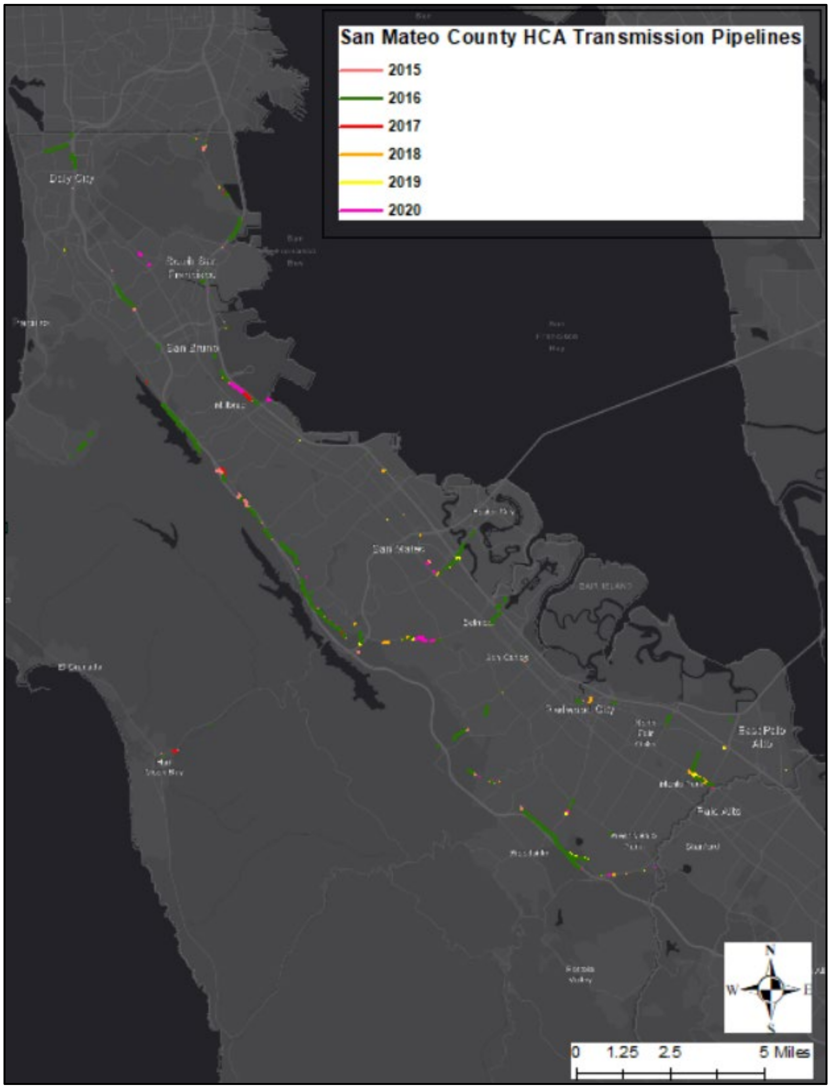

Figure 18. San Mateo County HCA Gas Transmission Pipelines. Colors show year by year HCA pipeline segment additions from 2015-2020 in San Mateo County. 2015 HCA pipeline segments are shown in pink. 2016 HCA pipeline segments are shown in green. 2017 HCA pipeline segments are shown in red. 2018 HCA pipeline segments are shown in orange. 2019 HCA pipeline segments are shown in yellow. 2020 HCA pipeline segments are shown in purple.

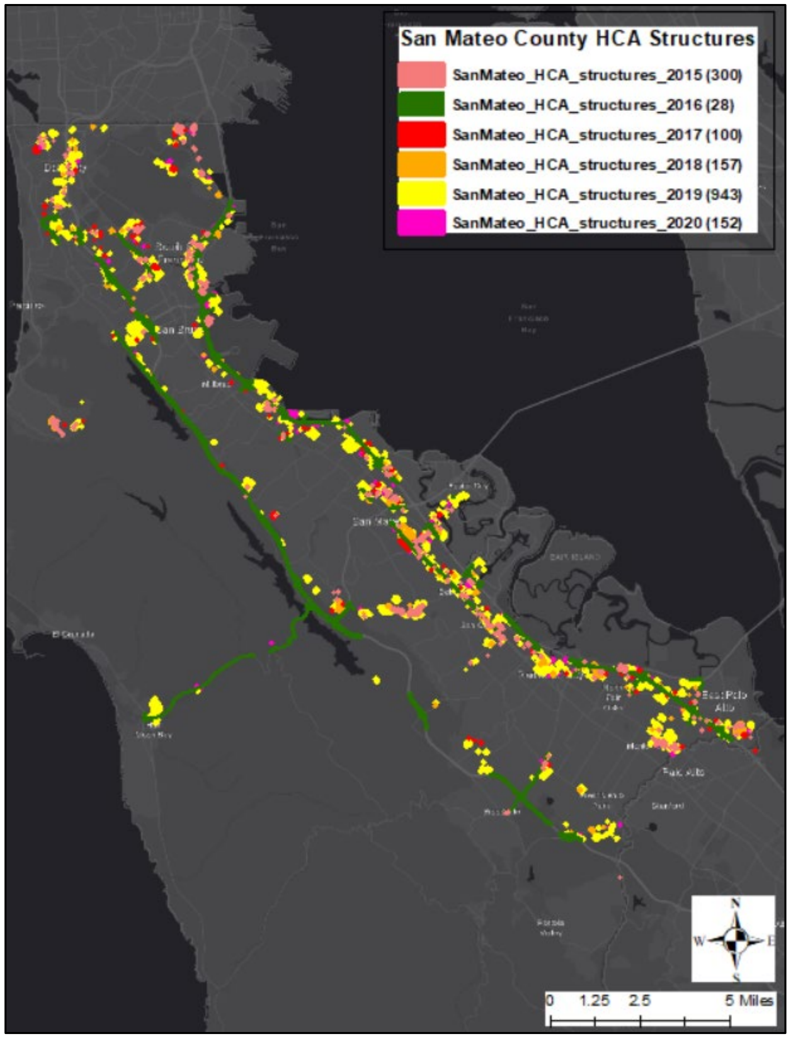

Figure 19. San Mateo County HCA structures. Colors show year by year HCA structure additions from 2015-2020 in San Mateo County. 2015 HCA structures are shown in pink. 2016 HCA structures are shown in green. 2017 HCA structures are shown in red. 2018 HCA structures are shown in orange. 2019 HCA structures are shown in yellow. 2020 HCA structures are shown in purple. Number of HCA structure additions by year are shown in paratheses in the legend.

Santa Clara County:

Santa Clara County is the most populous county in the 9 counties used for this project study area. **Figures 21 and 22** shows increases in HCA pipeline and structures throughout the 2015-2020 time period. In the time period for this project, there was an increase of 65 HCA pipeline miles added in Santa Clara County. Referring to **Figures 21 and 22**, there is a noticeable increase in the number of HCA structures in 2016 and 2018 which played a role into an increase in HCA pipeline mileage increasing for 2017 and 2019-2020. The reasons for an increase in HCA pipeline was due to a number of apartments, condos, and townhomes built along freeways and expressways in Santa Clara County. Other factors also included office buildings, places of public gatherings, shopping mall, restaurants, and parks opening. The city of San Jose has had a number of ongoing construction projects including transit centers and other infrastructure to address urban growth in the area.

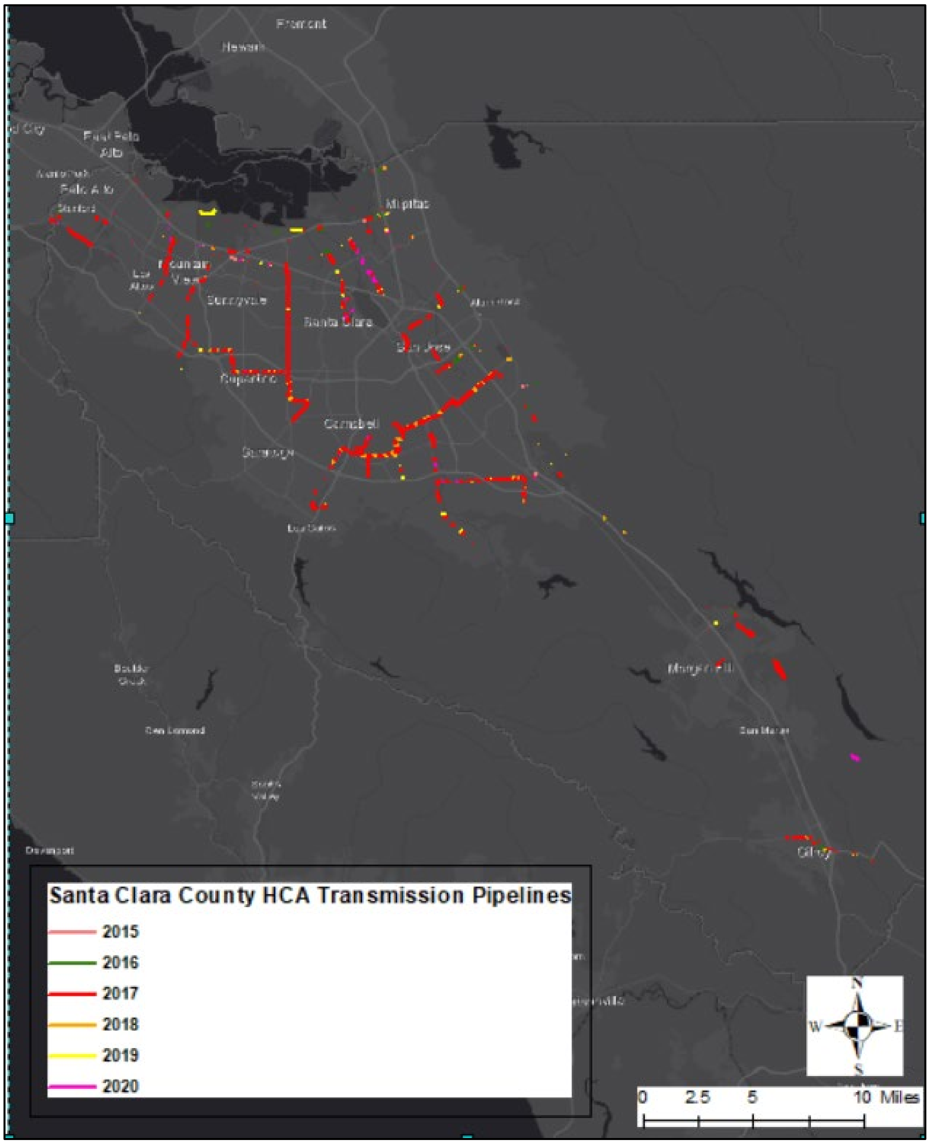

Figure 20. Santa Clara County HCA Gas Transmission Pipelines. Colors show year by year HCA pipeline segment additions from 2015-2020 in Santa Clara County. 2015 HCA pipeline segments are shown in pink. 2016 HCA pipeline segments are shown in green. 2017 HCA pipeline segments are shown in red. 2018 HCA pipeline segments are shown in orange. 2019 HCA pipeline segments are shown in yellow. 2020 HCA pipeline segments are shown in purple.

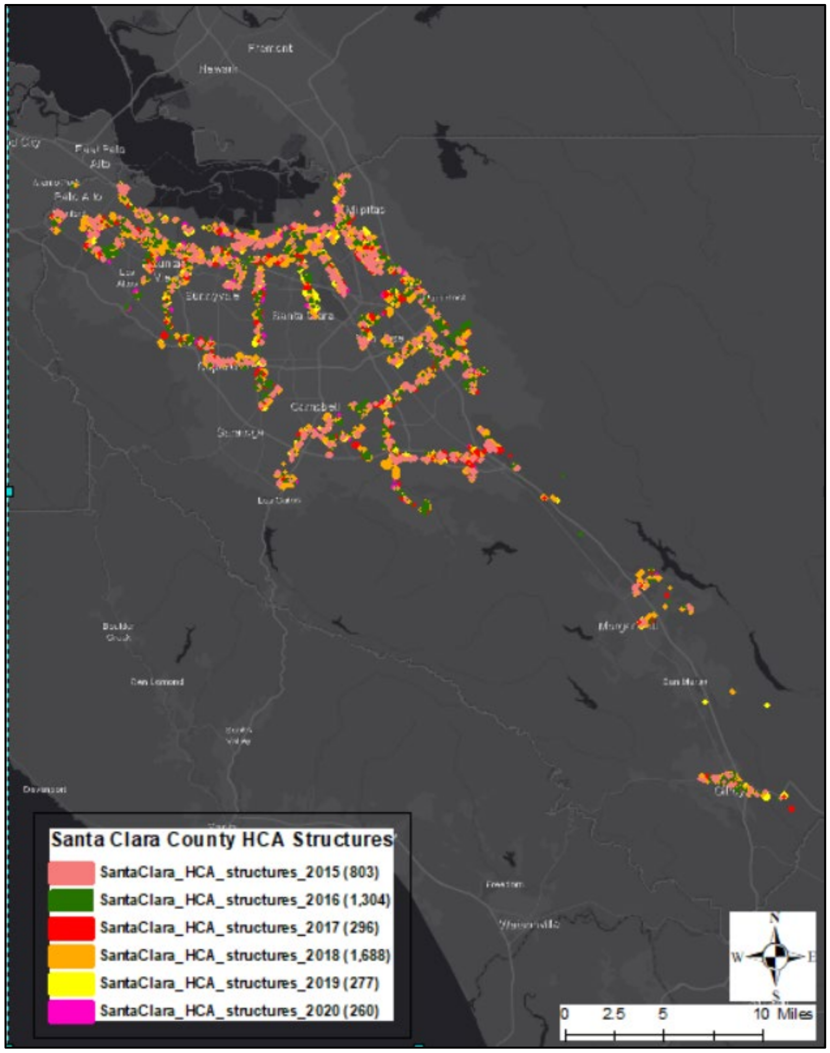

Figure 21. Santa Clara County HCA structures. Colors show year by year HCA structure additions from 2015-2020 in Santa Clara County. 2015 HCA structures are shown in pink. 2016 HCA structures are shown in green. 2017 HCA structures are shown in red. 2018 HCA structures are shown in orange. 2019 HCA structures are shown in yellow. 2020 HCA structures are shown in purple. Number of HCA structure additions by year are shown in paratheses in the legend.

Solano County:

In Solano County, the number of HCA pipeline miles added throughout the study period was roughly 12 miles (**Figure 22**). Most of the county has already had existing HCA pipeline from previous years but we can observe the number of HCA structures has increased over time (**Figure 23)**. The main cause for this increase is due to a number of homes and shopping areas being built along the major freeways along existing HCA pipeline. Solano County still has a number of new home construction going on currently so it will be interesting to see if the number of HCA structures will continue to increase as more homes and people are beginning to move to Solano County.

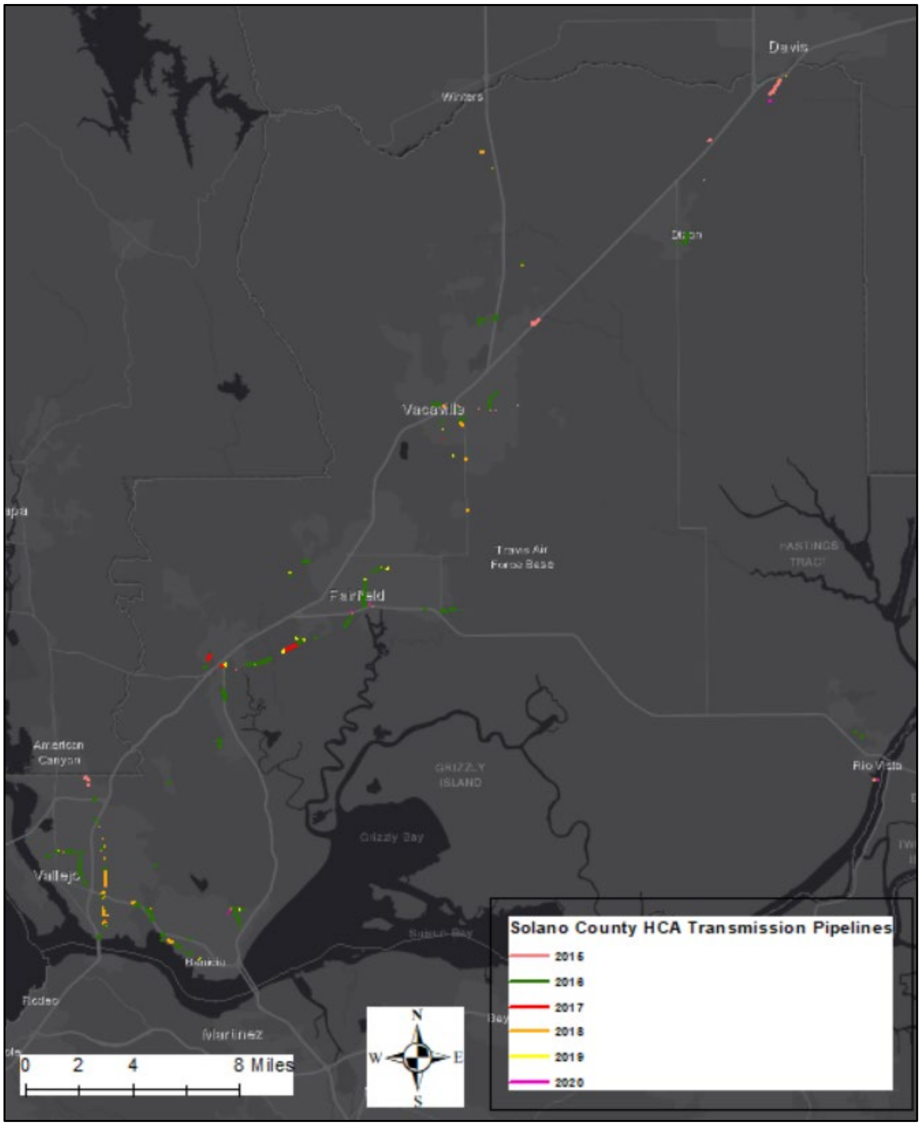

Figure 22. Solano County HCA Gas Transmission Pipelines. Colors show year by year HCA pipeline segment additions from 2015-2020 in Solano County. 2015 HCA pipeline segments are shown in pink. 2016 HCA pipeline segments are shown in green. 2017 HCA pipeline segments are shown in red. 2018 HCA pipeline segments are shown in orange. 2019 HCA pipeline segments are shown in yellow. 2020 HCA pipeline segments are shown in purple.

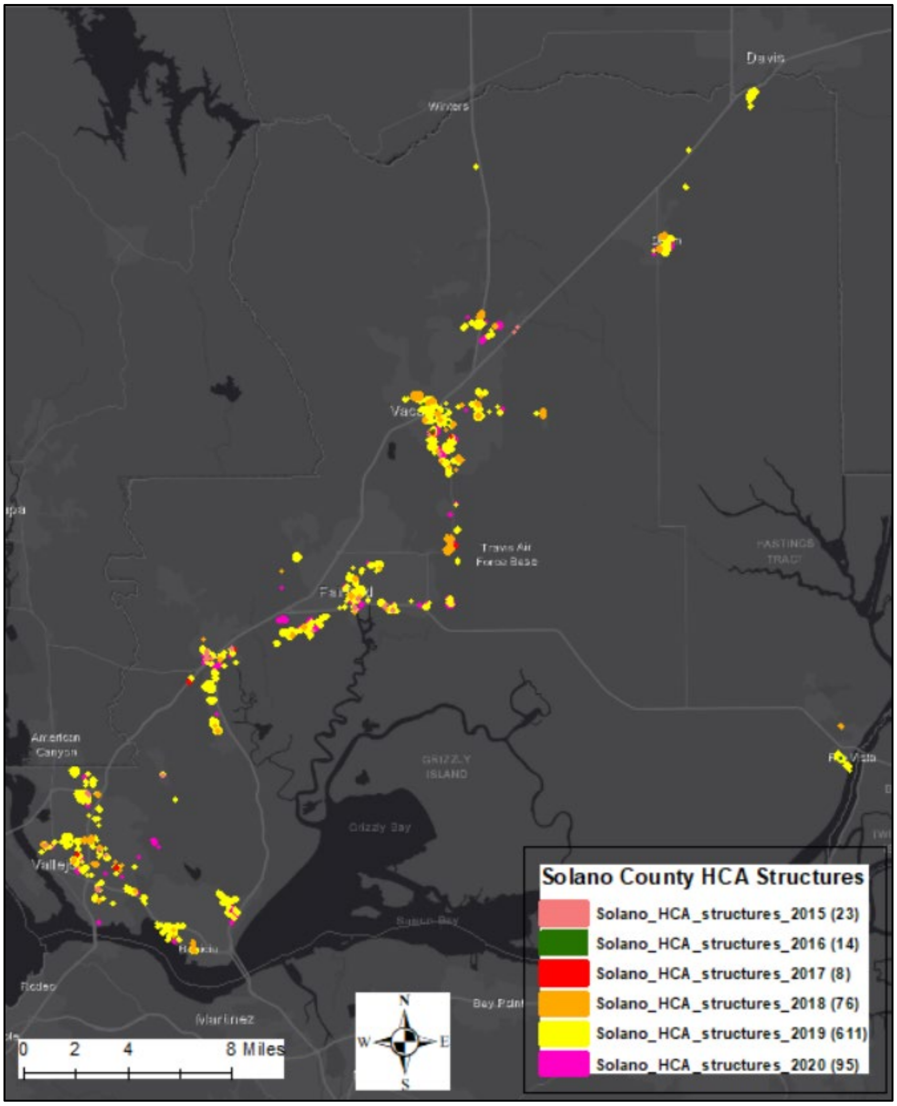

Figure 23. Solano County HCA structures. Colors show year by year HCA structure additions from 2015-2020 in Solano County. 2015 HCA structures are shown in pink. 2016 HCA structures are shown in green. 2017 HCA structures are shown in red. 2018 HCA structures are shown in orange. 2019 HCA structures are shown in yellow. 2020 HCA structures are shown in purple. Number of HCA structure additions by year are shown in paratheses in the legend.

Sonoma County:

Sonoma County hasn't shown much change over time. It is similar to Napa County as both counties were affected by the wildfires in 2017 and again in 2020. There was an addition of 26 miles of HCA pipeline segments added in 2016. After 2016 we haven't seen much change in HCA pipeline (see **Figure 24**), but we have seen a steady increase in HCA structures (see **Figure 25**). Since 2018 the HCA structure count has slowly increased over time as homes are being rebuilt and more businesses have opened along existing areas of HCA pipeline. There were areas of burned locations that new apartment complexes, shopping areas, outdoor areas, and restaurants are being built as a direct result of people coming back to the area as Sonoma County has been recovering from wildfire destruction.

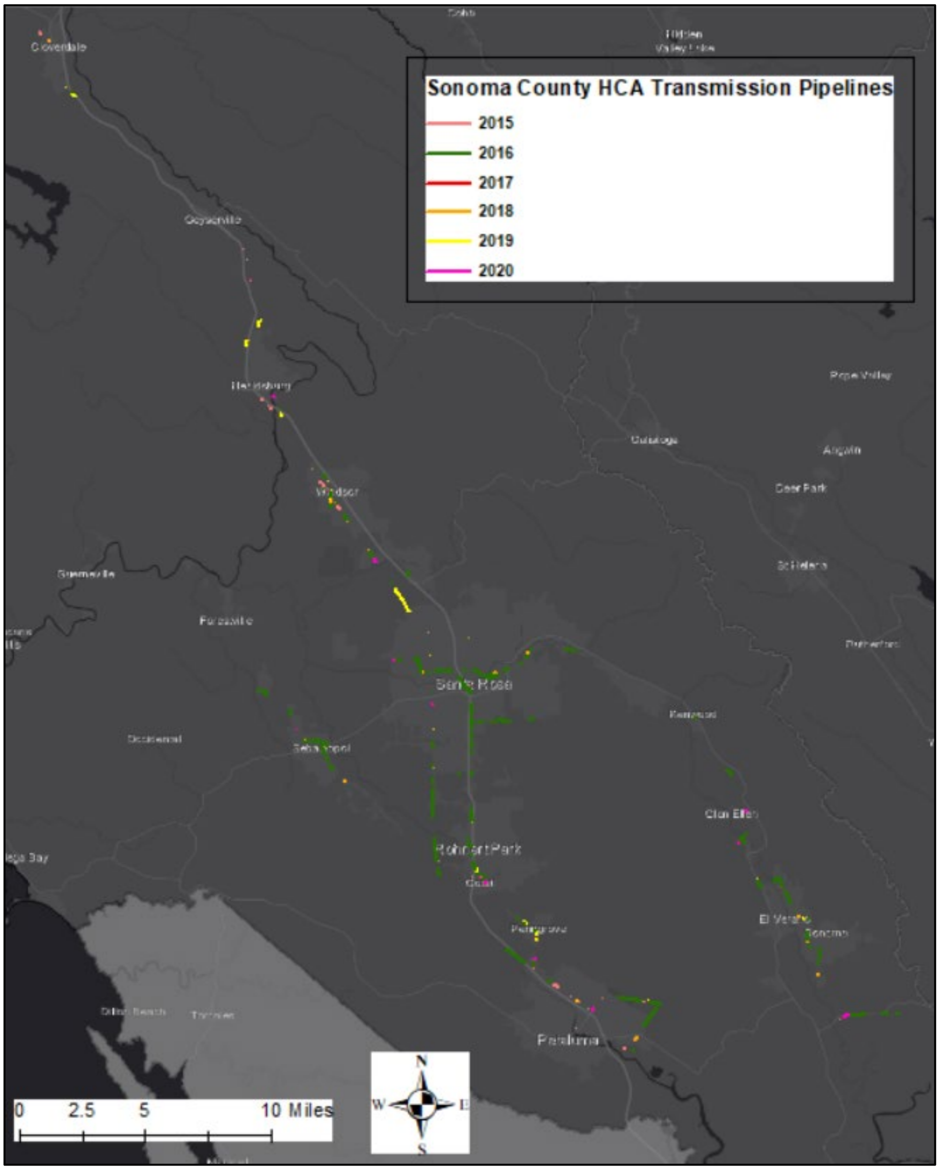

Figure 24. Sonoma County HCA Gas Transmission Pipelines. Colors show year by year HCA pipeline segment additions from 2015-2020 in Sonoma County. 2015 HCA pipeline segments are shown in pink. 2016 HCA pipeline segments are shown in green. 2017 HCA pipeline segments are shown in red. 2018 HCA pipeline segments are shown in orange. 2019 HCA pipeline segments are shown in yellow. 2020 HCA pipeline segments are shown in purple.

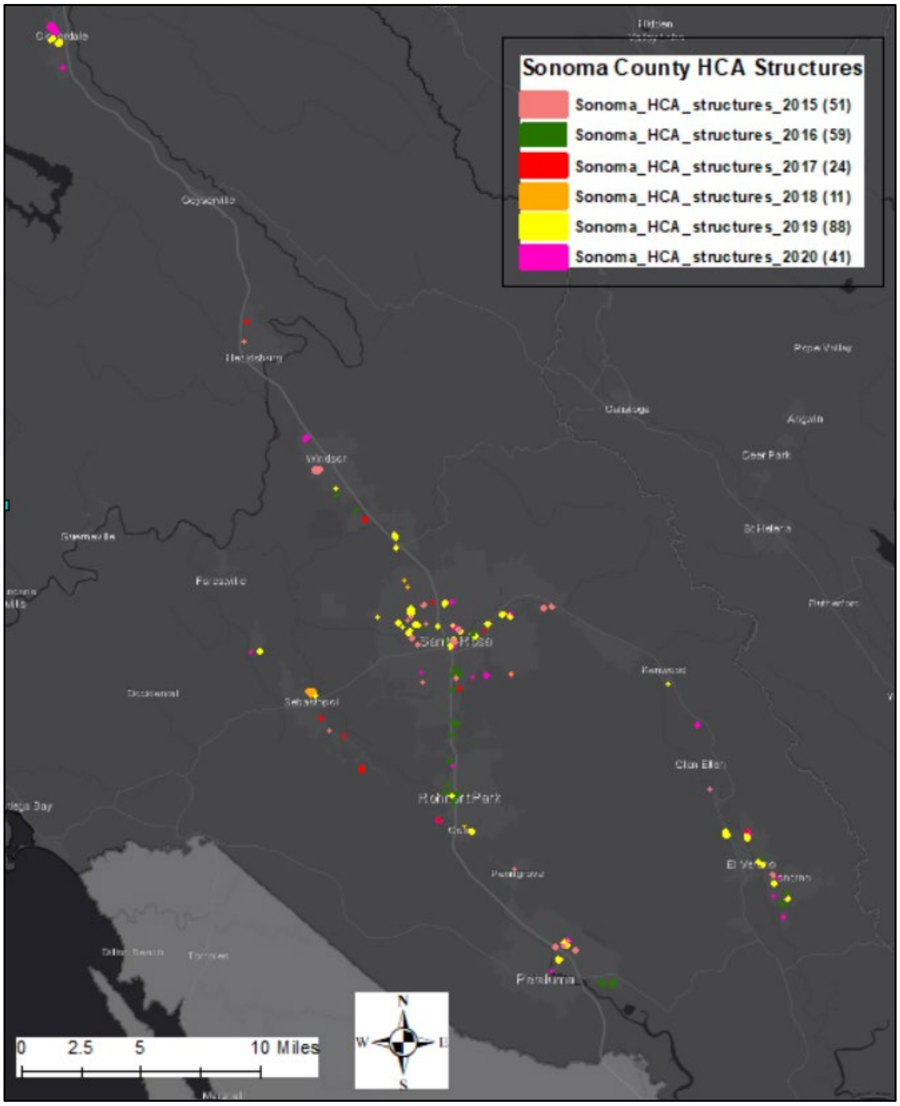

Figure 25. Sonoma County HCA structures. Colors show year by year HCA structure additions from 2015-2020 in Sonoma County. 2015 HCA structures are shown in pink. 2016 HCA structures are shown in green. 2017 HCA structures are shown in red. 2018 HCA structures are shown in orange. 2019 HCA structures are shown in yellow. 2020 HCA structures are shown in purple. Number of HCA structure additions by year are shown in paratheses in the legend.

Conclusion and Future Work

Overall, throughout the nine counties in the Bay Region has shown numerous indicators of urban growth having a direct impact on HCA pipeline and structures being added into Pacific Gas and

Electric Co. maintenance and risk management. This project determined roughly 390 miles of HCA pipeline and 12,264 HCA structures were added from the years 2015 to 2020. Furthermore, 3,189 HCA structures are defined as Class 1 and 2 and 9,065 HCA structures were defined as Class 3 or 4 (417 are Class 4). With the ongoing construction throughout the region have impacted the company in trying to find new ways for multiple organizations to make an impact and increase safety and lessen the risk on the Gas Transmission Pipeline system.

Some of deliverables that have been implemented and in use as a direct result of this project was creating a feature service of our updated HCA / Class Location layer was made which would be available for company use. **Figure 26**, shows a web application I designed for our Pipeline Patrol stakeholders to show daily updates of HCA mileage that has been patrolled via aircraft. This web application has benefited the team to indicate what has been patrolled and what is left to patrol to ensure they meet their federal patrolling requirements of HCA transmission pipeline.

Figure 27, is a mobile application which has been designed for field crews to perform and conduct their field surveys. For example, it includes a form to indicate whether the section of pipe they visited has had its routine maintenance completed. If there are any issues when visiting an HCA site, the field crew could take photos and make comments using drop down options or describe the issue in detail on a form. This mobile application updates existing dashboards to indicate how much of the HCA maintenance has been done, where observations have been made, and any hazards or risks that were identified along the HCA pipe segment.

Lastly, another end product created from this project and currently in use is an HCA / Class Location dashboard showing changes in HCA in the study area. This dashboard shows changes in new and removed buildings, what is their class location, and HCA. The same dashboard shows changes from previous years in our study area locations to new and existing structures from our study areas from 2015-2020.

We hope to continue this study to engage stakeholders more and create a variety of products such as a web map for our leak survey team to monitor the new locations of HCA pipeline and what risks maybe in these areas. Another interesting application would be for our geohazards team as some of the imagery processed in this project identified locations of debris and erosion areas near gas transmission pipeline

As urban growth continues to impact the Gas Transmission Pipeline system at Pacific Gas and Electric Co. the need for more user-friendly dashboards and displaying up to date changes in HCA and Class Location will be desired to handle business needs. I hope this project will eventually be extended to other regions in the Gas Transmission Pipeline system to areas such as Sacramento due to the increase in construction in this area.

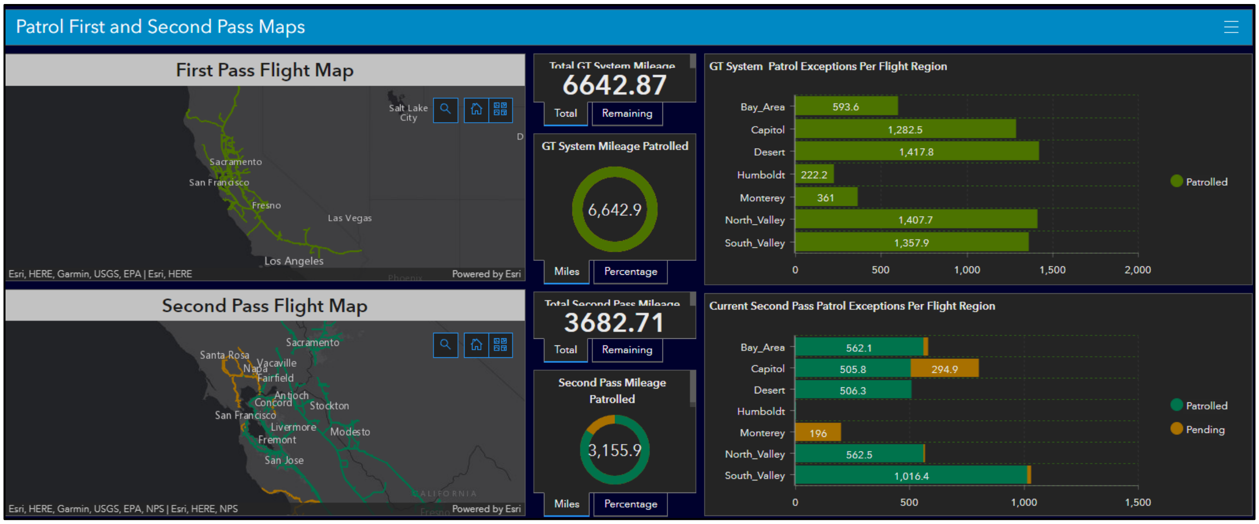

Figure 26. Pipeline Patrol Dashboard Application. First Pass Map shows all Gas Transmission miles, what has been patrolled, what is left to patrol for individual divisions. Second Pass Maps show HCA Gas Transmission miles that have been patrolled or still needing to be patrolled on a monthly basis.

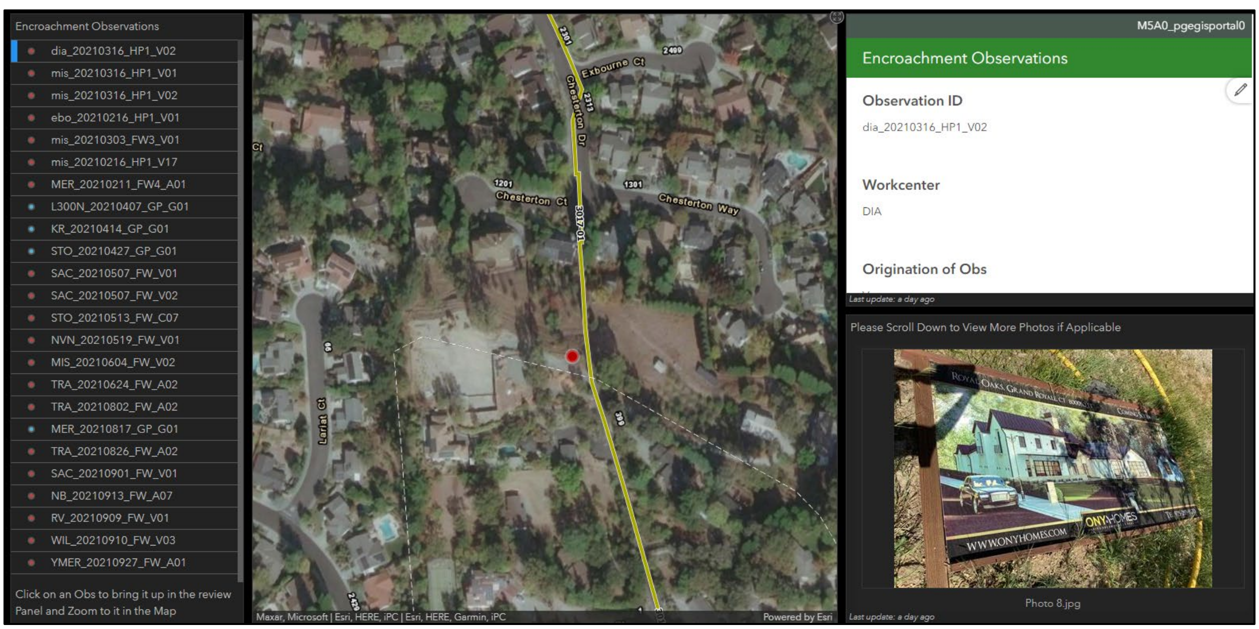

Figure 27. Encroachment Observation Application. This application is designed for field crews to investigate new construction observations near existing HCA pipeline. Ground Patroller can use their mobile device to take and upload photos and add a description of what the new construction is in real time to inform stakeholders that there is a potential encroachment to the pipeline that may be captured as an HCA structure in the future.

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