City of Louisville

Marshall Fire Water System Recovery

Summary Report

Corona Environmental Consulting, LLC

2/3/2025

Executive Summary

On December 30, 2021, the Marshall Fire destroyed over 1,000 buildings and displaced over 40,000 people becoming the costliest fire in Colorado history. Due to extreme winds, the fire moved rapidly through the City of Louisville (Louisville), the Town of Superior (Superior), and unincorporated Boulder County. Both Louisville and Superior experienced significant infrastructure damage, including power loss and water pressure reductions. In Louisville, a significant amount of the produced water was lost through the service lines of destroyed structures. To avoid loss of water distribution system pressure, Louisville made the decision to send untreated reservoir water into the distribution system, allowing firefighters to continue utilizing hydrants to slow the fire. While this maintained the life and property saving goal of providing water supplies for firefighting, the untreated water entering the distribution system required Louisville to issue a city-wide Boil Water order.

In the aftermath of the fire, Louisville's Water System Recovery Plan was developed with the immediate goal of safely returning water service to undamaged areas of the City, while simultaneously determining if there was any water system damage or contamination in areas directly impacted by the fire. Recent post-wildfire studies have shown that drinking water can be contaminated by organic compounds that leach from burnt plastic plumbing and ash that can enter depressurized water infrastructure following a wildfire. For example, benzene, a carcinogen, and other volatile organic compounds (VOCs) have been detected in residential drinking water in fire impacted areas of similar disasters (Proctor et al., 2020). Considering these recent studies and consulting with State regulators and outside experts, Louisville developed sampling and flushing plans for the distribution system, standing structures, destroyed structures, and the meter pits of structures during the rebuilding process. The objective of the Water System Recovery Plan was to return water service to undamaged areas as quickly and safely as possible while simultaneously monitoring the fire impacted areas for contaminants and ensuring adequate removal of those contaminants throughout the rebuilding process. Due to the potential VOC presence, a Do Not Use order was issued by Louisville in the fire-impacted areas.

Upon completion of the Water System Recovery sampling, over 800 water samples were collected, with nearly 100,000 individual analyses, representing the largest post-fire water sampling campaign to date. This extensive sampling effort and mitigation of impacted areas performed by Louisville allowed for standing structures to be cleared in a timely manner so water use could resume and provided confidence that fire-related contamination was evacuated from the distribution system. VOCs and semi-volatile organic compounds (SVOCs) were detected at elevated levels in water samples collected from the distribution system, standing homes, and burned structures within the Marshall Fire burn zone, which indicated likely fire-related contamination. Sampling before and after flushing confirmed that flushing was highly effective at removing fire-related contamination from infrastructure, including the water mains and plumbing inside buildings impacted by the fire. When fire-related contaminants were detected, the City's repeated flushing efforts removed contamination and water service has been safely restored throughout the fire impacted areas. New service lines installed in the burn zone have also been sampled and demonstrated to be free of contamination as residents continue to rebuild.

This report also summarizes the key lessons learned and translates those into recommendations for other utilities. The main takeaway is the vital importance of having emergency response plans in place before disaster strikes so that mitigation efforts can commence as soon as possible. The recommendations include plans to protect critical assets, control water losses, restore water quality, communicate with the community, conduct water testing to determine the extent of fire-related contamination, and restore water quality.

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List of Acronyms

CDPHE	Colorado Department of Health and the Environment
Corona	Corona Environmental Consulting, LLC
E. Coli	Escherichia coli
EPA	Environmental Protection Agency
GC-MS	Gas Chromatography/Mass Spectrometry
Louisville	City of Louisville
MCL	Maximum contaminant level
MGD	Million gallons per day
MRL	Maximum reporting level
ND	Non-detect
QA/QC	Quality assurance/quality control
SDWA	Safe Drinking Water Act
Superior	City of Superior
SVOC	Semi-volatile organic compound
TICs	Tentatively Identified Compounds
VOC	Volatile organic compound

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ALS Environmental Laboratories

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1 The Marshall Fire

On December 30, 2021, the Marshall Fire destroyed over 1,000 buildings and displaced over 40,000 people becoming the costliest fire in Colorado history. Due to extreme winds, the fire moved rapidly through the City of Louisville (Louisville), the Town of Superior (Superior), and unincorporated Boulder County. Both Louisville and Superior experienced significant infrastructure damage, including power loss and water pressure reductions. Superior lost power to their single water treatment plant and was unable to provide water to the distribution system, leading Louisville to provide water through an interconnect.

As firefighting efforts continued throughout December 30, Louisville experienced low water pressure at hydrants in use by firefighters. The spreading fire forced utilities to shut down power and gas throughout the impacted areas, further hampering support systems at water treatment facilities, including one of Louisville's treatment plants which relied on natural gas for backup power. Without power, Louisville staff were unable to remotely monitor water storage tank levels, requiring staff to enter the active fire area to determine that water levels in the tank were critically low. To avoid loss of pressure, Louisville made the decision to send untreated reservoir water into the distribution system, allowing firefighters to continue utilizing hydrants to slow the fire. While this preserved the life and property saving goal of maintaining water supplies for firefighting, the decision to send untreated water into the distribution system was only considered due to the extreme nature of the disaster and would later require Louisville to issue a city-wide Boil Water order.

Coordinating with the local power companies, Louisville was soon able to resume operation of their second plant by connecting a mobile gas trailer to the backup generator. Even with both plants running at a full combined capacity of 13 million gallons per day (MGD), pressure in the distribution system was still low due to the firefighting demands and the water being lost through destroyed structures. As the fire had moved through Louisville, destroyed structures were losing water through their City service line, with estimates ranging from 50% to 90% of produced water being lost through destroyed structures. To mitigate the water loss, Louisville staff began coordinating with firefighting teams to move through the burned areas shutting off curb stops to individual destroyed structures or closing valves to entire subdivisions once firefighting efforts in an area were concluded. These efforts continued throughout the night of December 30, into December 31.

By the end of the day on December 31, the fire was considered contained. Due to the use of untreated reservoir water in the distribution system, as required to maintain firefighting efforts, Louisville and the Colorado Department of Public Health and Environment (CDPHE) issued a city-wide Boil Water order to residents. With a winter storm approaching, a team of Louisville staff with assistance from numerous neighboring utilities began preparing to return the water system to compliance by performing extensive chlorination, flushing and targeted sampling before the Boil Water order could be lifted.

In the aftermath of the fire, Louisville's Water System Recovery Plan was developed with the immediate goal of safely returning water service to undamaged areas of the City, while simultaneously determining if there was any water system damage or contamination in areas directly impacted by the fire. Louisville quickly reached out to the CDPHE along with outside experts to develop a water system recovery plan. The team included representatives from Louisville, Superior, CDPHE, Colorado's regional branch of the

Environmental Protection Agency (EPA), California EPA, Oregon EPA, the US EPA, Purdue University, Oregon State University, University of Colorado, and Corona Environmental Consulting (Corona). With combined input from the various perspectives, next steps were developed for rapidly returning the water system to safe and compliant operation. The next steps were incorporated into a *Return to Service Plan* which was drafted and submitted to CDPHE for approval. One concern raised by CDPHE and the outside experts was the presence of volatile organic compounds (VOCs) from burnt materials and their potential health impacts. As such, a Do Not Use order was issued by Louisville in the fire-impacted areas. Considering the public health implications of possible exposure to hazardous organic compounds after the fires, Louisville promptly worked to collect and test water samples for chemical and bacterial contamination following the fires. Given the fact that wildfires have led to long-term water quality problems in other areas of the country (Olson, 2020) , Louisville proactively developed water testing and flushing plans for the destroyed structures, standing structures impacted by the fire, and meter pits for new builds. To keep the community educated about the safety of their drinking water, these results were posted on a publicly available dashboard online for the residents to see the water testing results for their individual homes. The flushing and sampling strategy could serve as a framework for rapidly developing post-wildfire response plans for other cities in the US that may need them in the future.

The following report will detail the sampling efforts conducted by Corona and Louisville to understand the impact the wildfire had on water quality and to return normal use of water to the impacted communities as fast as possible. This includes a summarization of the results and the decisions that were made based on the information collected.

2 Water System Recovery Overview

Louisville's Water System Recovery Plan was developed with the immediate goal of safely returning water service to undamaged areas of Louisville, while simultaneously determining if there was any water system damage or contamination that would prohibit returning service to areas directly impacted by the fire. The longer-term goal was to work in tandem with Louisville's recovery program as the community began the process of rebuilding to ensure safe water was delivered to rebuilt or repaired structures. The following sections explain why there was a concern for water system contamination, and how the flushing and sampling plan addressed those concerns in each area of the water system recovery.

2.1 Background

Wildfires are increasing in intensity and in the total number of acres burned (Westerling, 2016). A number of climate-related factors contribute to the increase in wildfires including extended fire seasons, increased frequency of dry years (Pausas & Keeley, 2021), and fuel accumulation from a century of active fire suppression (Calkin et al., 2015). With the increase in wildfires in residential areas, many lessons have been learned regarding the required response from utilities and the impact of these fires on drinking water quality (Draper et al., 2022; Jankowski et al., 2023; Proctor et al., 2020; Whelton et al., 2023). Due to potential pressure loss in water system after fires, drinking water should be tested for microbial contamination at a minimum (CDC, 2023).

Recent post-wildfire studies have also shown that drinking water is often contaminated by organic compounds that leach from burnt materials that can enter damaged water service lines. For example, benzene, a carcinogen, and other VOCs or semi-volatile organic compounds (SVOCs) have been commonly detected in residential drinking water in fire-affected areas (Proctor et al., 2020). Following the Tubbs Fire in 2017, benzene was detected at a concentration of up to 40 mg/L (Whelton et al., 2023) , which has a maximum contaminant level (MCL) of 0.005 mg/L. A service line collected after the 2018 Camp Fire (Paradise, CA) contained water contaminated with 95 organic compounds, where 32 of those compounds were correlated with the pyrolysis of PVC pipes (Draper et al., 2022). VOCs detected at levels exceeding drinking water limits in recent fires include benzene, methylene chloride, naphthalene, styrene, and others. A summary of these studies is provided in Table 1, including the data that will be discussed in this report from the Marshall Fire.

Table 1. Recent wildfires and the associated VOC contamination in drinking water

Fire Name	Year	Location	Burn area (acres)	Number of destroyed structures	Summary of VOCs detected
Tubbs Fire	2017	Napa, Sonoma, and Lake counties, CA	36,810	5,643	Benzene, dichloromethane, naphthalene, styrene, tert-butyl alcohol, toluene, vinyl chloride
Camp Fire	2018	Butte County, CA	153,336	18,000	Benzene, dichloromethane, naphthalene, styrene, tert-butyl alcohol, toluene, vinyl chloride
Marshall Fire	2021	Boulder County, CO	6,026	1,084	Benzene, styrene, toluene, 1,2-dichlorobenzene, and others (A full list of compounds is included in the Appendix)

Sparked by the health concerns of elevated VOC leaching from burnt plumbing after wildfires, a recent bench-scale study sought to determine which types of plumbing may release VOCs when damaged by fires. Isaacson et al. thermally degraded 11 different common plumbing materials (i.e. PEX, HDPE, PP, PVC, and CPVC) and found that 10 out of the 11 materials leached benzene at elevated temperatures (Isaacson et al., 2021). The same study also found a positive correlation between an increase in temperature and an increase in VOC leaching. It is likely that drinking water becomes contaminated after wildfires due to one or two primary factors: (1) thermal degradation of plastic plumbing pipes (PEX, PVC, HDPE) and fittings, and (2) the entry of ash and burnt components into service lines particularly during depressurization events caused by firefighting efforts. Benzene and VOC contamination of drinking water following wildfires is clearly a public health concern. There is a clear need to improve our understanding of post-wildfire water quality impacts and to develop response plans for testing and restoring water quality following these natural disasters.

2.2 Regulatory Requirements

Louisville routinely monitors contaminants in drinking water as required by the EPA and CDPHE. As directed by the Safe Drinking Water Act (SDWA), the EPA regularly identifies and regulates contaminants by setting a drinking water standard. Drinking water standards apply to all public water systems, including Louisville. In Colorado, CDPHE is the primacy agency and is responsible for enforcing EPA drinking water standards. The enforceable standard in most cases is set as an MCL. The MCL is the maximum level allowed of a contaminant in water which is delivered to any user of a public water system (EPA, 2023). Louisville monitors contaminants throughout the year and reports the results to CDPHE; the results are publicly available in Louisville's annual drinking water quality report which can be found at: LouisvilleCO.gov/Water.

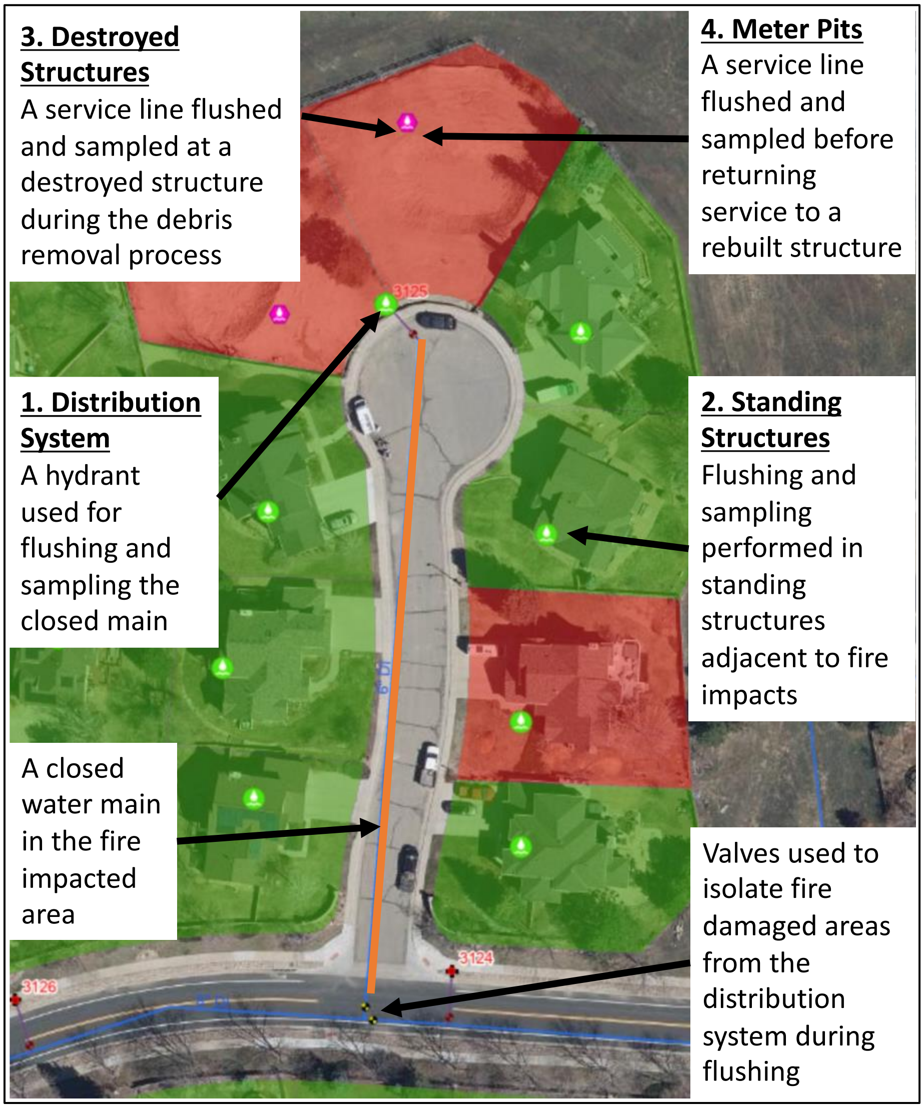
As mentioned in the previous section, the primary contaminants of concern historically found in post-wildfire studies VOCs and SVOCs. A number of VOCs and SVOCs are regulated and have enforceable MCLs; others are not currently regulated by the EPA or CDPHE but may be monitored proactively to indicate the presence of contaminants of concern. While developing the Water System Recovery plan, Louisville decided to monitor a full suite of VOCs and SVOCs, including both regulated and unregulated contaminants as a proactive measure. A list of the regulated VOCs and SVOCs along with their MCLs is included in the appendices.

2.3 Stages of Water System Recovery

Incorporating lessons learned from recent post-wildfire studies with the impacts of the Marshall Fire on Louisville's water system, a plan was developed for flushing, sampling, and reporting throughout Louisville. The stages were broken down as following:

1. Distribution System
2. Standing Structures
3. Destroyed Structures
4. Meter Pits

The sampling and analytical plans for each stage of the Water System Recovery are detailed in the following sections. Figure 1 provides an example of the stages of sampling in a fire impacted street in Louisville.



3. Destroyed Structures
A service line flushed and sampled at a destroyed structure during the debris removal process

4. Meter Pits
A service line flushed and sampled before returning service to a rebuilt structure

1. Distribution System
A hydrant used for flushing and sampling the closed main

2. Standing Structures
Flushing and sampling performed in standing structures adjacent to fire impacts

A closed water main in the fire impacted area

Valves used to isolate fire damaged areas from the distribution system during flushing

Figure 1. An example of the flushing and sampling stages in a fire impacted neighborhood

3 Laboratory Analytical Plan

At present, US Environmental Protection Agency Method 524.2 (Measurement of purgeable organic compounds in water by capillary column gas chromatography / mass spectrometry) is often applied for drinking water VOC analysis after wildfires. US EPA Method 524.4 (Measurement of Purgeable Organic Compounds in Water by Gas Chromatography/Mass Spectrometry Using Nitrogen Purge Gas) is another method used for the analysis of VOCs in drinking water. This method is effective at concentrating the trace levels of VOCs sometimes found in drinking water. US Environmental Protection Agency Methods 8260C (SW-846) Volatile Organic Compounds by Gas Chromatography/Mass Spectrometry (GC/MS) can also be used to provide analysis for parameters after wildfires. EPA Method 8270E was identified to quantify SVOC in the water samples using Gas Chromatography/Mass Spectrometry (GC-MS).

Table 2 lists VOCs detected in water distribution systems after experiencing impacts from a wildfire since 2017. Previously studied wildfire impacted communities have exceeded short- and long-term drinking water exposure standards, as shown with the asterisks in Table 2. The parameters in the table below were targeted for water distribution system testing and laboratory analysis in Louisville's *Return to Service Plan*.

Table 2. VOCs detected in wildfire impacted distribution system sampling since 2017

Parameter and CAS #		
Acetonitrile (75-05-8)	Acetone (67-64-1)	Acrolein (107-02-8)
Acrylonitrile (107-13-1)	**Benzene (71-43-2) ***	Bromochloromethane (74-97-5)
Bromodichloromethane (75-27-4)	Bromoform (75-25-2)	n-Butylbenzene (104-51-8)
sec-Butylbenzene (135-98-8)	*tert*-Butylbenzene (98-06-6)	Carbon disulfide (75-15-0)
Carbon tetrachloride (56-23-5)	Chlorobenzene (108-90-7)	Chlorodibromomethane (124-48-1)
Chloromethane (74-87-3)	4-Chlorotoluene (106-43-4)	Dibromochloromethane (124-48-1)
1,2-Dichlorobenzene (95-50-1)	1,4-Dichlorobenzene (106-46-7)	1,1-Dichloroethane (75-34-3)
1,2-Dichloroethane (107-06-2)	1,1-Dichloroethene (75-35-4)	*cis*-1,2-Dichloroethene (156-59-2)
trans-1,2-Dichloroethylene (156-60-5)	1,2-Dichloropropane (78-87-5)	Ethanol (64-17-5)
Ethylbenzene (100-41-4)	Ethyl-*tert*-butyl ether (ETBE) (100-41-4)	Iodomethane (74-88-4)
Isopropylbenzene (98-82-8)	**Methylene chloride (75-09-2) ***	**Methyl ethyl ketone (MEK) (78-93-3) ***
Methyl isobutyl ketone (MIBK) (108-10-1)	**Methyl-*tert*-butyl ether (MTBE) (1634-04-4) ***	**Naphthalene (91-20-3) ***
Styrene (100-42-5) *	***tert*-Butyl alcohol (TBA) (75-65-0) ***	Tetrachloroethylene (127-18-4)
Tetrahydrofuran (THF) (109-99-9) *	**Toluene (108-88-3) ***	1,2,3-Trichlorobenzene (87-61-6)
1,2,4-Trichlorobenzene (120-82-1)	1,1,1-Trichloroethane (71-55-6)	1,1,2-Trichloroethane (79-00-5)
Trichloroethylene (79-01-6)	Trichloromethane (67-66-3)	1,2,4-Trimethylbenzene (95-63-6)
1,3,5-Trimethylbenzene (108-67-8)	**Vinyl chloride (VCM) (75-01-4) ***	*ortho*-Xylene (75-01-4)
meta-Xylene (108-38-3)	*para*-Xylene (106-42-3)	

(*) This parameter exceeded a short- or long-term drinking water exposure level in post-wildfire distribution system sampling since 2017. At present, there is limited understanding of the most common chemicals associated with post-wildfire water contamination. Parameters reported above have been those most commonly analyzed, not necessarily the ones of most frequency or concern.

3.1 Laboratories

Considering the urgent nature of the samples, Louisville and Corona worked to identify laboratories with capabilities to analyze samples for contaminants of fire-related concern. In addition to analytical capabilities, rapid turnaround time was a key criterion in selecting labs to perform analysis given the need to inform decisions as quickly as possible about returning potable water service to service connections. Initially, Louisville utilized existing laboratory support services from their primary contract laboratory, Colorado Analytical, to perform VOC analysis (EPA 524.2); however, the lab indicated they would not be able meet demands from the growing number of samples to be analyzed over a short period of time or expand analysis beyond VOC analysis (EPA 524.2). Colorado Analytical did continue to support Louisville's regulatory compliance monitoring analysis including bacteriological analysis. Another local municipal laboratory (South Adams County) graciously provided interim support of VOC analysis (EPA 524.2) early in the sample analysis campaign.

Corona requested analytical support for both VOCs and SVOCs from regional and national analytical laboratories. Laboratories expressed several challenges to support the sample analysis efforts including:

- Not having analytical capabilities for both VOCs and SVOCs, including Tentatively Identified Compounds (TICs)
- Inability to meet expedited turnaround time expectations to return results in as few as 3 days given laboratory capacity and shipping logistics constraints
- Bottle shortages given supply chain limitations at the time

Louisville used ALS Environmental and Eurofins Test America initially for VOC analysis and ultimately proceeded to use ALS Environmental for all subsequent VOC and SVOC analysis. The laboratories and methods used are detailed in Table 3.

Table 3. Laboratories and methods used for Marshall Fire water system sampling

Laboratory	Methods			
	Bacti	VOCs: 524.2	VOCs: 8260C with TICs	SVOCs: 8270E with TICs
Colorado Analytical	X	X		
South Adams County		X		
Eurofins Test America			X	
ALS Environmental			X	X

3.2 Laboratory and Field Analytical Methods

Field sample collection. Water sampling was conducted for the analysis of coliforms, total chlorine, VOCs and SVOCs. VOC sampling (including VOCs and SVOCs) was recommended due to previous contamination of drinking water following wildfires and natural disaster events in other locations. Immediately after the fire, VOC samples were collected followed by flushing, sampling, approximately 72-hour stagnation, and repeat sampling. Louisville began development of an extensive sampling program to target areas with confirmed VOC contamination; those specific methods are detailed further in subsequent sections.

Free chlorine. Free chlorine was monitored using EPA DPD Method 8021 utilizing a Hach DR300.

Laboratory VOC Analyses. EPA Methods 524.2, 524.4, and 8260C were applied by different labs with differing chemicals included in the method. Previous post-wildfire sampling events have utilized similar EPA methods to quantify post-wildfire contamination including EPA methods EPA Method EPA Method 524.2(Solomon et al., 2021a), as well as USEPA Method 5021A for VOC analysis and Method 8270 E for SVOC analysis (Jankowski et al., 2023). In collaboration with CDPHE and other experts, a list was developed that included the required compounds to quantify with testing. This list of target analytes was compiled from lists of contaminants commonly detected after other wildfires. A list of all compounds analyzed is included in the Appendix.

Laboratory SVOC Analyses. EPA Method 8270E was used to quantify SVOCs in the water samples using GC-MS. The compounds quantified in this analysis included are listed in the Appendix.

TICs. Tentatively Identified Compounds can be identified using GCMS and a compound matching library can be used to help identify compounds based on their mass spectra. TIC analysis can be applied for the determination of both volatile and semi-volatile compounds in water. This analysis was conducted to tentatively identify unknown compounds in the water that may have been released from damaged plumbing.

Bacterial monitoring. In coordination with CDPHE and with the goal of lifting the Boil Water order, total coliforms and Escherichia coli (E. coli) were monitored during the initial return to service phase of the water system recovery while the system was chlorinated and flushed. This report does not further detail this sampling effort, as shortly after the initial chlorination and sampling effort, samples were absent (negative) for total coliforms and E. coli.

4 VOC and SVOC Field Sampling Plan

4.1 Distribution System

Louisville’s drinking water is supplied by treating reservoir water at the City’s two treatment facilities. Treated drinking water is then carried throughout Louisville in large underground pipes (water mains) which typically run underneath streets and create the water distribution system. These water mains then connect to buildings via smaller service lines which are buried beneath the ground and often enter residences in the basement. Water mains also connect to fire hydrants to provide water for firefighting. Underground valves allowed Louisville operations staff to shut off connections to structures or isolate areas of the distribution system that were impacted.

In the immediate aftermath of the fire, Louisville's primary water system recovery goal became the chlorination and subsequent flushing of the entire distribution system as required to lift the Boil Water Order. While performing flushing (Figure 2), the team utilized field chlorine testing and collected samples to submit to laboratories for microbial contamination monitoring. Additional sampling was performed for contaminants found in recent post-wildfire studies, including VOCs and SVOCs. On January 6, 2022, flushing was completed and all sample results in the non-fire impacted neighborhoods met regulatory requirements with no coliforms detected, allowing Louisville to safely lift the Boil Water order and return water service to the undamaged areas of the City. A full flush of the distribution system typically takes about 6 weeks, but with mutual aid and around-the-clock effort from Louisville staff, the flushing was completed in 4 days.

Figure 2. A hydrant being used to flush water in the fire impacted area

Simultaneous with returning water service to undamaged areas of Louisville, teams began flushing, sampling, and damage assessment of the fire-impacted neighborhoods. Recent post-wildfire studies indicated a high likelihood of VOCs leaching from melted pipes and other materials in damaged or destroyed structures. With the possibility of water main depressurization caused by firefighting efforts, contaminants could be pulled into the distribution system and spread through water mains until pressure was returned to the system. After the fire moved through a neighborhood, Louisville operators had closed service line valves to destroyed structures (curb stops) and water mains entering the damaged areas to reduce water loss and prevent the spread of fire related contamination into the undamaged portions of the distribution system.

Louisville, CDPHE, and Corona developed a flushing and sampling plan for each of the hydraulically isolated damaged areas to systematically flush any contamination and perform sampling until it could be determined that the water mains were free from contamination.

4.1.1 Distribution System Sample Methods

Figure 3. A blow-off opened to a trickle for sample collection

- Upon identifying a hydraulically isolated water main in the burned areas, a hydrant or blow-off was identified for flushing and sampling. A blow-off valve is connected to dead-end water mains to allow for flushing or release of air.
- Louisville staff opened necessary valves to supply water to the hydrant or blow-off.
- The hydrant or blow-off was slowly opened to release a trickle of water (Figure 3).
- Corona staff would immediately collect the "stagnant" VOC samples, followed by the "stagnant" SVOC samples.
- The hydrant or blow-off was then opened fully to flush the water main for 5 minutes.
- After 5 minutes, a free chlorine sample was collected and analyzed in the field using a Hach DR300. (Chlorine levels in stagnant water are typically close to non-detect (0 mg/L), while the target chlorine residual of recently treated water moving through the distribution system is ≥ 1 mg/L).
- If the free chlorine level was less than 1 mg/L, flushing was resumed with additional chlorine samples performed approximately every 5 minutes.
- Once the measured chlorine level was 1 mg/L or higher, flushing was concluded, and flow was reduced to a trickle.
- Corona staff then collected the "flushed" VOC samples, followed by "flushed" SVOC samples.
- City staff closed the hydrant or blow-off, followed by closing water main valves to continue isolating the area until sample results were received and next steps determined.

Following sample collection, Corona worked with several analytical laboratories to perform VOC and SVOC analysis as detailed in the Laboratory Analytical Plan section. Results for this sampling are detailed in Distribution System results section.

When sample analysis was completed by the analytical laboratory, results were reviewed by Corona and Louisville staff. If any contaminants exceeded a regulatory MCL or were found at a level indicating the possible presence of fire-related contamination, that section of the distribution system was flagged for further flushing and sampling. The flushing and sampling were continued until all regulated contaminants were below their respective MCLs and in most cases were non-detect (ND).

As a proactive measure, a number of distribution system sample points were selected for periodic sampling throughout the first year after the fire. While these locations had already received a cleared sample result, they were selected as monitoring sites to determine if any fire related contamination was harbored in the distribution system.

4.2 Standing Structures

A standing structure was defined as a building inside or immediately adjacent to the burn area that was not significantly structurally impacted by the fire. Standing structure flushing and sampling began after successfully flushing and receiving cleared VOC and SVOC sample results for each hydraulically isolated neighborhood. To avoid spreading fire-related contamination between buildings in the burn area, water service was turned off at these structures until all sample results at the connected water main were below their respective MCLs. Upon receiving notice that distribution system sample results had been cleared, Louisville coordinated with property owners to flush their individual service lines through the building and perform sampling to investigate possible contamination.

4.2.1 Standing Structure Sample Methods

- Louisville staff coordinated with customers to schedule flushing and sampling when the customer was ready to safely return to their residence and had requested water service (due to freezing weather, some customers preferred to delay return to water service until fire recovery was further progressed).
- At the scheduled appointment time, Louisville and Corona staff would meet the customer at their address.
- Customers were asked to confirm that all valves inside the home (showers, sinks, etc.) were shut off to preserve the stagnant sample.
- Louisville staff would then open a curb stop (Figure 4) to temporarily return water service to a building.
- If accessible, the cold water tap at the kitchen sink (Figure 5) was opened to a trickle; If not accessible, an alternate location was identified in coordination with the customer.

Figure 4. A curb stop used to return water service to a standing structure for flushing and sampling

Figure 5. A sink being flushed during sample collection

- Corona staff would immediately collect the “stagnant” VOC samples, followed by the “stagnant” SVOC samples.
- The customer was then asked to open all valves (hot and cold) at sinks, showers, and bathtubs throughout the building to flush the service line and all of the pipes within the building.
- After flushing for 20 minutes, Corona staff collected and field analyzed a chlorine sample using a Hach DR300. (Free chlorine levels in stagnant water are typically close to non-detect (0 mg/L), while the target chlorine residual of recently treated water moving through the distribution system is ≥ 1 mg/L).
- If the free chlorine level was less than 1 mg/L, flushing was resumed with additional chlorine samples performed approximately every 5 minutes.
- Once the measured free chlorine level was 1 mg/L or higher, flushing was concluded, and the customer was asked to shut off all the valves.
- At the kitchen sink or approved alternate location, Corona staff then collected the “flushed” VOC samples, followed by “flushed” SVOC samples.
- Louisville staff closed the curb stop to the building pending cleared sample results.

Following sample collection, Corona worked with several analytical laboratories to perform VOC and SVOC analysis as detailed in the Laboratory Analytical Plan section. Results for this sampling are detailed in the Standing Structure results section.

When sample analysis was completed by the analytical laboratory, results were reviewed by Corona and Louisville staff. If any contaminants exceeded a regulatory MCL or were found at a level indicating the possible presence of fire-related contamination, the customer was informed of the results by Louisville and additional flushing and sampling was scheduled. The flushing and sampling were continued until all regulated contaminants were below their respective MCLs and in most cases were ND.

Upon receiving a cleared sample result meeting all regulatory requirements for safe drinking water, Louisville would coordinate with customers to reopen the curb stop and return water service to the building. Additional guidance on flushing interior plumbing was provided to customers when water service was returned.

4.3 Destroyed Structures

A destroyed structure was defined as a building damaged beyond repair by the fire. Due to the severe damage at these locations, water service was shut off for the foreseeable duration of the rebuilding process.

During the construction process, a building is typically re-connected to the existing water service line used by the previous building. In this case, the nature of the disaster would require contractors to excavate the building and some of the surroundings to remove the destroyed material, including a portion of the service line. Louisville proactively determined to sample a subset of destroyed structures from the existing and replaced service lines to confirm that no further contamination lingered within the service line.

4.3.1 Destroyed Structure Sample Methods

- Louisville staff coordinated with customers to schedule flushing and sampling.
- Several locations were selected where the service line could be accessed safely outside the destroyed building prior to any debris removal. The remaining locations were sampled after debris removal and the contractor left the service line accessible for Louisville sampling Figure 6.
- As Louisville and Corona staff were not entering the building, the customer was not required to be present.
- Louisville staff would slightly open the curb stop to temporarily return water service to the service line
- Corona staff would immediately collect the "stagnant" VOC samples, followed by the "stagnant" SVOC samples.
- The curb stop was then fully opened to flush the service line
- After flushing for 5 minutes, Corona staff collected and field analyzed a free chlorine sample using a Hach DR300. (Free chlorine levels in stagnant water are typically close to non-detect (0 mg/L), while the target free chlorine residual of recently treated water moving through the distribution system is ≥ 1 mg/L).
- If the free chlorine level was less than 1 mg/L, flushing was resumed with additional chlorine samples performed approximately every 5 minutes.
- Once the measured free chlorine level was 1 mg/L or higher, flushing was concluded.
- Corona staff then collected the "flushed" VOC samples, followed by "flushed" SVOC samples.
- Louisville staff closed the curb stop to the service line.

Figure 6. Sampling an accessible service line at a destroyed structure

Following sample collection, Corona worked with several analytical laboratories to perform VOC and SVOC analysis as detailed in the Laboratory Analytical Plan section. Results for this sampling are detailed in the Destroyed Structure results section.

When sample analysis was completed by the analytical laboratory, results were reviewed by Corona and Louisville staff. If any contaminants exceeded a regulatory MCL or were found at a level indicating the possible presence of fire-related contamination additional flushing and sampling was scheduled. The flushing and sampling were continued until all regulated contaminants were below their respective MCLs and in most cases were ND.

In contrast with the other simultaneous sampling efforts, sampling at destroyed structures did not trigger a return to water service upon receiving cleared sample results. These locations were in the process of removing debris and rebuilding structures and would still need to request water service through Louisville when they reached that stage of construction.

4.4 Meter Pits

In coordination with CDPHE, Louisville and Corona developed a sample plan to monitor VOCs and SVOCs at a subset of the homes being rebuilt throughout Louisville. While it was anticipated that the previous stages of flushing and sampling had confirmed that all fire related water system contamination had been flushed from the system, the meter pit sampling would ensure that new connections to rebuilt structures were also free from fire related contamination. A statistically significant number of structures from each hydraulically isolated neighborhood were included in the sample plan as a way to distribute the samples evenly throughout Louisville.

To avoid the possibility of flushing contamination into the new plumbing in rebuilt structures, sampling was performed at the meter pit before Louisville connected the service line to the home for service. A service line passes through a water meter which records water usage through a service line and is typically either located in the basement of a building or in a meter pit buried in the yard of the property. Louisville is installing meter pits in the yard or driveway of all the rebuilt buildings for more streamlined access.

4.4.1 Meter Pit Sample Plan

- Louisville staff coordinated with customers and their contractors to schedule flushing and sampling when the contractor had completed installation of the meter pit, including the service lines on either side.
- As Louisville and Corona staff were not entering the building, the customer was not required to be present.
- Louisville staff would slightly open the curb stop to temporarily provide water to the service line entering the meter pit.
- Corona staff would immediately collect the “stagnant” VOC samples, followed by the “stagnant” SVOC samples.
- The curb stop was then fully opened to flush the service line; a hose was used to run the flushed water to the street if needed (Figure 7)
- After flushing for 5 minutes, Corona staff collected and field analyzed a free chlorine sample using a Hach DR300. (Free chlorine levels in stagnant water are typically close to non-detect (0 mg/L), while the target free chlorine residual of recently treated water moving through the distribution system is ≥ 1 mg/L).
- If the free chlorine level was less than 1 mg/L, flushing was resumed with additional chlorine samples performed approximately every 5 minutes.
- Once the measured free chlorine concentration was 1 mg/L or higher, flushing was concluded.
- Corona staff then collected the “flushed” VOC samples, followed by “flushed” SVOC samples.
- Louisville staff closed the curb stop to the service line.

Figure 7. A meter pit being flushed after stagnant sample collection

Following sample collection, Corona worked with several analytical laboratories to perform VOC and SVOC analysis as detailed in the Laboratory Analytical Plan section. Results for this sampling are detailed in the Meter Pit results section.

When sample analysis was completed by the analytical laboratory, results were reviewed by Corona and Louisville. If any contaminants exceeded a regulatory MCL or were found at a level indicating the possible presence of fire-related contamination additional flushing and sampling was scheduled. The flushing and sampling were continued until all regulated contaminants were below their respective MCLs and in most cases were ND.

Upon receiving a cleared sample result meeting all regulatory requirements for safe drinking water, the City would coordinate with customers or contractors to complete the installation of the water meter and open the curb stop, providing water service to the building.

5 Results

Louisville and Corona reviewed each VOC and SVOC sample result as it was returned from the analytical laboratory. In addition to providing sample results, labs include details on their internal quality assurance and quality control (QA/QC). Some results are flagged for possible cross contamination, or to indicate that a specific analyte failed QA/QC by the lab. The implications of these flagged results were considered, and if necessary additional sampling was performed.

If sample results indicated that a fire-related contaminant was found to exceed an EPA MCL[1], the steps detailed in the Laboratory Analytical Plan section were followed, including additional flushing and sampling until the result was below the MCL.

Table 4 summarizes the number of samples collected in each stage, the number of individual compounds analyzed, and the contaminants detected or exceeding the EPA MCL. For perspective on the sampling timeline, Figure 8 shows the number of sample events occurring per month in each stage of water system recovery over time. A full list of all compounds analyzed at any stage of sampling is included in the Appendix under All Compounds Analyzed in Marshall Fire Water System Sampling.

In this report, a detection is considered to be any result equal to or exceeding the laboratory Method Reporting Limit (MRL). The MRL is the smallest concentration of a specific analyte that the laboratory can report with reasonable accuracy and precision. Occasionally, laboratories will detect analytes below the MRL, but they are flagged to indicate they may be inaccurate. A compound may exceed the MRL and be considered a detection but still be at an extremely low concentration well below the health based MCL enforced by the EPA and CDPHE.

Note that six compounds are included in both the VOC and SVOC laboratory methods due to their vapor pressure and solubility bordering the definition of both categories:

- 1,4-Dichlorobenzene
- 1,2,4-Trichlorobenzene
- Naphthalene
- 1,2-Dichlorobenzene
- 1,3-Dichlorobenzene
- Hexachlorobutadiene

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[1] As expected, in most samples disinfection byproducts (i.e. Chloroform, Bromodichlormethane, Dibromochloromethane, Bromoform which comprise Total Trihalomethanes (TTHM)) were detected below allowable USEPA Maximum Contaminant Limits (MCL) for Drinking Water. The MCL for Total Trihalomethanes which is the sum of Chloroform, Bromodichloromethane, Dibromochloromethane, and Bromoform is 80 ug/L. These are not fire-related contaminants of concern and do not indicate contamination caused by the fire. Detections of disinfection byproducts are not included in any sample counts or results in this report.

These compounds were analyzed as both VOCs and SVOCs for some of the samples in this sampling campaign. For the purposes of this report, the highest result of the two methods was used. A review of all samples analyzed under both methods which had results above the MRL found that the result from the VOC method was always higher than the SVOC result due to differences in the analytical methods. Therefore, the analytes are categorized as VOCs in subsequent summary tables and only the VOC result is included in summary statistics. In some instances, these six compounds were only analyzed using the SVOC method. The SVOC results are used in these cases, but the compound is classified as VOC for the purposes of reporting and calculating summary statistics.

5.1 Systemwide Summary

The sample results are summarized below (Table 4) for all sample types. The distribution system (186 stagnant and 182 flushed samples) was sampled more than the other sample locations, followed by standing structures (142 stagnant, 128 flushed samples), meter pits (81 stagnant, 81 flushed samples), and destroyed structures (35 stagnant, 34 flushed samples). In total, 869 samples were collected, which included 95,988 individual analyses conducted. Only 542 analytes (0.56%) were above the MRL and 31 analytes (0.03%) exceeded a health based MCL. The stagnant destroyed structure samples were most likely to have water samples that exceeded an MCL compared to the other sample types (0.14%). In other similar post-wildfire sampling, destroyed structure water samples also had more MCL exceedances. Solomin et al observed destroyed sample MCL exceedances for benzene at 21% whereas the standing structures only had 1% of samples over the MCL (Solomon et al., 2021b). This is likely due to the significant amount of fire related contaminants entering plumbing through a destroyed structure.

Louisville has made results publicly available through an online map. The map allows customers to click on individual sample locations and review the history of sampling at the location as well as to view the PDF laboratory results. The online map is located at:

https://gis.louisvilleco.gov/portal/apps/webappviewer/index.html?id=110f32386ee14f84a72adb035644bafe

Table 4. Sample results categorized by sample stage and sample type

Sample Stage	Sample Type	Number of Samples Collected	Number of Total Analyses	Number of Total Analyses >MRL	Percent >MRL	Number of Total Analyses >MCL	Percent >MCL
Distribution System	Stagnant	186	19,790	125	0.63%	11	0.06%
	Flushed	182	19,752	52	0.26%	3	0.02%
Standing Structures	Stagnant	142	14,568	111	0.76%	7	0.05%
	Flushed	128	14,310	45	0.31%	0	0%
Destroyed Structures	Stagnant	35	4,109	31	0.75%	6	0.15%
	Flushed	34	3,910	11	0.28%	0	0%
Meter Pits	Stagnant	81	9,078	117	1.29%	3	0.03%
	Flushed	81	9,078	36	0.40%	1	0.01%
TOTAL		869	94,595	528	0.56%	31	0.03%

Regardless of the sample stage, the stagnant samples were more likely to exceed the MRL or the MCL than flushed samples which is shown in Table 5 with results from all sample stages combined into either the stagnant or flushed category. Of the 31 analyses that exceeded an MCL at any stage of water sampling, 27 were found in stagnant samples and 4 in flushed samples. This indicates that flushing pipes was effective at removing fire-related contamination, as was also seen in the Camp Fire (Solomon et al., 2021b). Additionally, all 31 of the contaminants exceeding an MCL were VOCs.

Table 5. Sample results from all stages summarized by sample type

Sample Type	Number of Samples Collected	Number of Total Analyses	Number of Total Analyses >MRL	Percent >MRL	Number of Total Analyses >MCL	Percent >MCL
Stagnant	444	47,050	384	0.81%	27	0.06%
Flushed	425	47,545	144	0.31%	4	0.01%

Table 6 summarizes the differences between VOC and SVOC results. Both methods had greater than 200 analyses that exceeded the MRL. Only VOCs exceeded an MCL in all 31 instances.

Table 6. Comparison of VOC and SVOC sample results from all stages

Sample Method	Number of Total Analyses	Number of Total Analyses >MRL	Percent >MRL	Number of Total Analyses >MCL	Percent >MCL
SVOCs	52,508	222	0.42%	0	0%
VOCs	42,087	306	0.73%	31	0.07%

Figure 8 shows the number of sample events occurring per month in each stage of water system recovery. In the initial months after the fire, the focus was on returning water service to un-damaged standing structures by sampling throughout the distribution system as well as inside standing structures. Sampling then moved into destroyed structures and meter pits, while maintaining occasional proactive distribution system sampling to confirm fire related contamination had been fully removed by flushing.

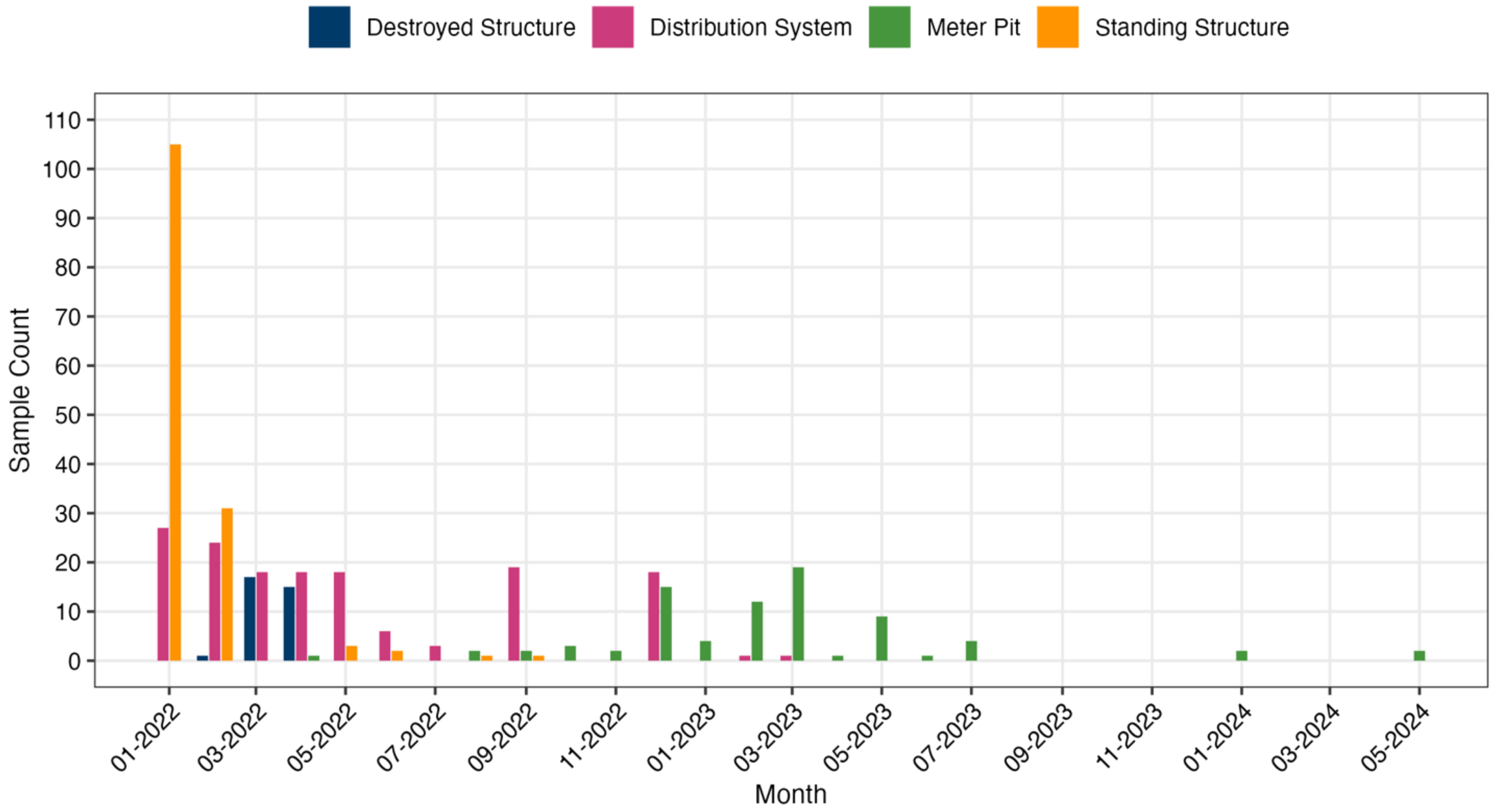

Figure 8. Sample collection events for all stages of water system recovery shown on the dates the sampling occurred

Contaminants that were found to exceed an MCL are shown in Table 4; only VOCs exceeded an MCL. Figure 9 includes results from all sample stages and shows the concentrations over time of contaminants which were found to exceed an MCL in at least one sample result. Benzene is a carcinogenic compound that has commonly been detected in drinking water after wildfires likely due to factors like pyrolysis and smoke intrusion from depressurization contributing to the benzene contamination (Proctor et al., 2020; Solomon et al., 2021b). In the drinking water analysis conducted here, benzene was detected above the MCL on 12 different occasions. Similarly, styrene and ethylbenzene were detected above the MCL (9 and 2 detections above the MCL respectively) and have previously been detected in other wildfires, though they have not historically been investigated as thoroughly as benzene (Proctor et al., 2020). Carbon tetrachloride was also detected above the MCL in 3 water samples in. It is difficult to pinpoint where the carbon tetrachloride originated from, but it has been detected in burnt PVC pipes in another study (Chong et al., 2019). It is also possible that carbon tetrachloride was detected as a result of contamination from nearby construction and not from fire contamination. Carbon tetrachloride is also used in the manufacture of brake and machinery cleaners, industrial-strength structural and plastic adhesives, and synthetic rubbers (ATSDR, 2017).

Table 7. Fire-related VOCs exceeding the EPA MCL during any stage of water system sampling

Contaminant	Type	Number of Detections >MCL	MCL (µg/L)	Maximum Concentration (µg/L)	Detected in Historic Post-Wildfire Drinking Water Sampling
Benzene	VOC	15	5	221	Y
Styrene	VOC	11	100	8,300	Y
Carbon Tetrachloride[1]	VOC	3	5	9.6	Y
Ethylbenzene	VOC	2	700	1,600	Y

[1] Follow up sampling and typical carbon tetrachloride sources indicate possible construction or sampling cross contamination for meter pit results, not necessarily fire-related contamination

Figure 9. Concentrations over time of the contaminants that exceeded an MCL - includes results from all stages of water system recovery

The contaminants that most were most frequently detected at concentrations greater than the MRL are shown in Table 8. Bis(2-ethylhexyl)phthalate and bis(2-chloroethyl)ether are common laboratory contaminants picked up at very low levels while the samples were being analyzed and are not expected to be a fire-related contaminant; these contaminants are not shown in the summary figures.

Table 8. The ten VOCs and SVOCs with concentrations most frequently above the MRL

Contaminant	Type	Number of Analyses	Number of Detections >MRL[1]	Maximum Concentration >MRL (µg/L)	Detected in Historic Post-Wildfire Drinking Water Sampling
Bis(2-ethylhexyl)phthalate[2]	SVOC	739	66	18	N[2]
Bis(2-chloroethyl)ether[2]	SVOC	739	43	12	N[2]
Ethylbenzene	VOC	882	40	1600	Y
Toluene	VOC	882	39	512	Y
Acetone	VOC	853	38	1200	Y
Benzene	VOC	882	31	221	Y
Styrene	VOC	882	30	8,300	Y
1,2-Dichlorobenzene	VOC	765	27	29	Y
Naphthalene	VOC	910	25	42	Y
Isopropylbenzene	VOC	862	18	190	Y

[1] The MRL varied by contaminant, laboratory, calibration, and method.

[2] These contaminants are common laboratory contaminants picked up at the very low concentrations being monitored and are not expected to be fire related contaminants.

Figure 10 and Figure 11 show concentrations over time for the contaminants most frequently detected above the MRL. This includes sample results from all sample stages at all locations. An MCL is shown for regulated contaminants; unregulated contaminants do not have an MCL.

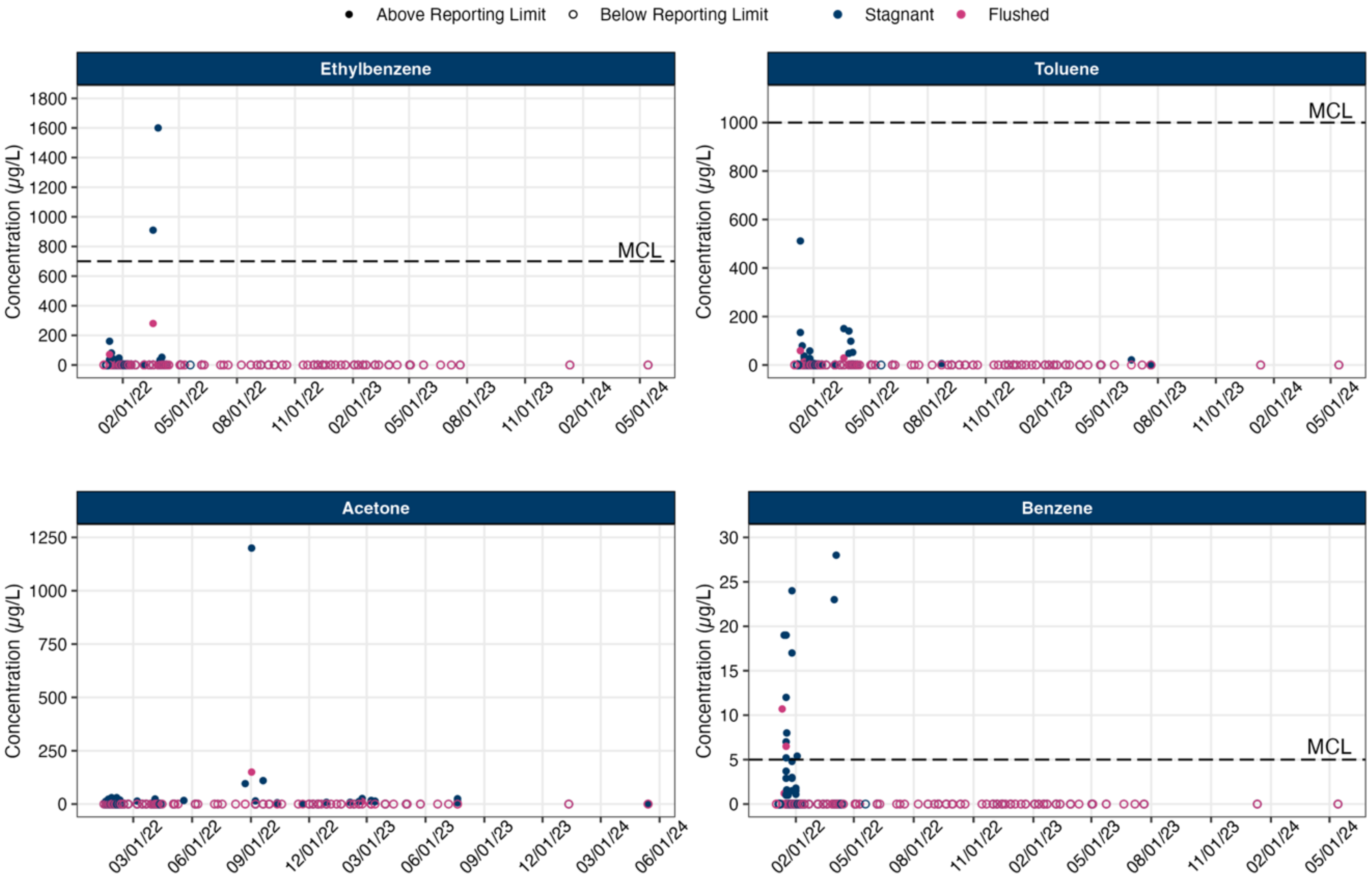

Figure 10. Sample concentrations over time for contaminants most frequently over the MRL – includes results from all stages of water system recover (1 of 2)

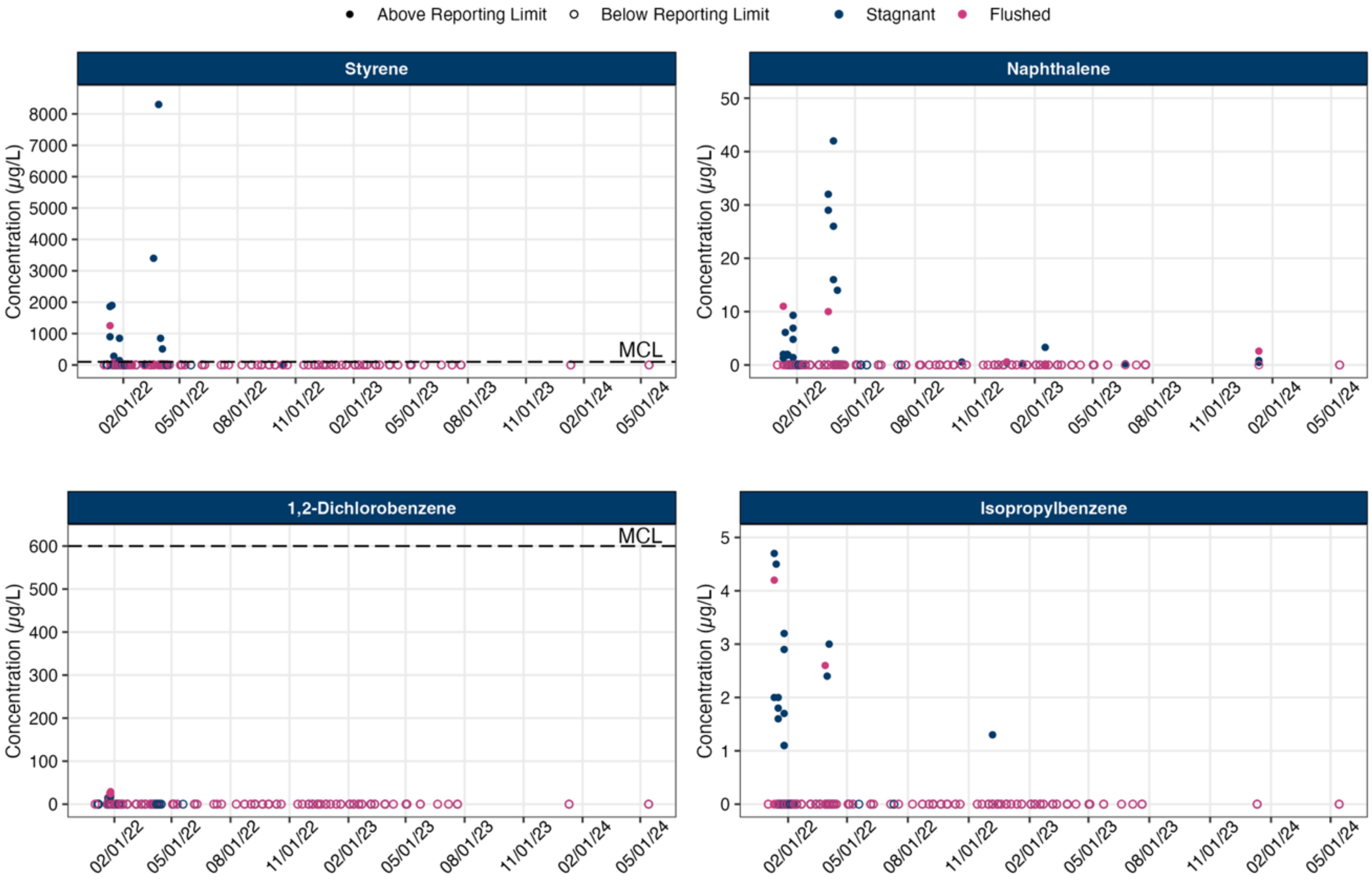

Figure 11. Sample concentrations over time for contaminants most frequently over the MRL – includes results from all stages of water system recovery (2 of 2)

5.2 Distribution System Results

Distribution system sampling began immediately after the fire and was performed routinely until March 2023. Table 9 summarizes the samples completed in the distribution system. Over 180 samples were performed throughout the water system, with a stagnant and flushed sample collected in nearly all those instances. The number of individual analytes exceeding the MCL was 14, with 11 of those exceedances in stagnant samples and 3 in a flushed sample. Similarly, the majority of analyses exceeding an MRL were in stagnant samples with 125, compared with 52 in flushed samples.

Table 9. Summary of distribution system sampling, results above MRL, and results exceeding an MCL

Sample Stage	Sample Type	Number of Samples Collected	Number of Total Analyses	Number of Total Analyses >MRL	Percent >MRL	Number of Analyses >MCL	Percent >MCL
Distribution System	Stagnant	186	19,790	125	0.63%	11	0.06%
	Flushed	182	19,752	52	0.26%	3	0.02%

Table 10 summarizes the three contaminants that exceeded an MCL in Distribution System samples: benzene, styrene, and carbon tetrachloride. Figure 12 shows the Distribution System sample results over time. As with sampling in other stages of the recovery, the general trend is a decrease in fire related contaminants with flushing of the distribution system which is particularly evident with the benzene and styrene concentrations.

Table 10. VOCs detected in distribution system sampling that exceeded the MCL

Sample Stage	Contaminant	Number of Detections >MCL	MCL (µg/L)	Maximum Concentration (µg/L)	Detected in Historic Post-Wildfire Drinking Water Sampling
Distribution System	Benzene	9	5	221	Y
	Styrene	4	100	1,862	Y
	Carbon Tetrachloride	1	5	6	Y

Figure 12. Contaminants detected above the MCL in distribution system sampling

5.3 Standing Structure Results

Upon receiving acceptable results for water samples in the hydraulically isolated distribution system water mains neighboring fire-impacted areas, sampling began in standing structures connected to those mains. The initial push to sample and clear standing structures was completed in January and February 2022, allowing residents to have water service returned to their homes after receiving acceptable results. A small number of samples were completed in the following months due to constraints for residents who were not able to return home or chose to delay testing.

Table 11 summarizes the samples completed in the standing structures. Over 140 samples were performed in standing structures, with a stagnant and flushed sample collected in most of those instances. The number of individual analytes exceeding the MCL was 7, with all those exceedances in stagnant samples. Similarly, most analyses exceeding an MRL were in stagnant samples with 111, compared with 45 in flushed samples.

Table 11. Summary of standing structure sampling, results above MRL, and results exceeding an MCL

Sample Stage	Sample Type	Number of Samples Collected	Number of Total Analyses	Number of Total Analyses >MRL	Percent >MRL	Number of Total Analyses >MCL	Percent >MCL
Standing Structures	Stagnant	142	14,568	111	0.76%	7	0.05%
	Flushed	128	14,310	45	0.31%	0	0%

Table 12 summarizes the two contaminants that exceeded an MCL in standing structure samples: benzene, and styrene. Figure 13 shows the standing structure sample results over time. As with sampling in other stages of the recovery, the general trend is a decrease in fire-related contaminants with flushing of the distribution system which is particularly evident with the benzene concentrations.

Table 12. VOCs detected in standing structure sampling that exceeded an MCL

Sample Stage	Contaminant	Number of Detections >MCL	MCL (µg/L)	Maximum Concentration (µg/L)	Detected in Historic Post-Wildfire Drinking Water Sampling
Standing Structures	Benzene	4	5	24	Y
	Styrene	3	100	1,900	Y

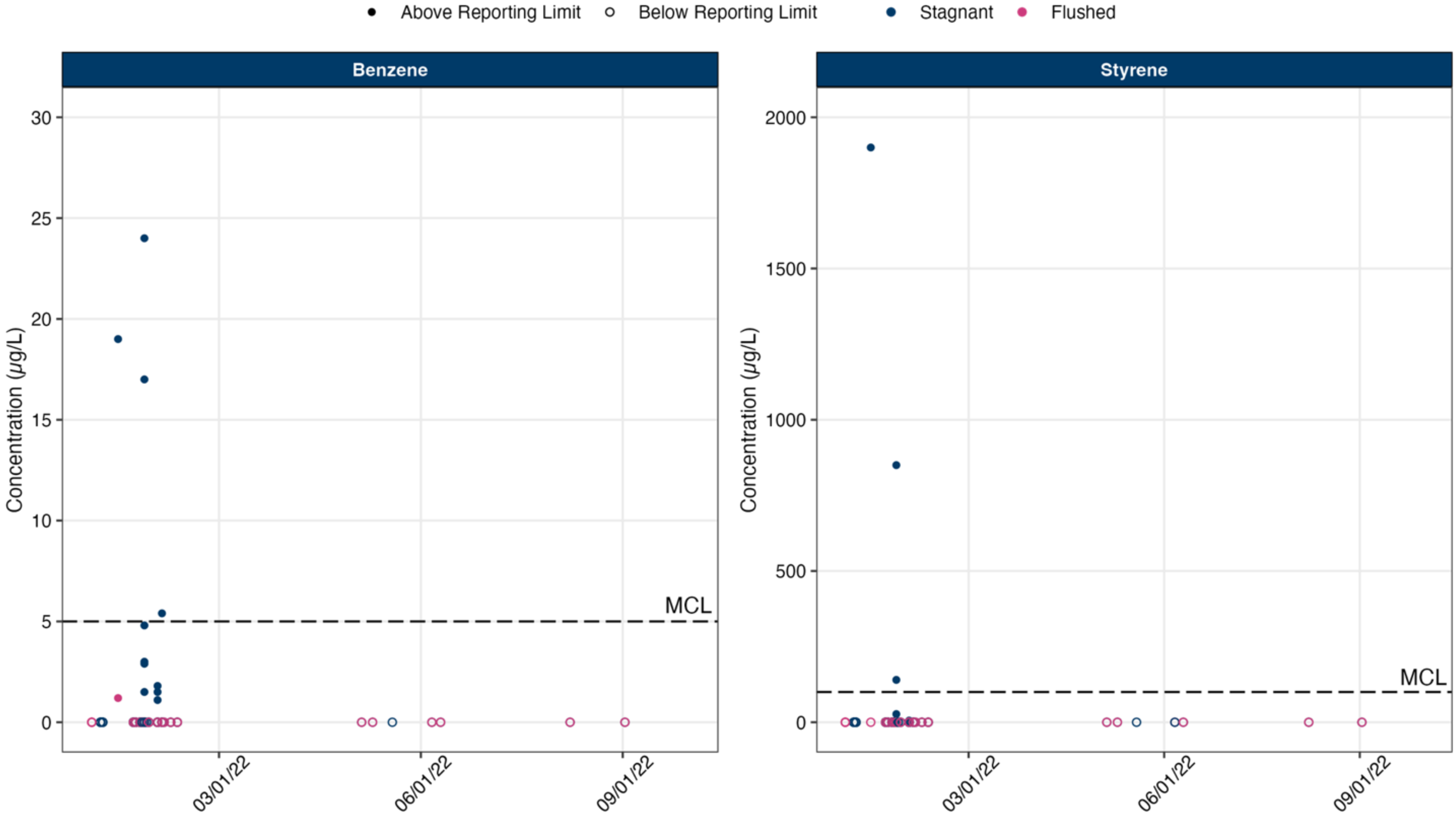

Figure 13. Contaminants detected above an MCL in standing structure sampling

5.4 Destroyed Structure Results

Destroyed structure sampling was performed after completion of the urgent return to service sampling for the distribution system and standing structures. This sampling stage began in February 2022 and was completed in April 2022.

Table 13 summarizes the samples completed in the destroyed structures. Over 30 samples were performed in destroyed structures, with a stagnant and flushed sample collected in nearly all those instances. The number of individual analytes exceeding the MCL was 6, with all those exceedances in stagnant samples. Similarly, most analyses exceeding an MRL were in stagnant samples with 31, compared with 11 in flushed samples.

Table 13. Summary of destroyed structure sampling, results above MRL, and results exceeding an MCL

Sample Stage	Sample Type	Number of Samples Collected	Number of Total Analyses	Number of Total Analyses >MRL	Percent >MRL	Number of Total Analyses >MCL	Percent Exceeding the MCL
Destroyed Structures	Stagnant	35	4,109	31	0.75%	6	0.15%
	Flushed	34	3,910	11	0.28%	0	0%

Table 14 summarizes the contaminants that exceeded an MCL in destroyed structure samples: styrene, ethylbenzene, and benzene. Figure 14 shows the destroyed structure sample results over time. As with sampling in other stages of the recovery, fire related contaminants decrease with flushing.

Table 14. VOCs detected in destroyed structure sampling that exceeded an MCL

Sample Stage	Contaminant	Number of Detections >MCL	MCL (µg/L)	Maximum Concentration (µg/L)	Detected in Historic Post-Wildfire Drinking Water Sampling
Destroyed Structures	Styrene	3	100	8,300	Y
	Ethylbenzene	2	700	1,600	Y
	Benzene	1	5	28	Y

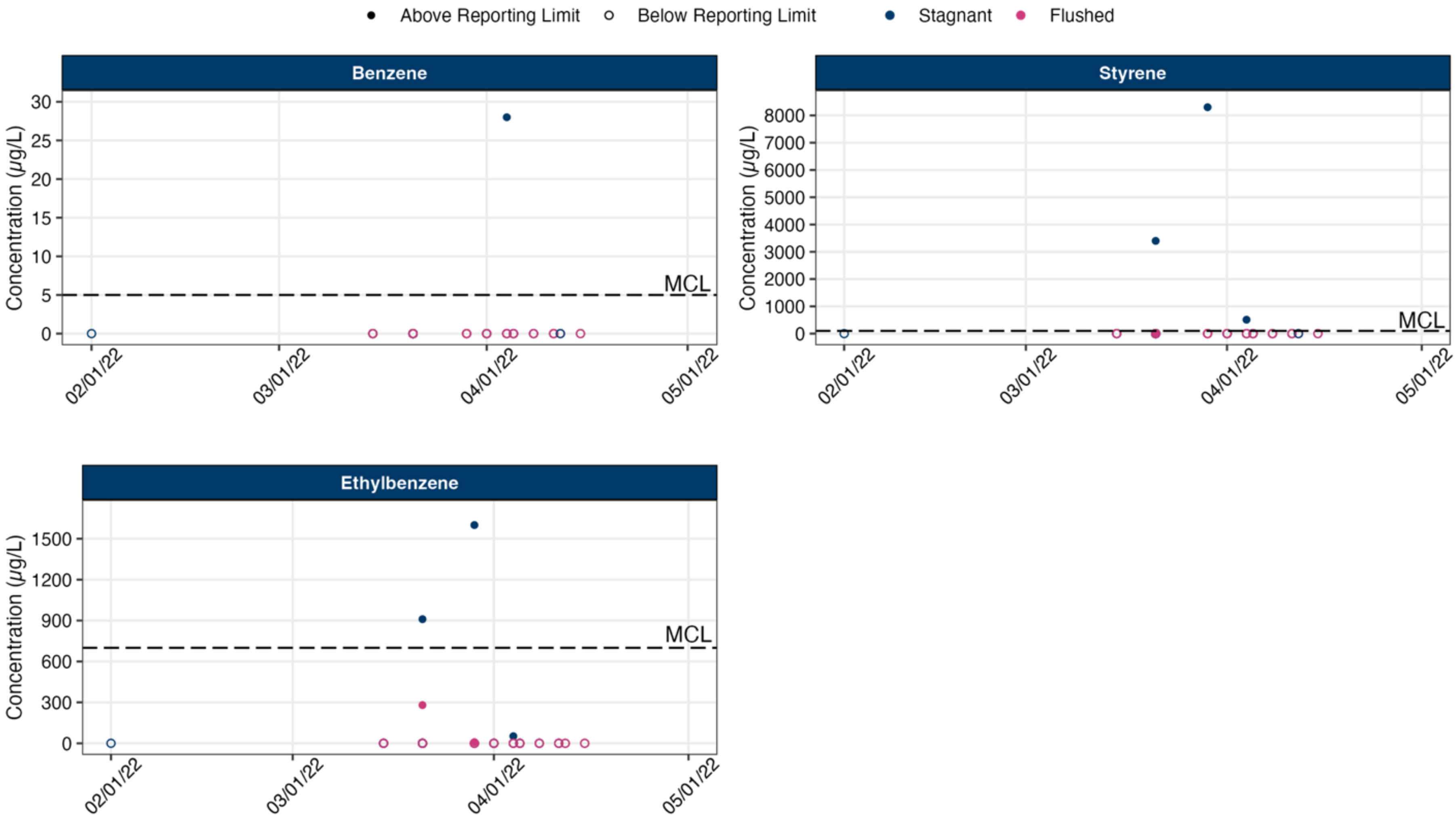

Figure 14. Contaminants detected above an MCL in destroyed structure sampling

5.5 Meter Pit Results

Meter pit sampling was conducted as destroyed structures were rebuilt. Louisville coordinated with property owners and contractors to access the replaced segment of service line either in the meter pit or in a stubbed-up location if the meter pit was not yet complete. The final required meter pit sample was completed in May 2024.

Table 15 summarizes the samples completed in meter pits. Over 80 samples were performed, with a stagnant and flushed sample collected in all those instances. The number of individual analytes exceeding the MCL was 4, with 3 of those exceedances in stagnant samples and 1 in a flushed sample. Similarly, most analyses exceeding an MRL were in stagnant samples with 117, compared with 36 in flushed samples.

Table 15. Summary of meter pit sampling, results above MRL, and results exceeding an MCL

Sample Stage	Sample Type	Number of Samples Collected	Number of Total Analyses	Number of Total Analyses >MRL	Percent >MRL	Number of Total Analyses > MCL	Percent Exceeding the MCL
Meter Pits	Stagnant	81	9,078	117	1.29%	3	0.03%
	Flushed	81	9,078	36	0.40%	1	0.01%

Table 16 summarizes the contaminants that exceeded an MCL in meter pit samples: carbon tetrachloride, benzene, and styrene. Figure 15 shows the meter pit sample results over time. As with sampling in other stages of the recovery, fire related contaminants decrease with flushing.

Table 16. VOCs detected in meter pit sampling that exceeded an MCL

Sample Stage	Contaminant	Number of Detections >MCL	MCL (µg/L)	Maximum Concentration (µg/L)	Detected in Historic Post-Wildfire Drinking Water Sampling
Meter Pits	Carbon Tetrachloride[1]	2	5	9.6	Y
	Benzene	1	5	23	Y
	Stryene	1	100	850	Y

[1] Follow up sampling and typical carbon tetrachloride sources indicate possible construction or sampling cross contamination, not fire-related contamination

Figure 15. Contaminants detected above an MCL in meter pit sampling (carbon tetrachloride may be construction or laboratory cross contaminant)

5.6 Neighborhood Overview

For ease of reference by customers, results are also broken down by the neighborhood in which they occurred. These neighborhoods are not necessarily distributed in the conventional definition; instead, samples collected within a hydraulically isolated area were grouped together, as they were likely representative of similar water quality and were all fed by the same group of water mains in the distribution system. Due to this distribution of samples by hydraulic isolation of the water distribution system, not every neighborhood will have samples collected in all stages of sampling, as representative samples may have been collected in a nearby distribution system. Additionally, the number of samples performed per neighborhood varies due to the areas that experienced greater depressurization during firefighting efforts and were more susceptible to fire related contamination, as shown in their detailed results.

Detailed results and maps are located in the Appendix in the section Sampling Results by Neighborhood. Table 17 summarizes samples completed in each neighborhood. Note that some sample locations do not fall into a specific neighborhood category but are included for completeness (e.g. Avista Hospital).

Table 17. Number of distribution system samples by neighborhood (including stagnant and flushed samples)

Neighborhood	Number of Samples			
	Destroyed Structure	Distribution System	Meter Pit	Standing Structure
Arapahoe	6	57	34	5
Avista Hospital	0	0	0	1
Centennial	0	1	0	0
Cherrywood	2	9	8	6
Club	0	0	2	2
Columbine	0	0	2	1
CTC	0	0	0	1
Dillon	0	0	2	1
Eldorado	8	50	16	0
Enclave	4	22	8	13
Fillmore	0	0	2	2
Fireside Elementary	0	0	0	1
Flatirons	0	12	0	16
Grove	0	1	0	0
Hillside	4	14	8	0

Neighborhood	Number of Samples			
	Destroyed Structure	Distribution System	Meter Pit	Standing Structure
Louisville Rec Center	0	0	0	1
Marshall	0	0	0	1
Meadow	0	0	4	3
Mt Evans	2	26	4	24
Mulberry	2	10	8	2
Owl	4	10	0	54
Pikes Peak	7	46	4	42
Pine	4	14	2	8
Pinehurst	0	0	4	0
Ridgeview	0	0	0	1
Spyglass	0	2	2	1
St Andrews	12	50	32	7
Tanager	0	0	2	1
Trail Ridge	12	26	8	71
Troon	0	16	4	2
Vista	2	2	4	2
Warbler	0	0	2	1
Total	**69**	**368**	**162**	**270**

6 Future Application and Conclusions

As Louisville has progressed through water system recovery, a number of critical steps have been documented and incorporated into their emergency response plans. These lessons learned may also be applicable to other utilities who experience a similar disaster.

Sampling results found that flushing was highly effective at removing fire-related VOC and SVOC contamination from infrastructure, including the water mains and plumbing inside buildings. Of the 31 analyses that exceeded an MCL, 27 were in stagnant samples and only 4 were in flushed samples. All 31 of the MCL exceedances were VOCs. While these fire-related contaminants were detected, Louisville's flushing efforts effectively removed contamination and water service is being safely restored throughout the fire impacted areas as residents continue to rebuild.

When developing the suggested utility response following a natural disaster, there are several components of an emergency response plan that should be considered. Sections of an emergency water response plan should include plans to protect critical assets, control water losses, communicate with the community, conduct water testing to determine the extent of fire-related contamination, and plan for restoring water quality.

Immediate water security plan during a disaster:

- Know where key water shutoff locations and emergency connections are located, and how to utilize them in an emergency
- Disconnect damaged properties and hydraulically isolate fire impacted areas to avoid cross contamination of the distribution system
- Disconnect damaged properties to minimize water losses
- Understand variances in neighborhoods that may require different methods of disconnecting properties
- Develop backup plans for providing water to the distribution system during power outages, as well as plans for monitoring water storage levels without power and restricted travel due to evacuations and fire damage
- Communicate with neighboring utilities and participate in inter-agency exercises to assist each other during emergencies
- Prepare a plan for an emergency system flush and disinfection – this includes understanding the required valve and hydrant operation to flush a fire-impacted area without contaminating the system

Communication plan:

- Implement systems for rapid communication of boil water notices or other time sensitive communication
- Develop systems for communicating water testing results to community members as well as providing updates as the system is returned to service after a disaster
- Be prepared with appropriate contacts at regulatory agencies included in Emergency Response Plan for quick communication

Water testing plan:

- Understand the system's underground infrastructure and be prepared to determine suitable locations for testing each impacted area after a disaster
- Identify appropriate sample methods in advance as well as laboratories that can assist in sample pickup and analysis with a suitable turnaround time; these should be documented in an Emergency Response Plan
- Train staff in sample collection methods
- While prioritizing public health, consider funding constraints and deadlines for development of testing plans and scheduling closeout testing within the reimbursement timeframes when possible

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Appendices

A1 VOC and SVOCs with Regulatory Limits

Parameter	VOC/SVOC	CAS NO	EPA MCL (µg/L)
Ethylbenzene	VOC	100-41-4	700
Styrene	VOC	100-42-5	100
1,4-Dichlorobenzene	VOC	106-46-7	75
1,2-Dichloroethane	VOC	107-06-2	5
Toluene	VOC	108-88-3	1000
Chlorobenzene	VOC	108-90-7	100
1,2,4 Trichlorobenzene	VOC	120-82-1	70
Tetrachloroethene	VOC	127-18-4	5
cis-1,2-Dichloroethene	VOC	156-59-2	70
trans-1,2-Dichloroethene	VOC	156-60-5	100
M,P-Xylene	VOC	179601-23-1	10,000
Carbon Tetrachloride	VOC	56-23-5	5
Benzene	VOC	71-43-2	5
1,1,1-Trichloroethane	VOC	71-55-6	200
Vinyl chloride	VOC	75-01-4	2
1,1-Dichloroethene	VOC	75-35-4	7
1,2-Dichloropropane	VOC	78-87-5	5
1,1,2-Trichloroethane	VOC	79-00-5	5
Trichloroethene	VOC	79-01-6	5
1,2-Dichlorobenzene	VOC	95-50-1	600
Benzo(a) Pyrene	SVOC	50-32-8	0.2
1,2-Dibromo-3-Chloropropane	VOC	96-12-8	0.2
Dinoseb	SVOC	88-85-7	7
1,2-Dibromomethane	VOC	106-93-4	0.05
Hexachlorobenzene	SVOC	118-74-1	1
Hexachlorocyclopentadiene	SVOC	77-47-4	50
Pentachlorophenol	SVOC	87-86-5	1

A2 Sampling Results by Neighborhood

A2.1 Arapahoe

Table 18. Summary of VOC/SVOC sampling performed in Arapahoe neighborhood

Neighborhood	Sample Stage	Type	Number of Samples	Number of Total Analyses	Number of Total Analyses >MRL	Percent >MRL	Number of Total Analyses >MCL	Percent Exceeding the MCL
Arapahoe	Standing Structure	Stagnant	3	354	1	0.29%	0	0%
		Flushed	2	230	0	0%	0	0%
	Meter Pit	Stagnant	17	1,904	16	0.84%	0	0%
		Flushed	17	1,904	3	0.16%	0	0%
	Distribution System	Stagnant	29	3,549	25	0.70%	4	0.11%
		Flushed	28	3,506	12	0.34%	1	0.03%
	Destroyed Structure	Stagnant	3	345	0	0%	0	0%
		Flushed	3	345	0	0%	0	0%

Figure 16. An overview of the sampling performed in the Arapahoe neighborhood

A2.2 Avista Hospital

Table 19. Summary of VOC/SVOC sampling performed at Avista Hospital

Neighborhood	Sample Stage	Type	Number of Samples	Number of Total Analyses	Number of Total Analyses >MRL	Percent >MRL	Number of Total Analyses >MCL	Percent Exceeding the MCL
Avista Hospital	Standing Structure	Stagnant	1	21	0	0%	0	0%

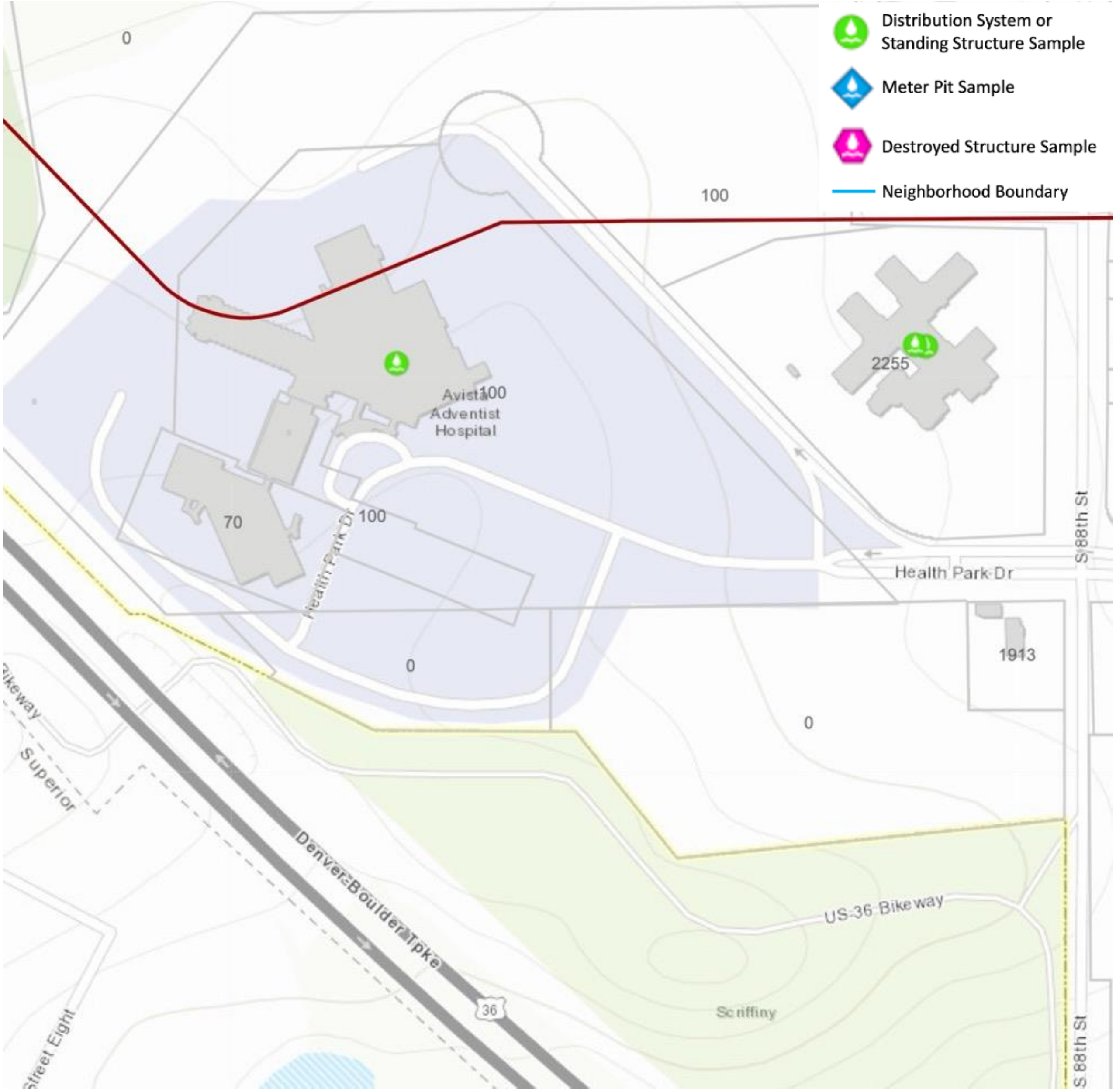

Figure 17. An overview of the sampling performed at Avista Hospital (some samples displayed are not VOC/SVOC but are chlorine residuals or bacti samples)

A2.3 Centennial

Table 20. Summary of VOC/SVOC sampling performed in the Centennial office park

Neighborhood	Sample Stage	Type	Number of Samples	Number of Total Analyses	Number of Total Analyses >MRL	Percent >MRL	Number of Total Analyses >MCL	Percent Exceeding the MCL
Centennial	Distribution	Stagnant	1	21	0	0%	0	0%

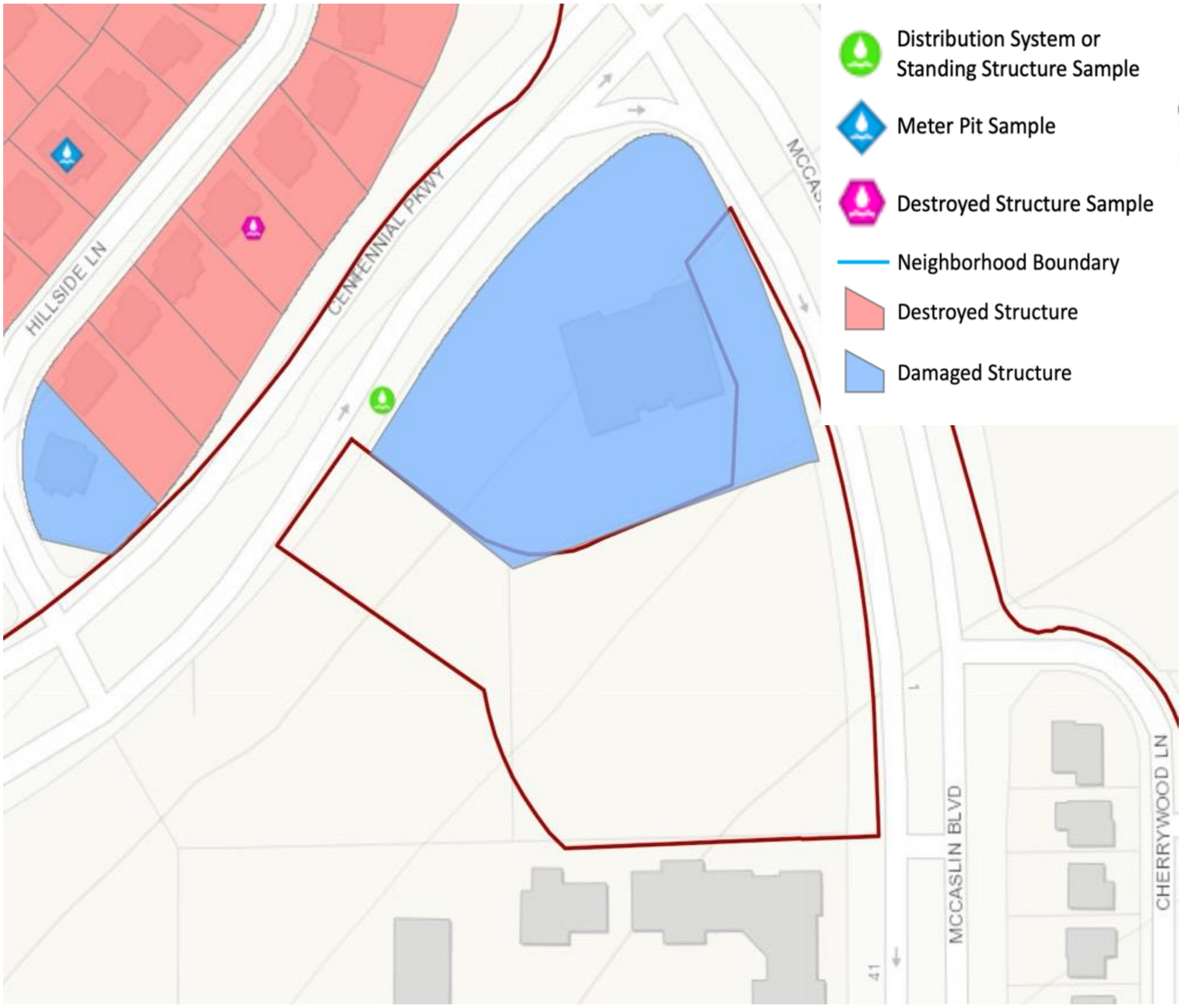

Figure 18. An overview of the sampling performed in the Centennial office park(some samples displayed are not VOC/SVOC but are chlorine residuals or bacti samples)

A2.4 Cherrywood

Table 21. Summary of VOC/SVOC sampling performed in the Cherrywood neighborhood

Neighborhood	Sample Stage	Type	Number of Samples	Number of Total Analyses	Number of Total Analyses >MRL	Percent >MRL	Number of Total Analyses >MCL	Percent Exceeding the MCL
Cherrywood	Standing Structure	Stagnant	4	272	1	0.37%	0	0%
		Flushed	2	230	1	0.43%	0	0%
	Meter Pit	Stagnant	4	448	2	0.45%	0	0%
		Flushed	4	448	1	0.22%	0	0%
	Distribution System	Stagnant	5	569	2	0.35%	0	0%
		Flushed	4	457	1	0.22%	0	0%
	Destroyed Structure	Stagnant	1	115	0	0%	0	0%
		Flushed	1	115	0	0%	0	0%

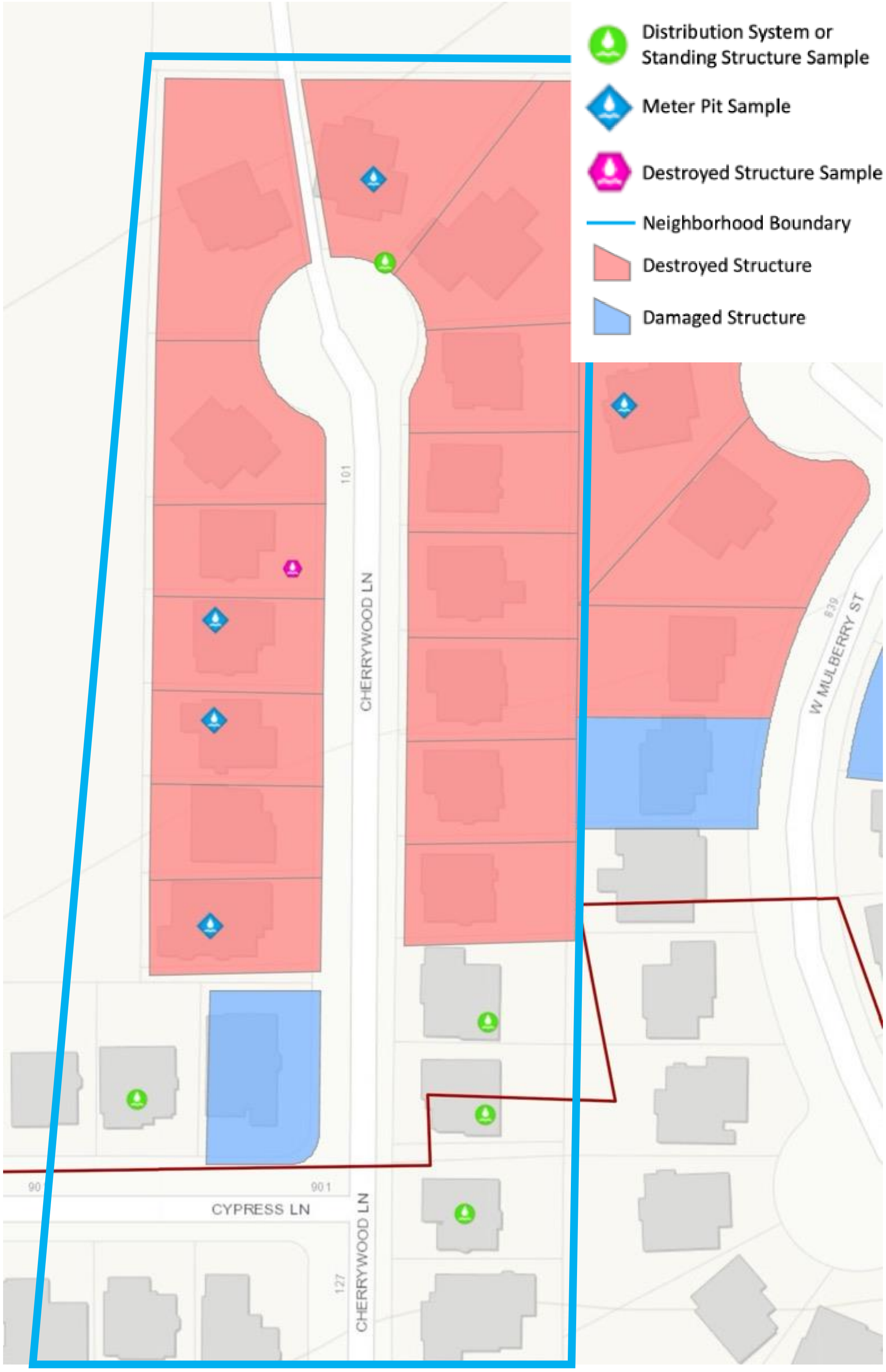

Figure 19. An overview of the sampling performed in the Cherrywood neighborhood

A2.5 Club

Table 22. Summary of VOC/SVOC sampling performed in the Club neighborhood

Neighborhood	Sample Stage	Type	Number of Samples	Number of Total Analyses	Number of Total Analyses >MRL	Percent >MRL	Number of Total Analyses >MCL	Percent Exceeding the MCL
Club	Standing Structure	Stagnant	2	42	0	0%	0	0%
	Meter Pit	Stagnant	1	112	2	1.79%	0	0%
		Flushed	1	112	1	0.89%	0	0%

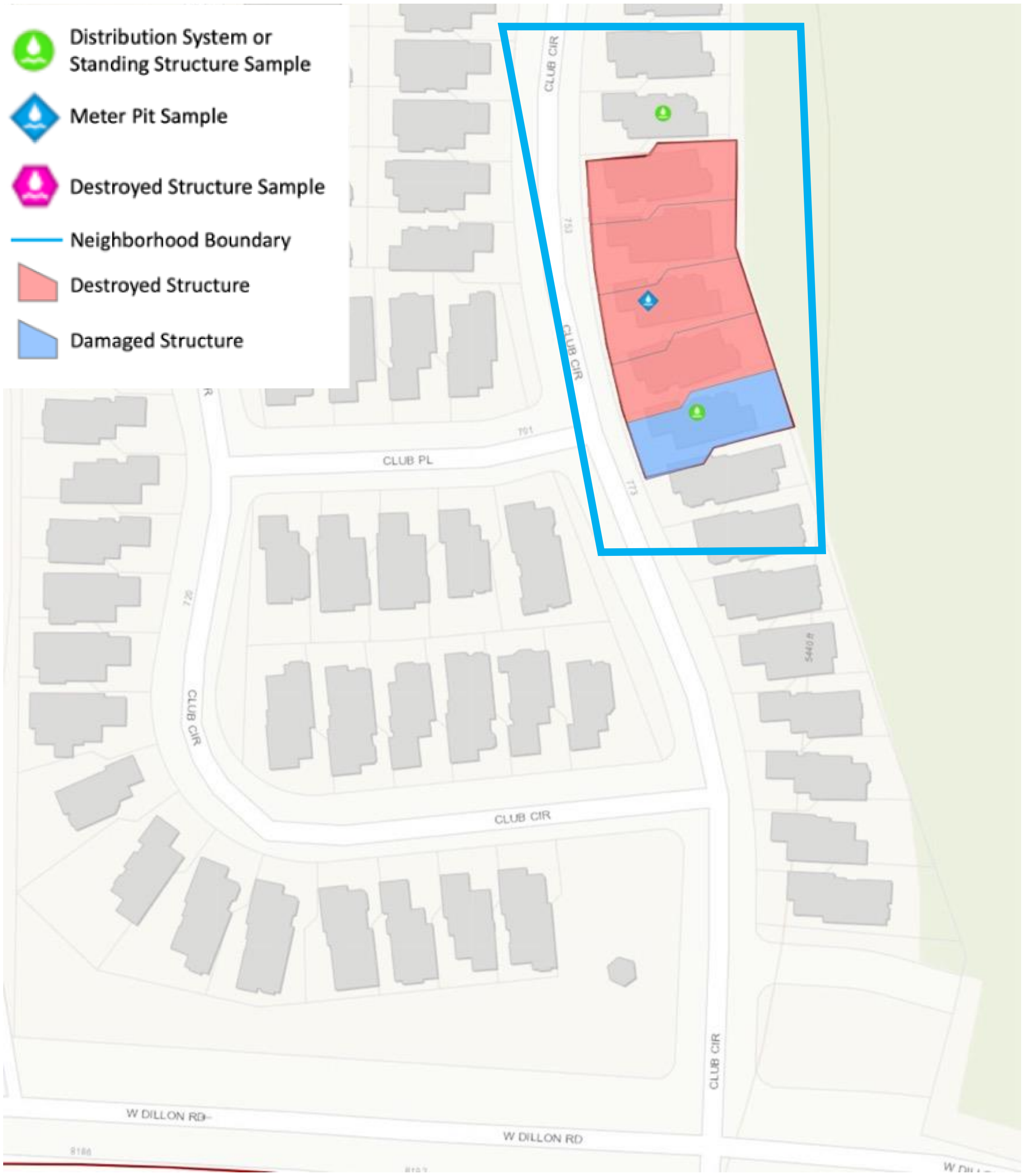

Figure 20. An overview of the sampling performed in the Club neighborhood

A2.6 Columbine

Table 23. Summary of VOC/SVOC sampling performed in the Columbine neighborhood

Neighborhood	Sample Stage	Type	Number of Samples	Number of Total Analyses	Number of Total Analyses >MRL	Percent >MRL	Number of Total Analyses >MCL	Percent Exceeding the MCL
Columbine	Standing Structure	Stagnant	1	21	0	0%	0	0%
	Meter Pit	Stagnant	1	112	10	8.93%	0	0%
		Flushed	1	112	1	0.89%	0	0%

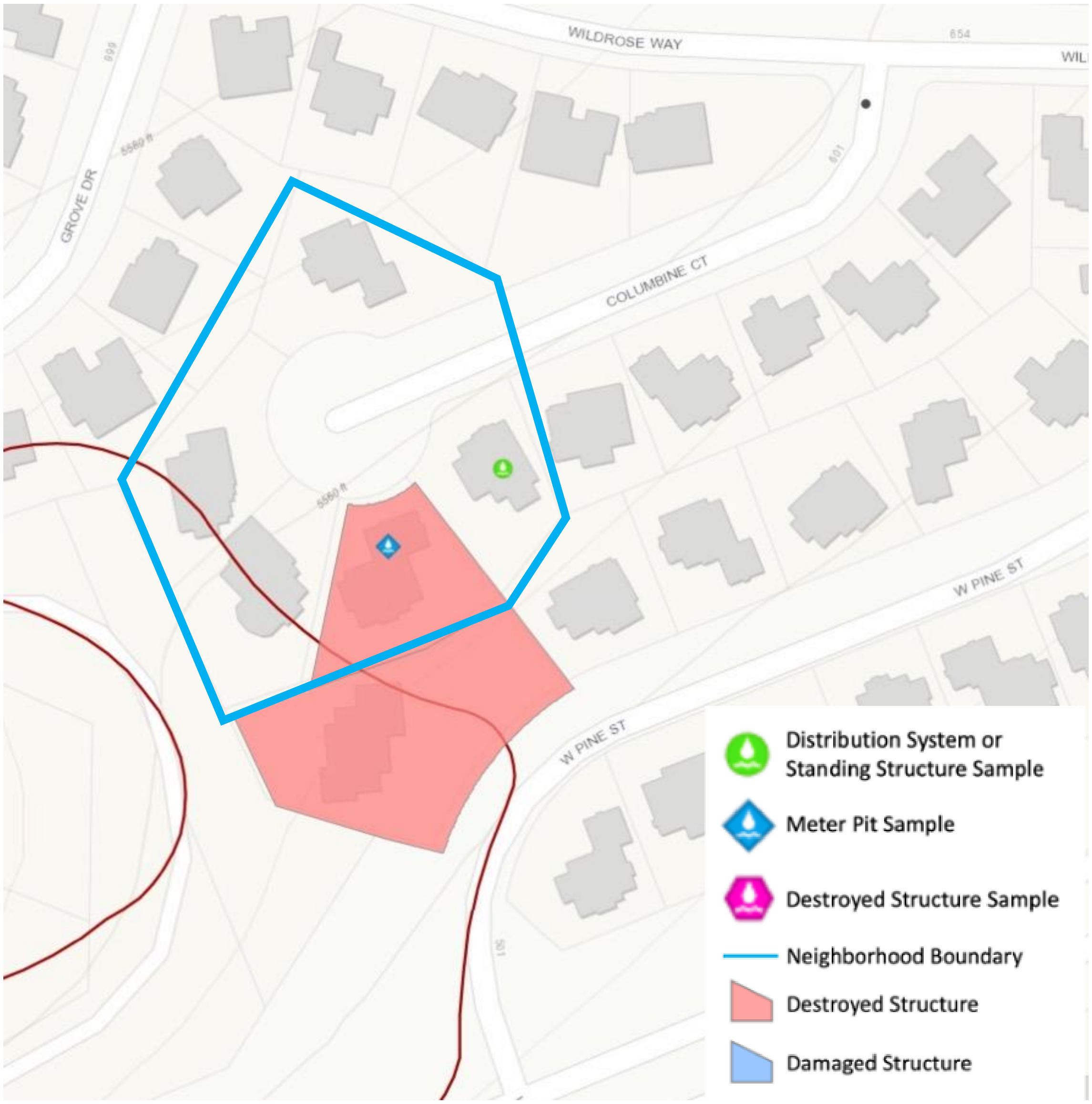

Figure 21. An overview of the sampling performed in the Columbine neighborhood

A2.7 CTC

Table 24. Summary of VOC/SVOC sampling performed in the CTC office park

Neighborhood	Sample Stage	Type	Number of Samples	Number of Total Analyses	Number of Total Analyses >MRL	Percent >MRL	Number of Total Analyses >MCL	Percent Exceeding the MCL
CTC	Standing Structure	Flushed	1	50	0	0%	0	0%

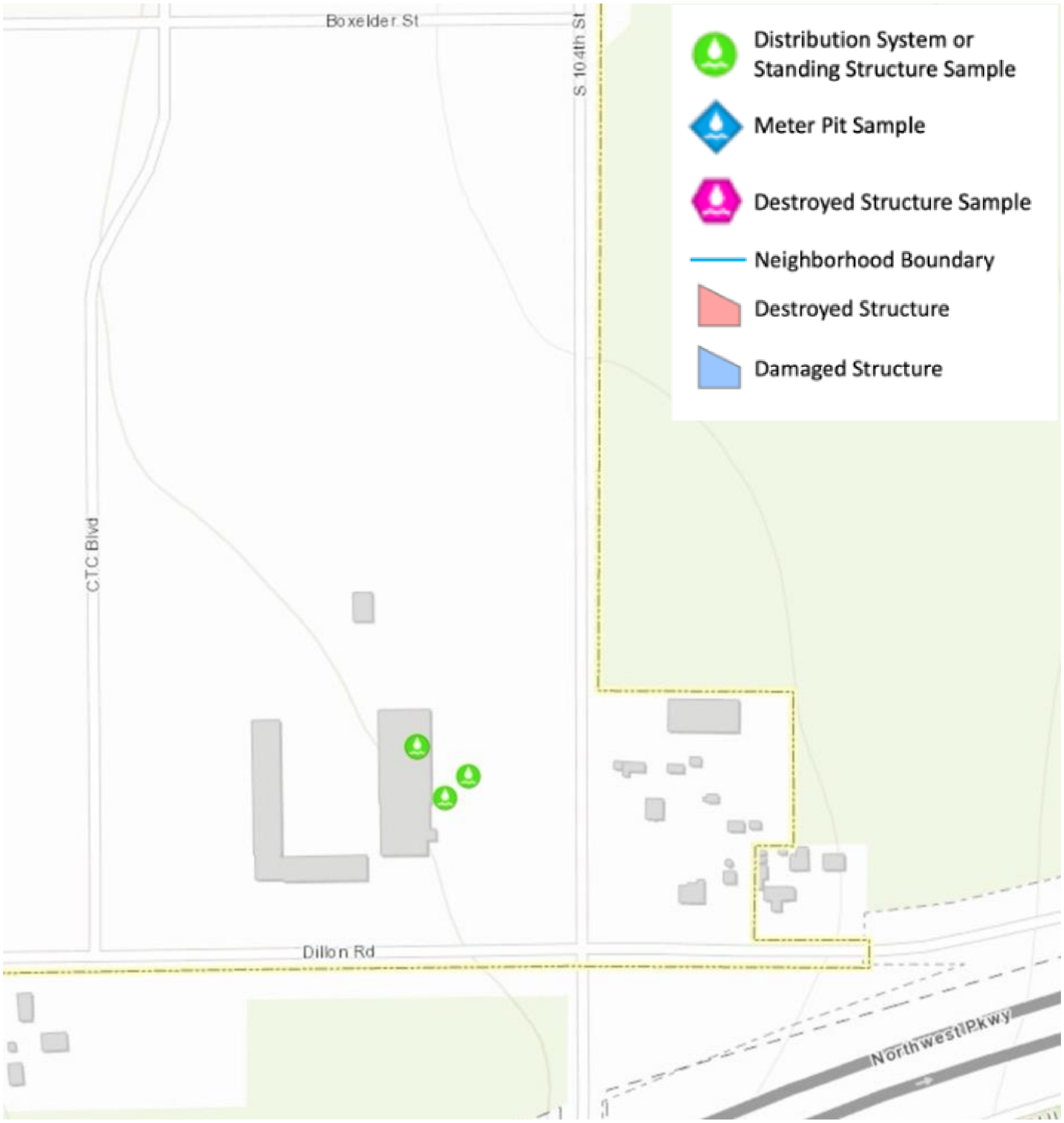

Figure 22. An overview of the sampling performed in the CTC office park(some samples displayed are not VOC/SVOC but are chlorine residuals or bacti samples)

A2.8 Dillon

Table 25. Summary of VOC/SVOC sampling performed in the Dillon neighborhood

Neighborhood	Sample Stage	Type	Number of Samples	Number of Total Analyses	Number of Total Analyses >MRL	Percent >MRL	Number of Total Analyses >MCL	Percent Exceeding the MCL
Dillon	Standing Structure	Flushed	1	50	0	0%	0	0%
	Meter Pit	Stagnant	1	112	0	0%	0	0%
		Flushed	1	112	0	0%	0	0%

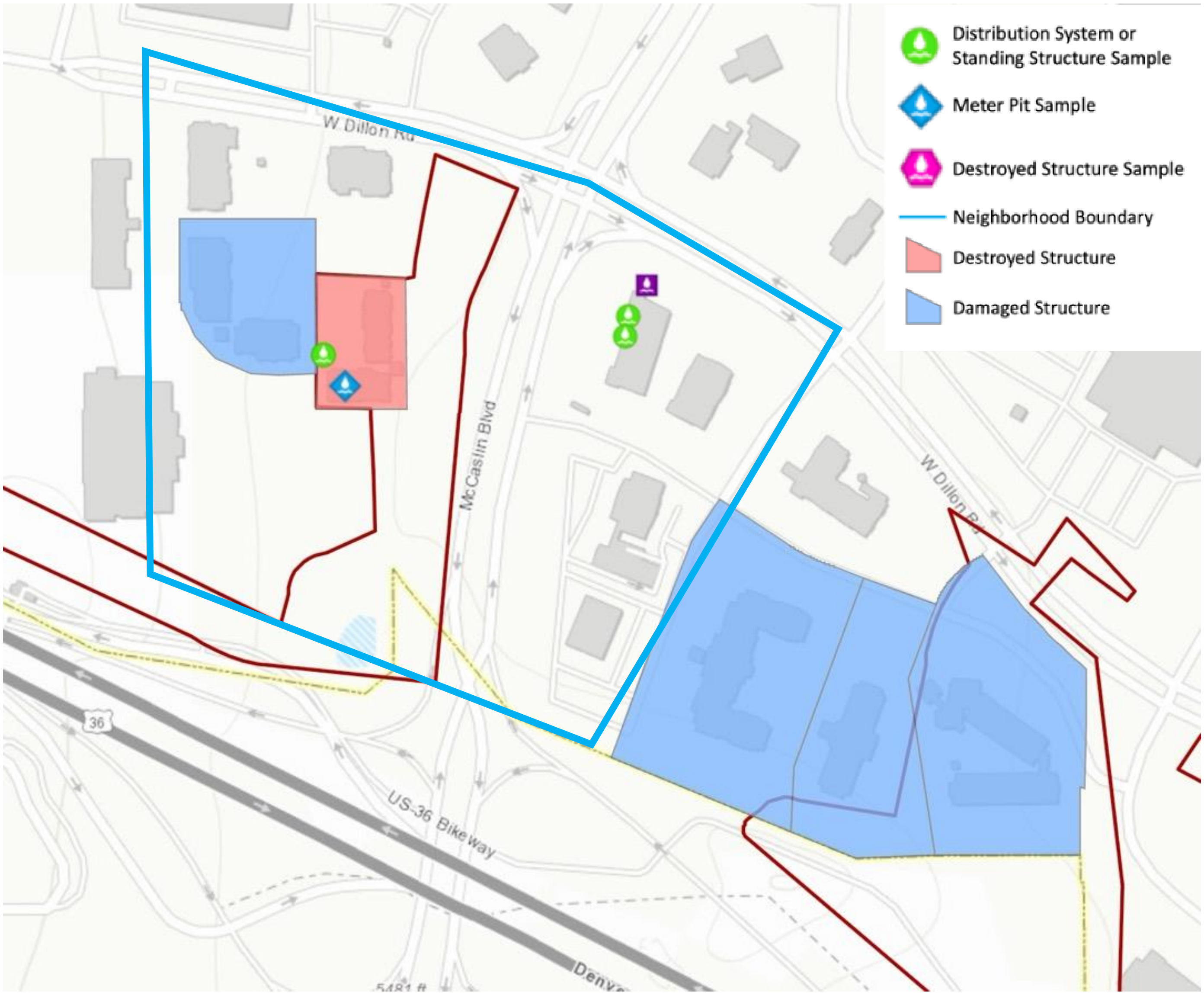

Figure 23. An overview of the sampling performed in the Dillon neighborhood

A2.9 Eldorado

Table 26. Summary of VOC/SVOC sampling performed in the Eldorado neighborhood

Neighborhood	Sample Stage	Type	Number of Samples	Number of Total Analyses	Number of Total Analyses >MRL	Percent >MRL	Number of Total Analyses >MCL	Percent Exceeding the MCL
Eldorado	Meter Pit	Stagnant	8	896	3	0.33%	0	0%
		Flushed	8	896	2	0.22%	0	0%
	Distribution System	Stagnant	25	2,563	8	0.31%	0	0%
		Flushed	25	2,425	8	0.33%	0	0%
	Destroyed Structure	Stagnant	4	460	0	0%	0	0%
		Flushed	4	460	0	0%	0	0%

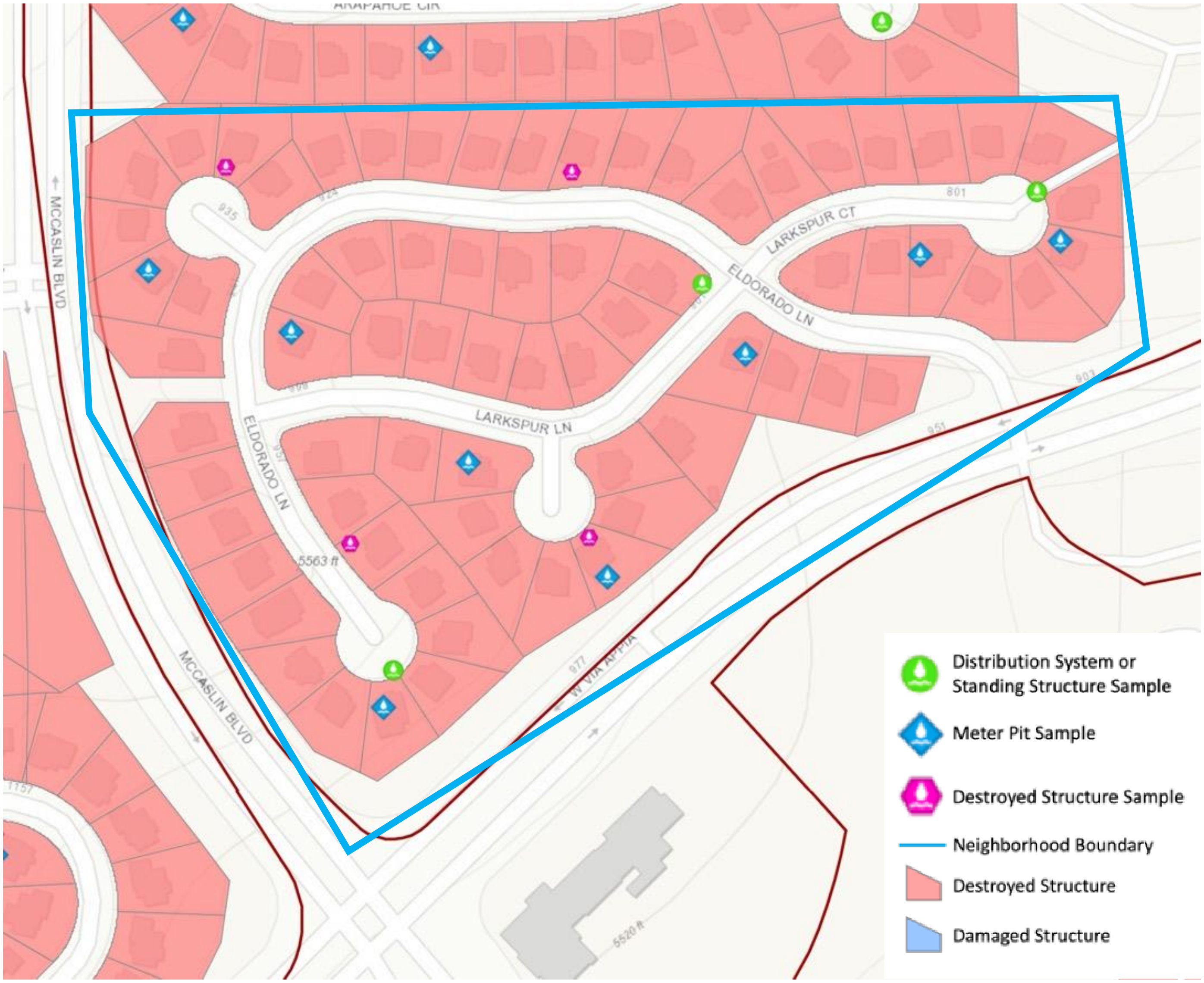

Figure 24. An overview of the sampling performed in the Eldorado neighborhood

A2.10 Enclave

Table 27. Summary of VOC/SVOC sampling performed in the Enclave neighborhood

Neighborhood	Sample Stage	Type	Number of Samples	Number of Total Analyses	Number of Total Analyses >MRL	Percent >MRL	Number of Total Analyses >MCL	Percent Exceeding the MCL
Enclave	Standing Structure	Stagnant	7	736	0	0%	0	0%
		Flushed	6	690	0	0%	0	0%
	Meter Pit	Stagnant	4	448	3	0.67%	0	0%
		Flushed	4	448	3	0.67%	0	0%
	Distribution System	Stagnant	11	1,101	5	0.45%	0	0%
		Flushed	11	1,397	2	0.14%	0	0%
	Destroyed Structure	Stagnant	2	230	0	0%	0	0%
		Flushed	2	230	0	0%	0	0%

Figure 25. An overview of the sampling performed in the Enclave neighborhood

A2.11 Fillmore

Table 28. Summary of VOC/SVOC sampling performed in the Fillmore neighborhood

Neighborhood	Sample Stage	Type	Number of Samples	Number of Total Analyses	Number of Total Analyses >MRL	Percent >MRL	Number of Total Analyses >MCL	Percent Exceeding the MCL
Fillmore	Standing Structure	Stagnant	2	42	0	0%	0	0%
	Meter Pit	Stagnant	1	112	1	0.89%	0	0%
		Flushed	1	112	0	0%	0	0%

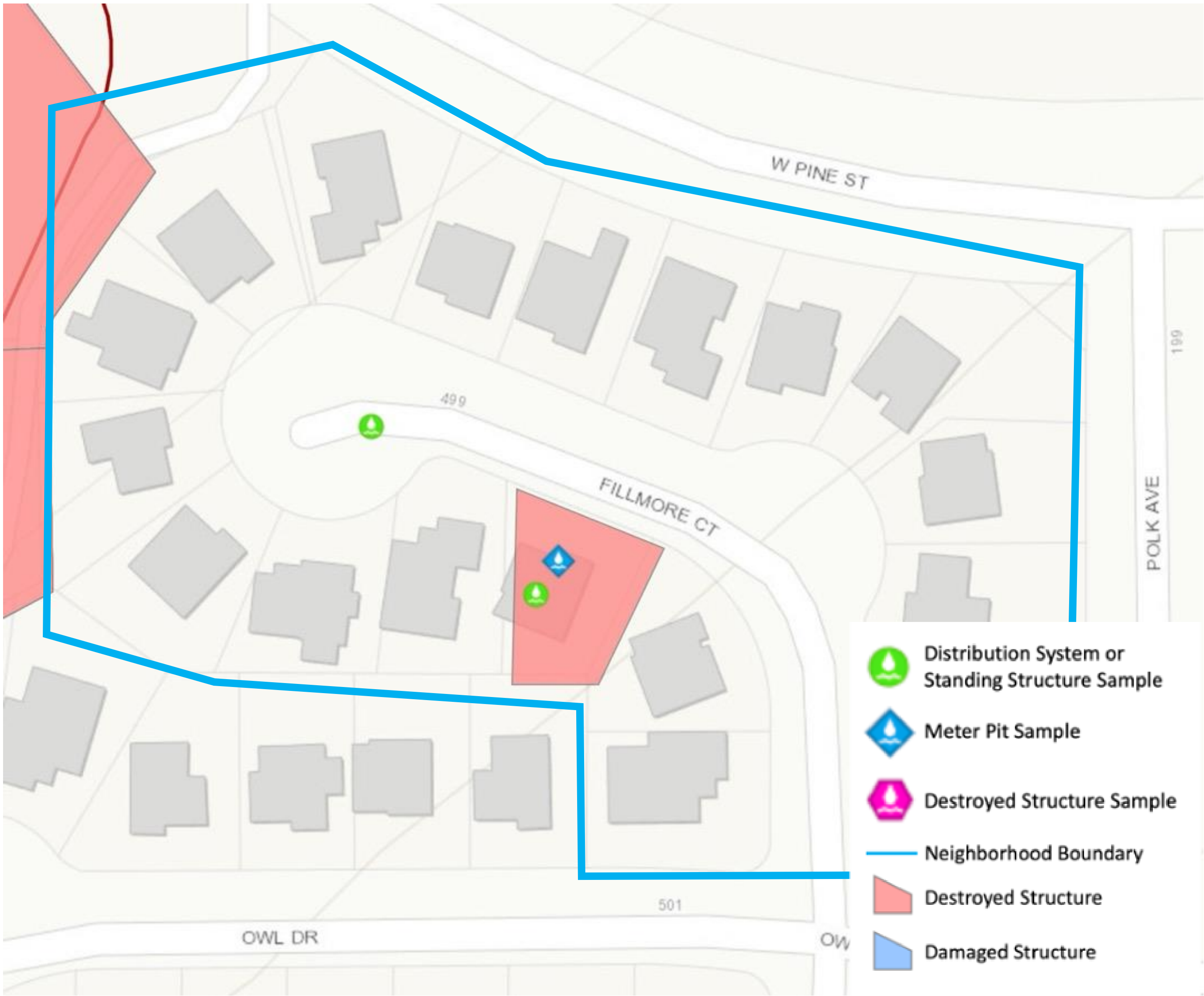

Figure 26. An overview of the sampling performed in the Fillmore neighborhood

A2.12 Fireside Elementary

Table 29. Summary of VOC/SVOC sampling performed at Fireside Elementary

Neighborhood	Sample Stage	Type	Number of Samples	Number of Total Analyses	Number of Total Analyses >MRL	Percent >MRL	Number of Total Analyses >MCL	Percent Exceeding the MCL
Fireside Elementary	Standing Structure	Stagnant	1	21	0	0%	0	0%

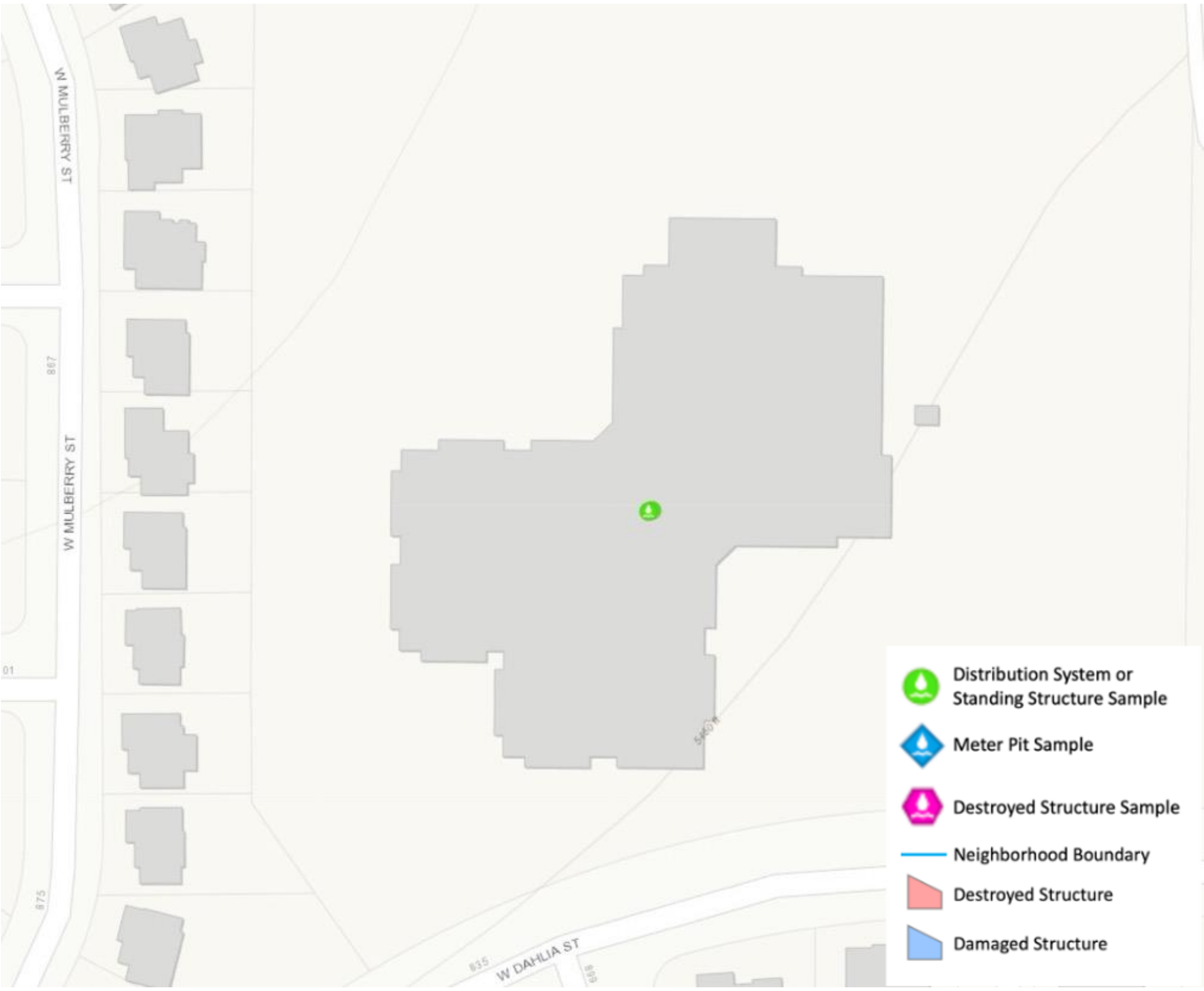

Figure 27. An overview of the sampling performed in Fireside Elementary

A2.13 Flatirons

Table 30. Summary of VOC/SVOC sampling performed in the Flatirons neighborhood

Neighborhood	Sample Stage	Type	Number of Samples	Number of Total Analyses	Number of Total Analyses >MRL	Percent >MRL	Number of Total Analyses >MCL	Percent Exceeding the MCL
Flatirons	Standing Structure	Stagnant	8	644	0	0%	0	0%
		Flushed	8	644	1	0.16%	0	0%
	Distribution System	Stagnant	6	615	1	0.16%	0	0%
		Flushed	6	615	1	0.16%	0	0%

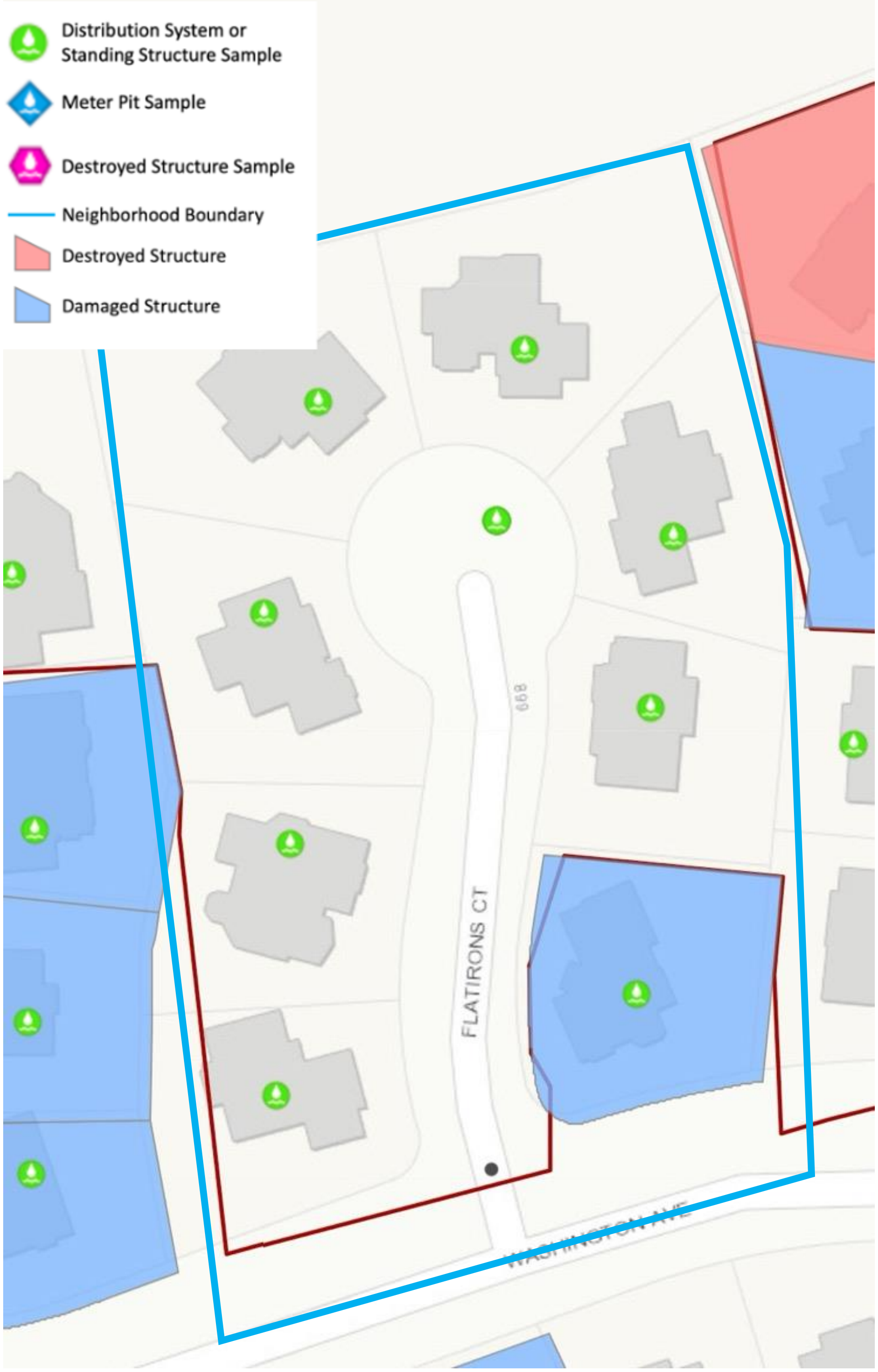

Figure 28. An overview of the sampling performed in the Flatirons neighborhood

A2.14 Grove

Table 31. Summary of VOC/SVOC sampling performed in the Grove neighborhood

Neighborhood	Sample Stage	Type	Number of Samples	Number of Total Analyses	Number of Total Analyses >MRL	Percent >MRL	Number of Total Analyses >MCL	Percent Exceeding the MCL
Grove	Distribution System	Stagnant	1	21	0	0%	0	0%

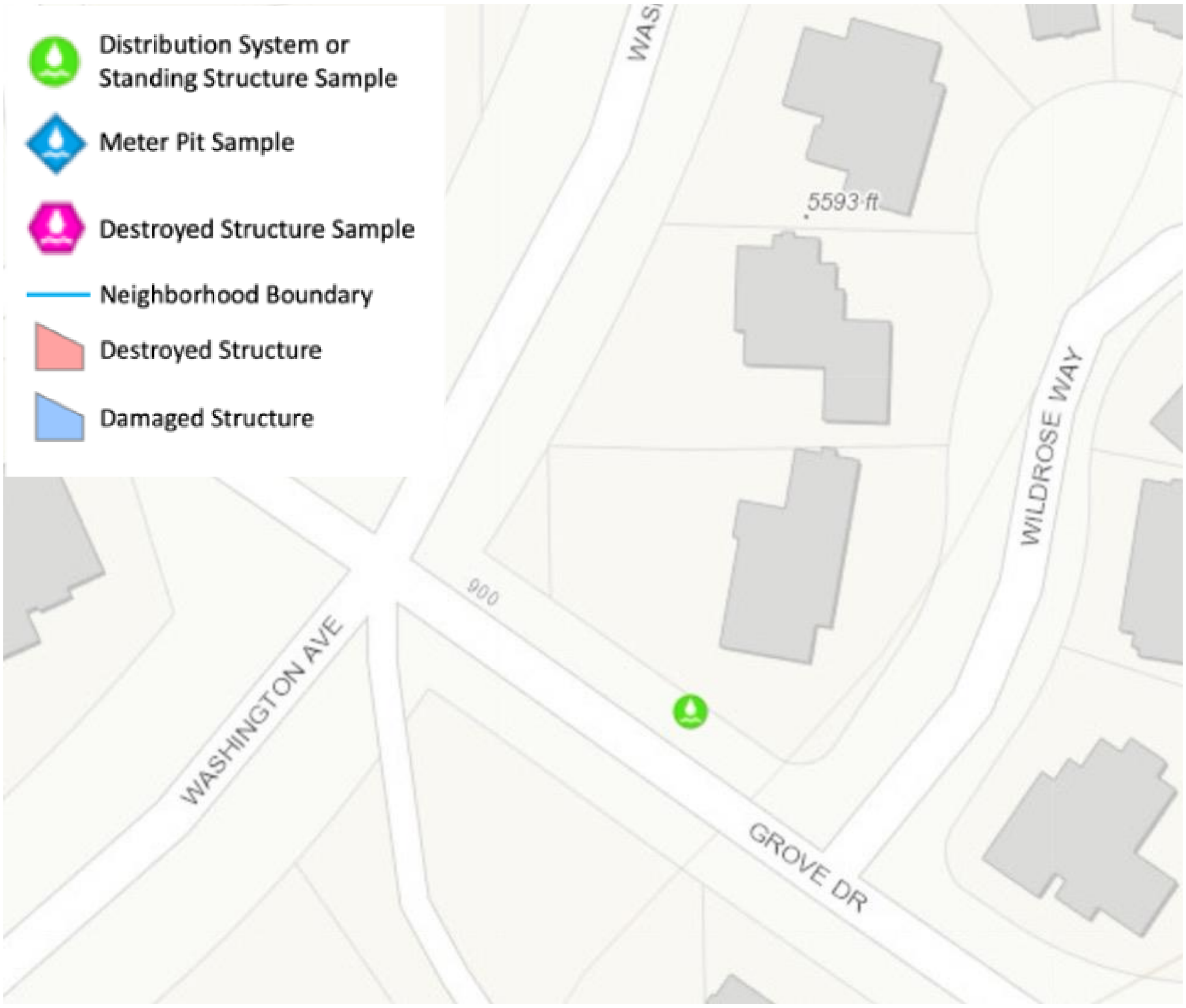

Figure 29. An overview of the sampling performed in the Grove neighborhood

A2.15 Hillside

Table 32. Summary of VOC/SVOC sampling performed in the Hillside neighborhood

Neighborhood	Sample Stage	Type	Number of Samples	Number of Total Analyses	Number of Total Analyses >MRL	Percent >MRL	Number of Total Analyses >MCL	Percent Exceeding the MCL
Hillside	Meter Pit	Stagnant	4	448	3	0.67%	0	0%
		Flushed	4	448	2	0.45%	0	0%
	Distribution System	Stagnant	7	661	1	0.15%	0	0%
		Flushed	7	661	1	0.15%	0	0%
	Destroyed Structure	Stagnant	2	230	0	0%	0	0%
		Flushed	2	230	0	0%	0	0%

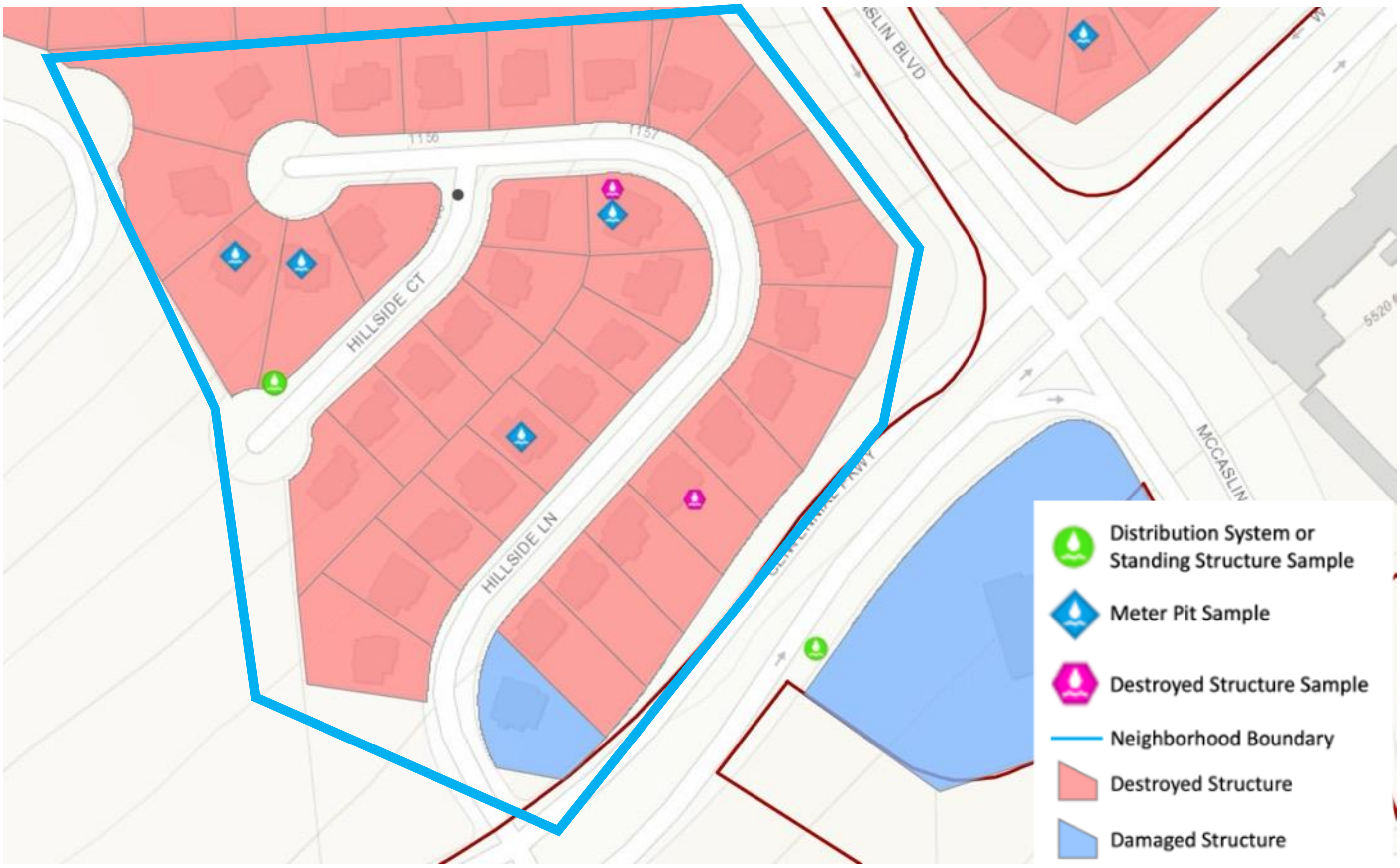

Figure 30. An overview of the sampling performed in the Hillside neighborhood

A2.16 Louisville Recreation Center

Table 33. Summary of VOC/SVOC sampling performed in the Louisville Rec Center

Neighborhood	Sample Stage	Type	Number of Samples	Number of Total Analyses	Number of Total Analyses >MRL	Percent >MRL	Number of Total Analyses >MCL	Percent Exceeding the MCL
Louisville Rec Center	Standing Structure	Stagnant	1	50	0	0%	0	0%

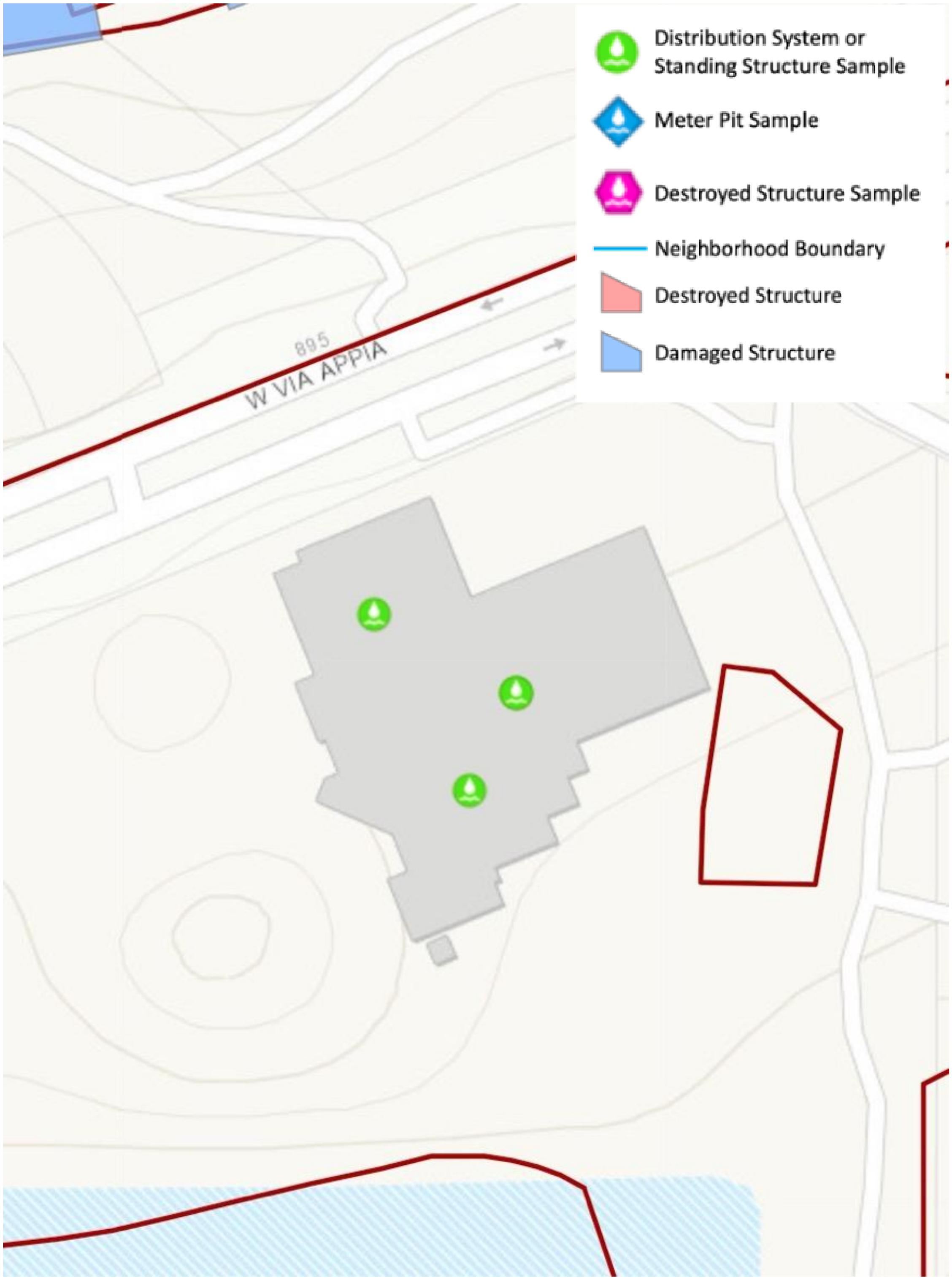

Figure 31. An overview of the sampling performed in the Louisville Recreation Center

A2.17 Marshall

Table 34. Summary of VOC/SVOC sampling performed in the Marshall neighborhood

Neighborhood	Sample Stage	Type	Number of Samples	Number of Total Analyses	Number of Total Analyses >MRL	Percent >MRL	Number of Total Analyses >MCL	Percent Exceeding the MCL
Marshall	Standing Structure	Flushed	1	50	0	0%	0	0%

Figure 32. An overview of the sampling performed in the Marshall neighborhood

A2.18 Meadow

Table 35. Summary of VOC/SVOC sampling performed in the Meadow neighborhood

Neighborhood	Sample Stage	Type	Number of Samples	Number of Total Analyses	Number of Total Analyses >MRL	Percent >MRL	Number of Total Analyses >MCL	Percent Exceeding the MCL
Meadow	Standing Structure	Stagnant	2	136	0	0%	0	0%
		Flushed	1	115	0	0%	0	0%
	Meter Pit	Stagnant	2	224	9	4.02%	0	0%
		Flushed	2	224	1	0.45%	0	0%

Figure 33. An overview of the sampling performed in the Meadow neighborhood

A2.19 Mt Evans

Table 36. Summary of VOC/SVOC sampling performed in the Mt Evans neighborhood

Neighborhood	Sample Stage	Type	Number of Samples	Number of Total Analyses	Number of Total Analyses >MRL	Percent >MRL	Number of Total Analyses >MCL	Percent Exceeding the MCL
Mt Evans	Standing Structure	Stagnant	12	1,968	14	0.71%	0	0%
		Flushed	12	1,968	9	0.46%	0	0%
	Meter Pit	Stagnant	2	230	9	3.91%	2	0.87%
		Flushed	2	230	0	0%	0	0%
	Distribution System	Stagnant	13	1,331	18	1.35%	2	0.15%
		Flushed	13	1,332	3	0.23%	0	0%
	Destroyed Structure	Stagnant	1	115	0	0%	0	0%
		Flushed	1	115	0	0%	0	0%

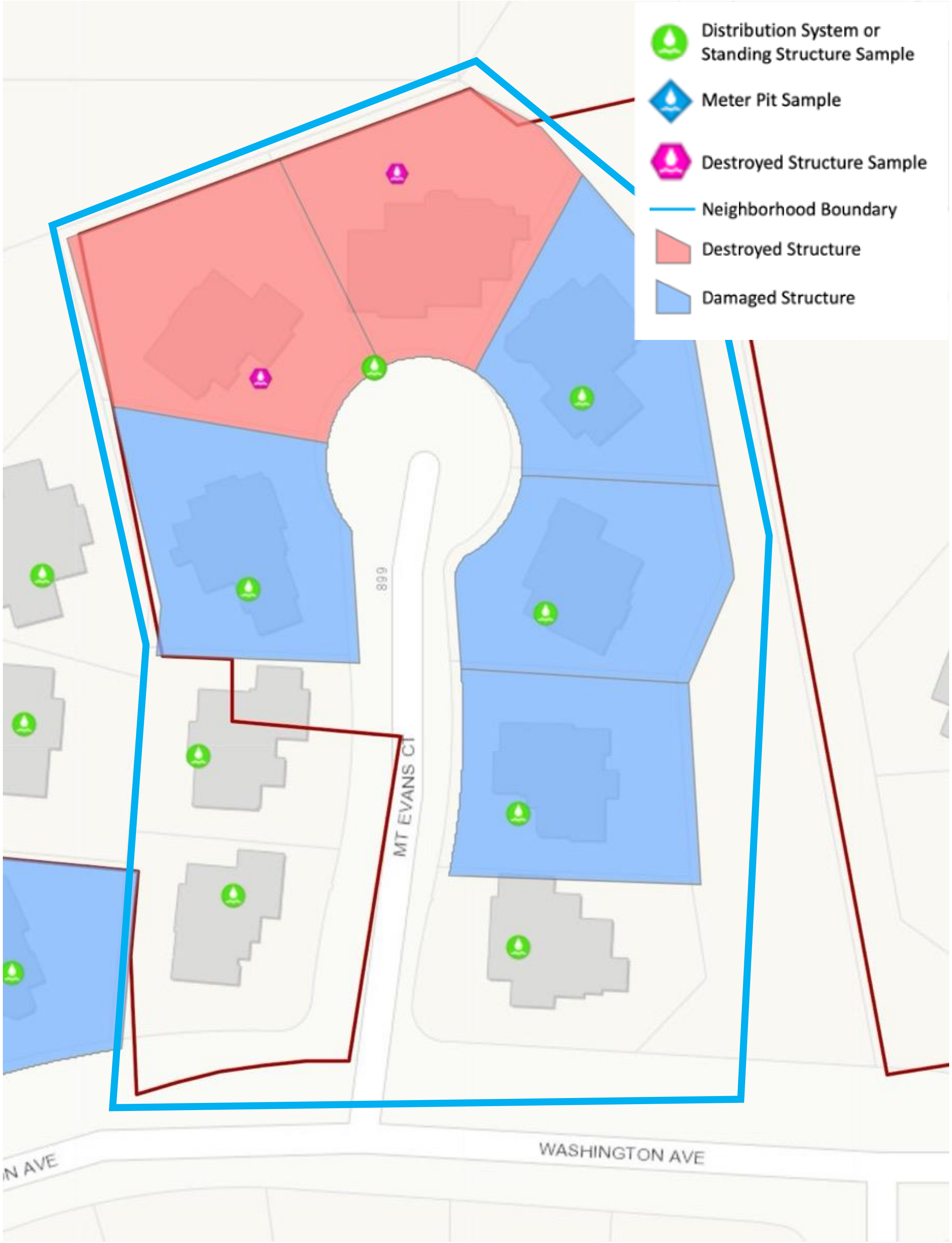

Figure 34. An overview of the sampling performed in the Mt Evans neighborhood

A2.20 Mulberry

Table 37. Summary of VOC/SVOC sampling performed in the Mulberry neighborhood

Neighborhood	Sample Stage	Type	Number of Samples	Number of Total Analyses	Number of Total Analyses >MRL	Percent >MRL	Number of Total Analyses >MCL	Percent Exceeding the MCL
Mulberry	Standing Structure	Stagnant	2	42	0	0%	0	0%
	Meter Pit	Stagnant	4	448	4	0.89%	0	0%
		Flushed	4	448	1	0.22%	0	0%
	Distribution System	Stagnant	5	569	5	0.88%	0	0%
		Flushed	5	569	1	0.18%	0	0%
	Destroyed Structure	Stagnant	1	115	0	0%	0	0%
		Flushed	1	115	0	0%	0	0%

Figure 35. An overview of the sampling performed in the Mulberry neighborhood

A2.21 Owl

Table 38. Summary of VOC/SVOC sampling performed in the Owlneighborhood

Neighborhood	Sample Stage	Type	Number of Samples	Number of Total Analyses	Number of Total Analyses >MRL	Percent >MRL	Number of Total Analyses >MCL	Percent Exceeding the MCL
Owl	Standing Structure	Stagnant	27	3,102	15	0.48%	0	0%
		Flushed	27	3,102	11	0.35%	0	0%
	Distribution System	Stagnant	5	569	0	0%	0	0%
		Flushed	5	569	0	0%	0	0%
	Destroyed Structure	Stagnant	2	230	0	0%	0	0%
		Flushed	2	230	0	0%	0	0%

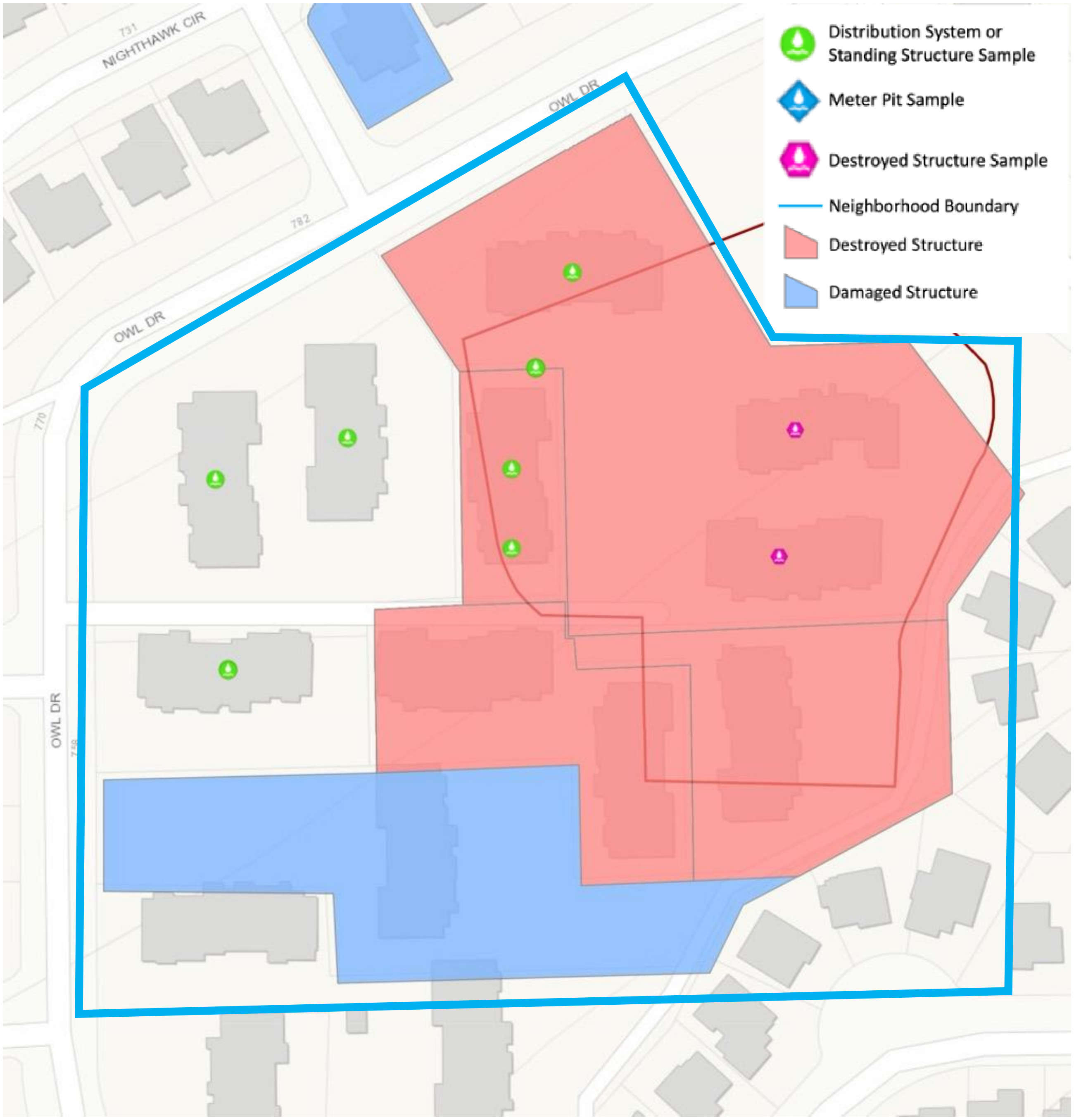

Figure 36. An overview of the sampling performed in the Owl neighborhood

A2.22 Pikes Peak

Table 39. Summary of VOC/SVOC sampling performed in the Pikes Peak neighborhood

Neighborhood	Sample Stage	Type	Number of Samples	Number of Total Analyses	Number of Total Analyses >MRL	Percent >MRL	Number of Total Analyses >MCL	Percent Exceeding the MCL
Pikes Peak	Standing Structure	Stagnant	21	3,071	70	2.28%	6	0.20%
		Flushed	21	2,918	23	0.79%	0	0%
	Meter Pit	Stagnant	2	224	11	4.91%	0	0%
		Flushed	2	224	2	0.89%	0	0%
	Distribution System	Stagnant	23	2,418	42	1.71%	4	0.16%
		Flushed	23	2,418	17	0.69%	2	0.08%
	Destroyed Structure	Stagnant	4	544	13	2.39%	2	0.37%
		Flushed	3	345	0	0%	0	0%

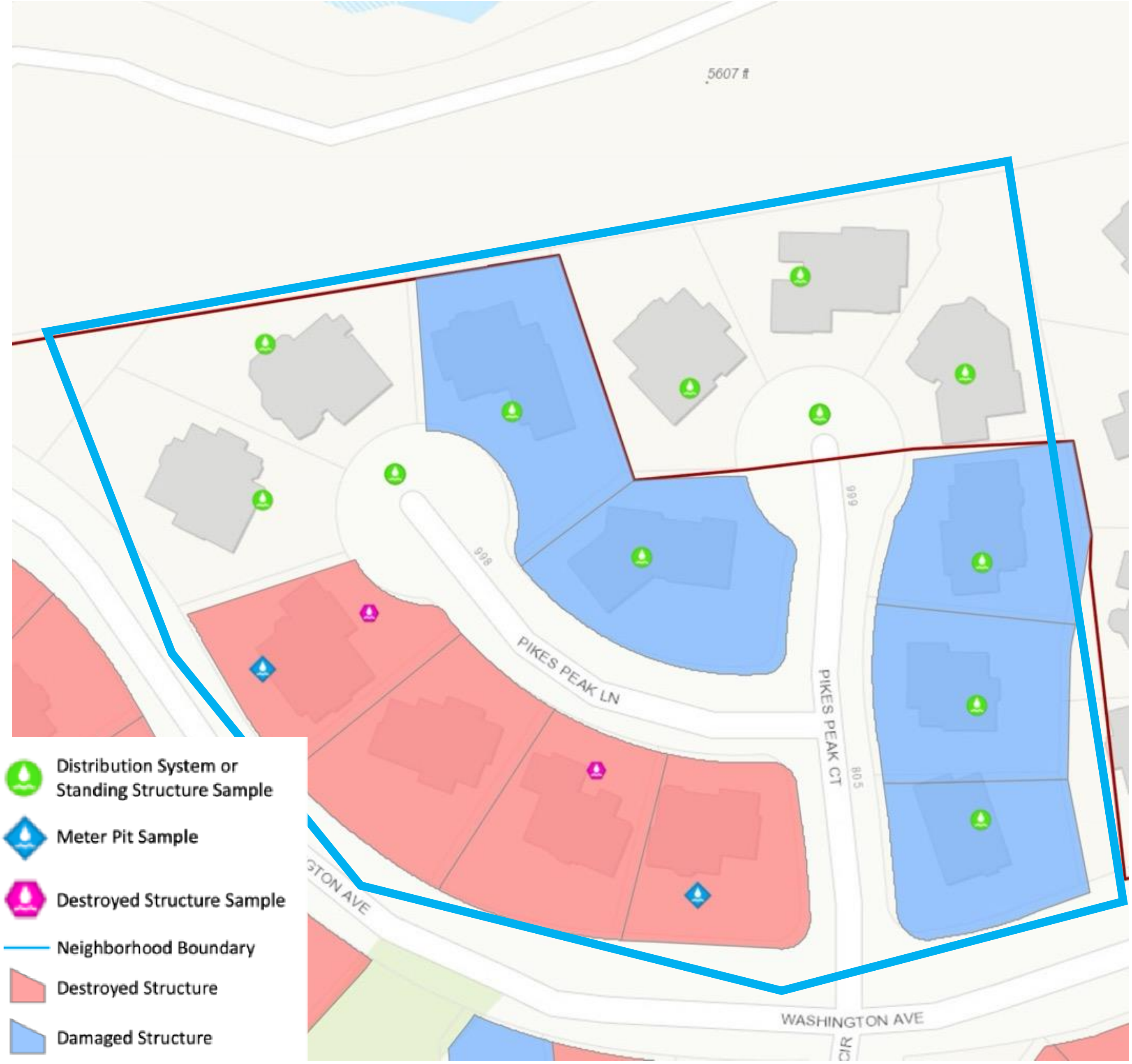

Figure 37. An overview of the sampling performed in the Pikes Peak neighborhood

A2.23 Pine

Table 40. Summary of VOC/SVOC sampling performed in the Pine neighborhood

Neighborhood	Sample Stage	Type	Number of Samples	Number of Total Analyses	Number of Total Analyses >MRL	Percent >MRL	Number of Total Analyses >MCL	Percent Exceeding the MCL
Pine	Standing Structure	Stagnant	4	391	3	0.77%	1	0.26%
		Flushed	4	460	0	0%	0	0%
	Meter Pit	Stagnant	1	112	2	1.79%	0	0%
		Flushed	1	112	1	0.89%	0	0%
	Distribution System	Stagnant	7	799	1	0.13%	0	0%
		Flushed	7	799	1	0.13%	0	0%
	Destroyed Structure	Stagnant	2	230	0	0%	0	0%
		Flushed	2	230	0	0%	0	0%

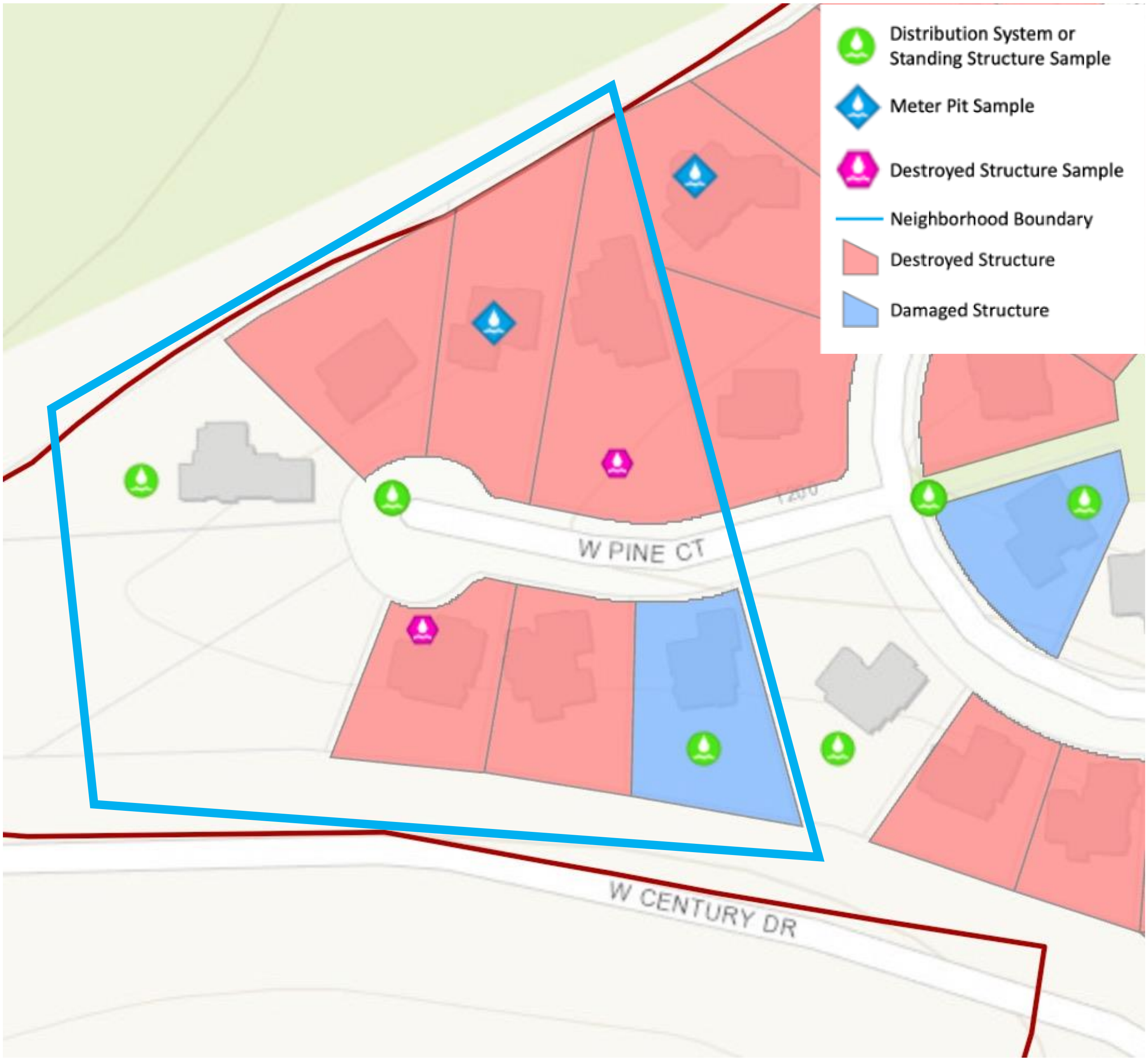

Figure 38. An overview of the sampling performed in the Pine neighborhood

A2.24 Pinehurst

Table 41. Summary of VOC/SVOC sampling performed in the Pinehurst neighborhood

Neighborhood	Sample Stage	Type	Number of Samples	Number of Total Analyses	Number of Total Analyses >MRL	Percent >MRL	Number of Total Analyses >MCL	Percent Exceeding the MCL
Pinehurst	Meter Pit	Stagnant	2	224	0	0%	0	0%
		Flushed	2	224	3	1.34%	0	0.45%

Figure 39. An overview of the sampling performed in the Pinehurst neighborhood

A2.25 Ridgeview

Table 42. Summary of VOC/SVOC sampling performed in the Ridgeview neighborhood

Neighborhood	Sample Stage	Type	Number of Samples	Number of Total Analyses	Number of Total Analyses >MRL	Percent >MRL	Number of Total Analyses >MCL	Percent Exceeding the MCL
Ridgeview	Standing Structure	Stagnant	1	21	0	0%	0	0%

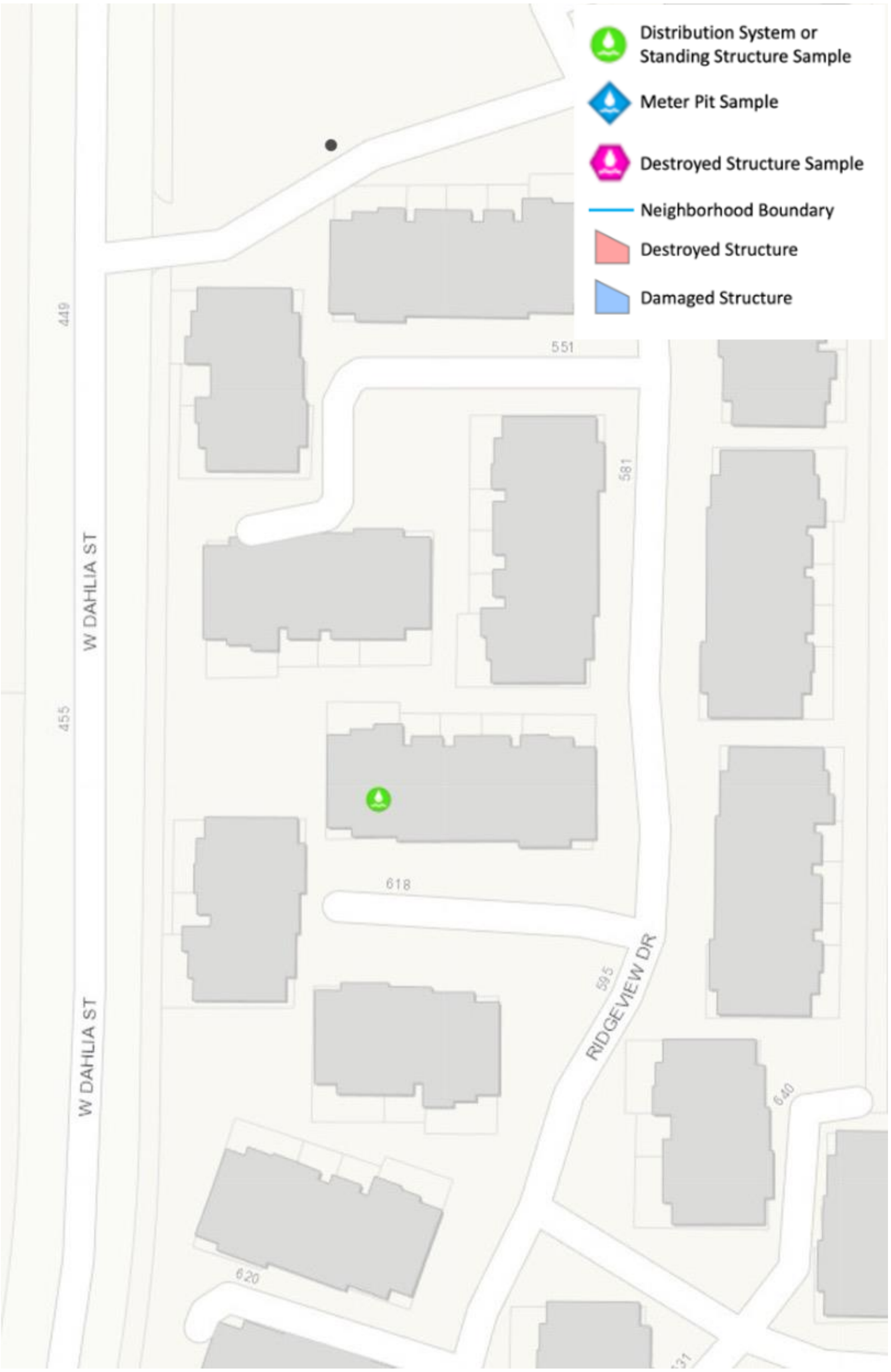

Figure 40. An overview of the sampling performed in the Ridgeview neighborhood

A2.26 Spyglass

Table 43. Summary of VOC/SVOC sampling performed in the Spyglass neighborhood

Neighborhood	Sample Stage	Type	Number of Samples	Number of Total Analyses	Number of Total Analyses >MRL	Percent >MRL	Number of Total Analyses >MCL	Percent Exceeding the MCL
Spyglass	Standing Structure	Stagnant	1	21	0	0%	0	0%
	Meter Pit	Stagnant	1	112	0	0%	0	0%
		Flushed	1	112	0	0%	0	0%
	Distribution System	Stagnant	1	112	0	0%	0	0%
		Flushed	1	112	0	0%	0	0%

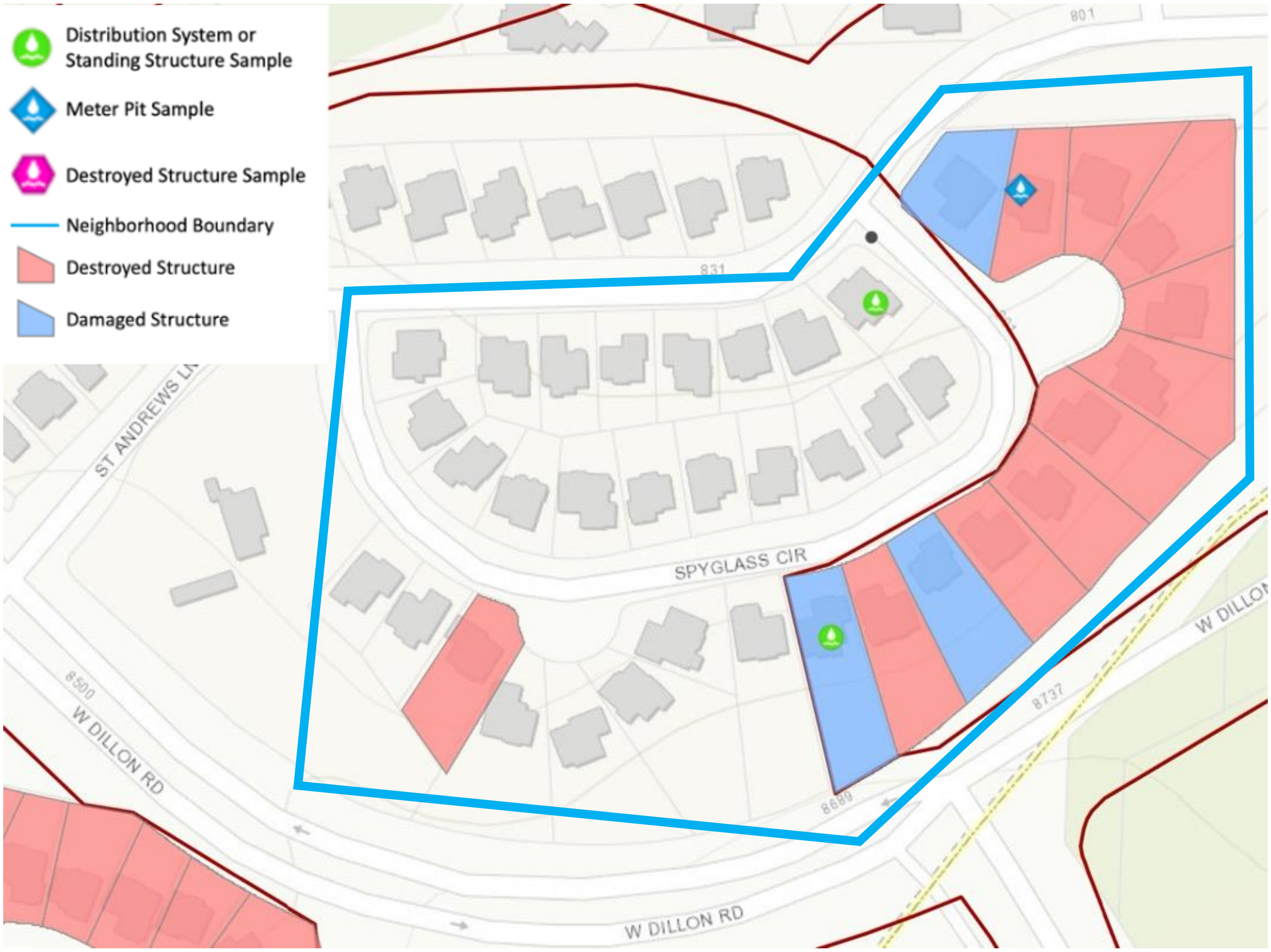

Figure 41. An overview of the sampling performed in the Spyglass neighborhood

A2.27 St Andrews

Table 44. Summary of VOC/SVOC sampling performed in the St Andrews neighborhood

Neighborhood	Sample Stage	Type	Number of Samples	Number of Total Analyses	Number of Total Analyses >MRL	Percent >MRL	Number of Total Analyses >MCL	Percent Exceeding the MCL
St Andrews	Standing Structure	Stagnant	4	272	0	0%	0	0%
		Flushed	3	280	0	0%	0	0%
	Meter Pit	Stagnant	16	1,792	17	0.95%	1	0.06%
		Flushed	16	1,792	3	0.17%	0	0%
	Distribution System	Stagnant	25	2,455	6	0.24%	0	0%
		Flushed	25	2,455	1	0.04%	0	0%
	Destroyed Structure	Stagnant	6	690	18	2.61%	4	0.58%
		Flushed	6	690	11	1.59%	0	0%

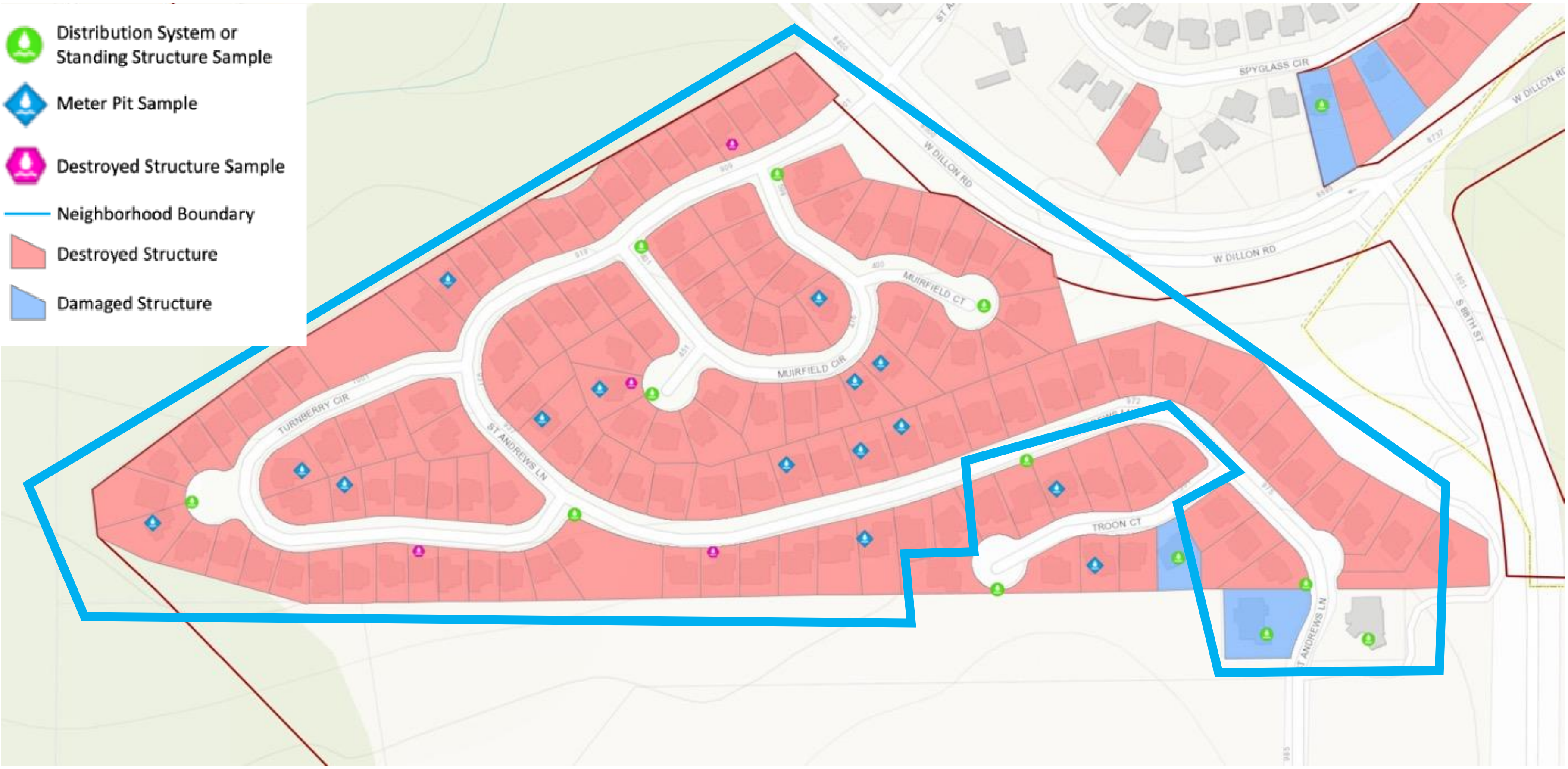

Figure 42. An overview of the sampling performed in the St Andrews neighborhood

A2.28 Tanager

Table 45. Summary of VOC/SVOC sampling performed in the Tanager neighborhood

Neighborhood	Sample Stage	Type	Number of Samples	Number of Total Analyses	Number of Total Analyses >MRL	Percent >MRL	Number of Total Analyses >MCL	Percent Exceeding the MCL
Tanager	Standing Structure	Stagnant	1	21	0	0%	0	0%
	Meter Pit	Stagnant	1	112	12	10.71%	0	0%
		Flushed	1	112	10	8.93%	0	0%

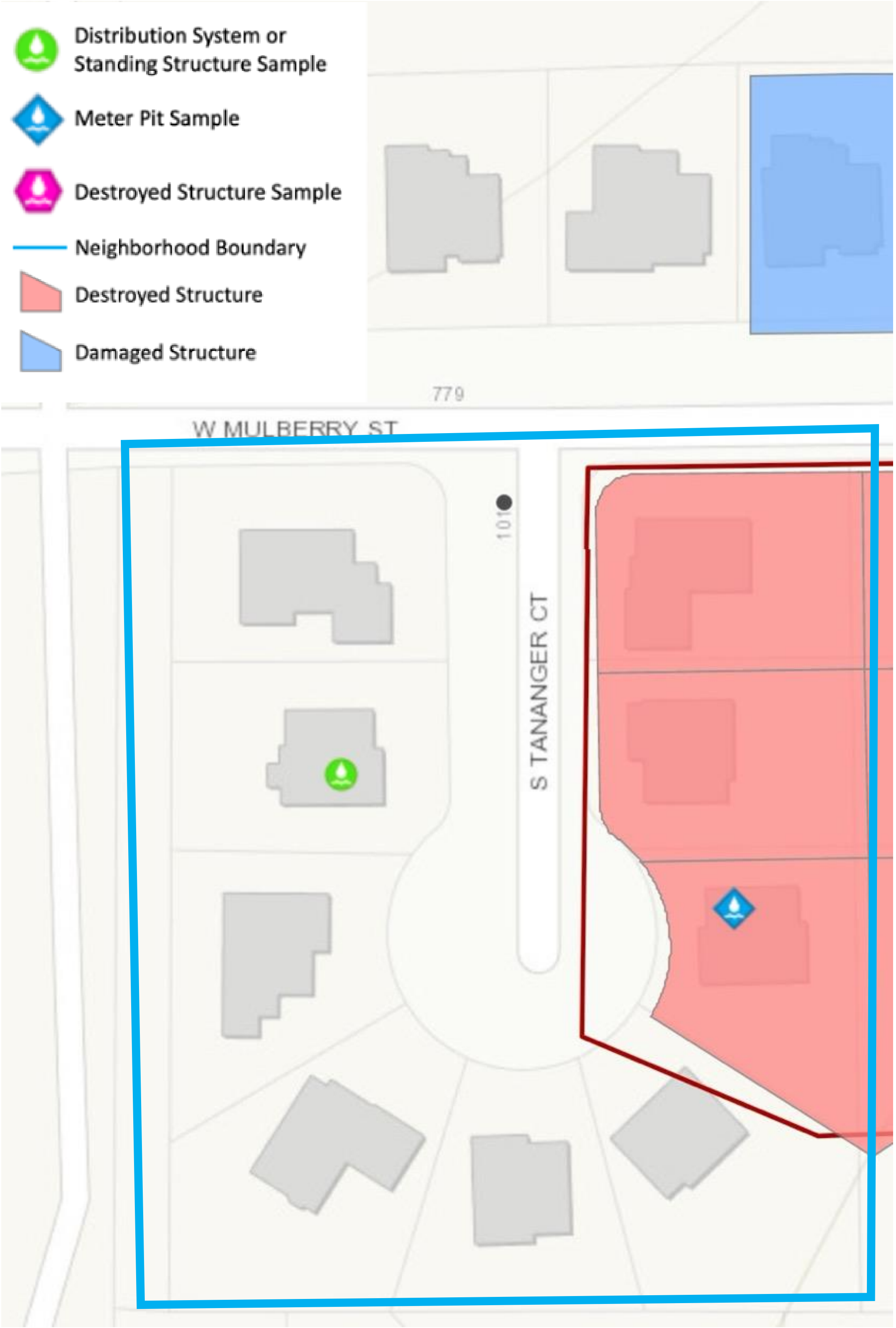

Figure 43. An overview of the sampling performed in the Tanager neighborhood

A2.29 Trail Ridge

Table 46. Summary of VOC/SVOC sampling performed in the Trail Ridge neighborhood

Neighborhood	Sample Stage	Type	Number of Samples	Number of Total Analyses	Number of Total Analyses >MRL	Percent >MRL	Number of Total Analyses >MCL	Percent Exceeding the MCL
Trail Ridge	Standing Structure	Stagnant	35	3,128	6	0.19%	0	0%
		Flushed	36	3,243	0	0%	0	0%
	Meter Pit	Stagnant	4	448	11	2.46%	0	0%
		Flushed	4	448	2	0.45%	0	0%
	Distribution System	Stagnant	13	1,477	6	0.41%	0	0%
		Flushed	13	1,477	3	0.2%	0	0%
	Destroyed Structure	Stagnant	6	690	0	0%	0	0%
		Flushed	6	690	0	0%	0	0%

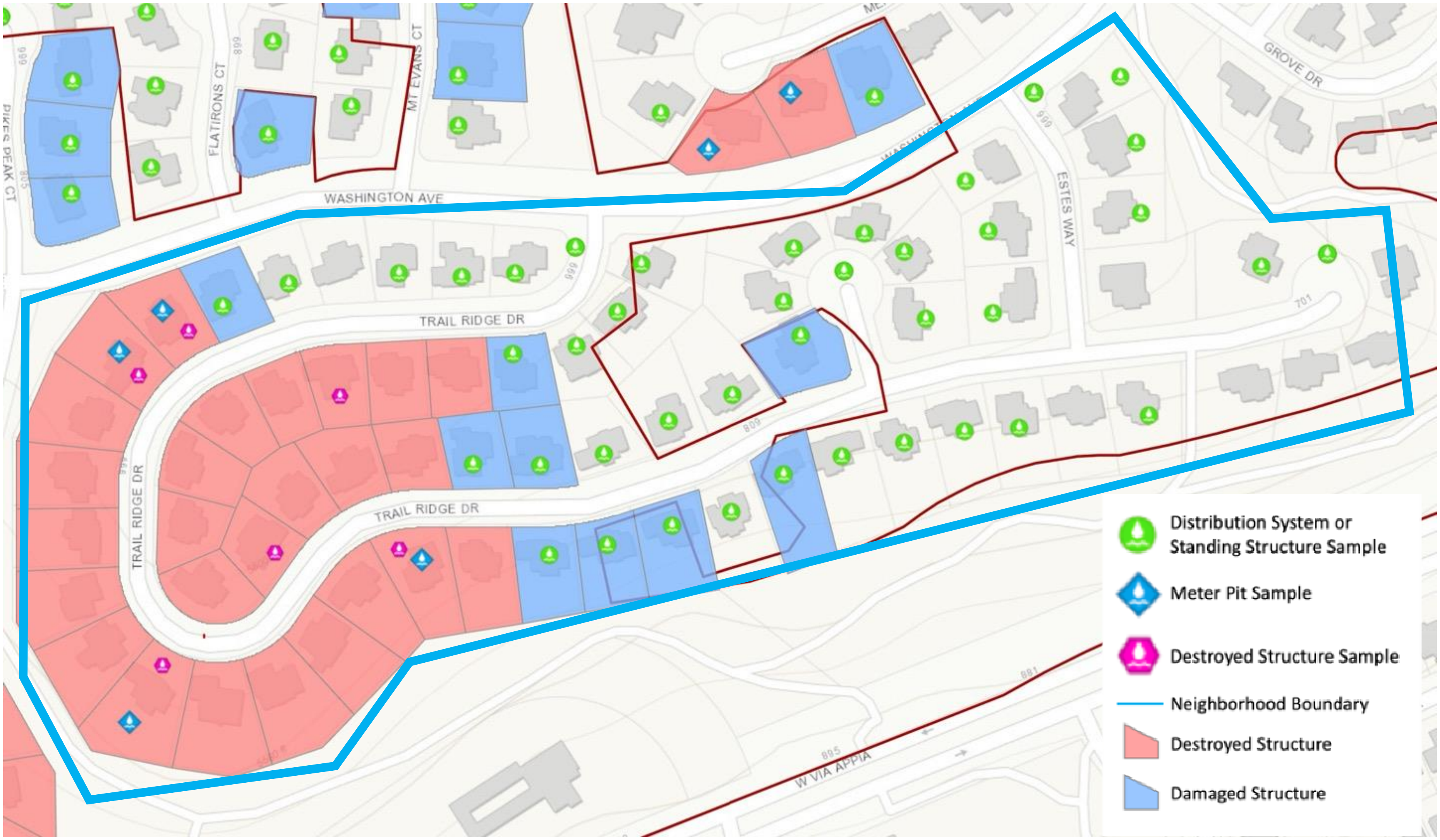

Figure 44. An overview of the sampling performed in the Trail Ridge neighborhood

A2.30 Troon

Table 47. Summary of VOC/SVOC sampling performed in the Troon neighborhood

Neighborhood	Sample Stage	Type	Number of Samples	Number of Total Analyses	Number of Total Analyses >MRL	Percent >MRL	Number of Total Analyses >MCL	Percent Exceeding the MCL
Troon	Standing Structure	Stagnant	1	115	1	0.87%	0	0%
		Flushed	1	115	0	0%	0	0%
	Meter Pit	Stagnant	2	224	0	0%	0	0%
		Flushed	2	224	0	0%	0	0%
	Distribution System	Stagnant	8	845	5	0.59%	1	0.12%
		Flushed	8	845	1	0.12%	0	0%

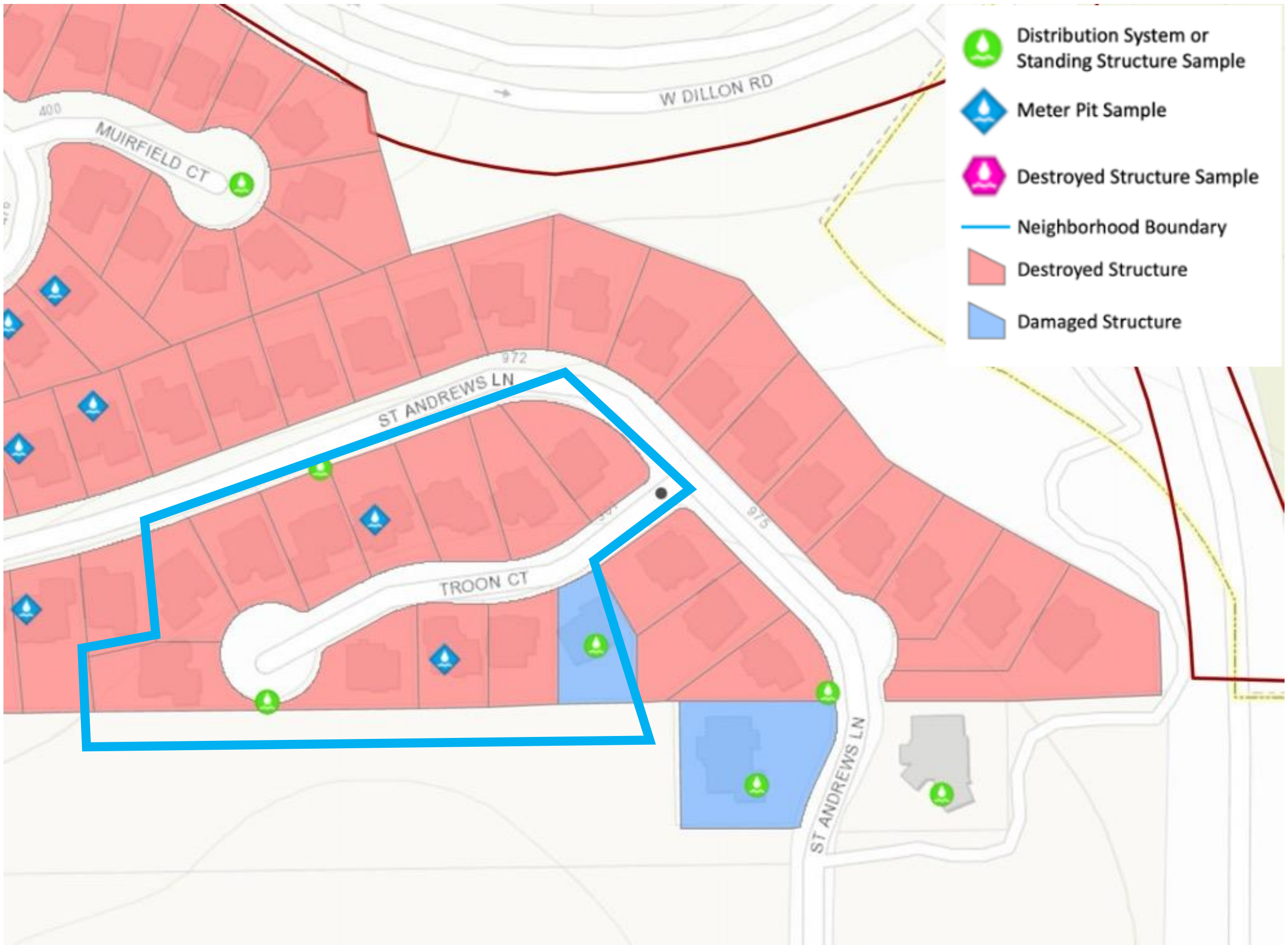

Figure 45. An overview of the sampling performed in the Troon neighborhood

A2.31 Vista

Table 48. Summary of VOC/SVOC sampling performed in the Vista neighborhood

Neighborhood	Sample Stage	Type	Number of Samples	Number of Total Analyses	Number of Total Analyses >MRL	Percent >MRL	Number of Total Analyses >MCL	Percent Exceeding the MCL
Vista	Standing Structure	Stagnant	1	115	0	0%	0	0%
		Flushed	1	115	0	0%	0	0%
	Meter Pit	Stagnant	2	224	1	0.45%	0	0%
		Flushed	2	224	0	0%	0	0%
	Distribution System	Stagnant	1	115	0	0%	0	0%
		Flushed	1	115	0	0%	0	0%
	Destroyed Structure	Stagnant	1	115	0	0%	0	0%
		Flushed	1	115	0	0%	0	0%

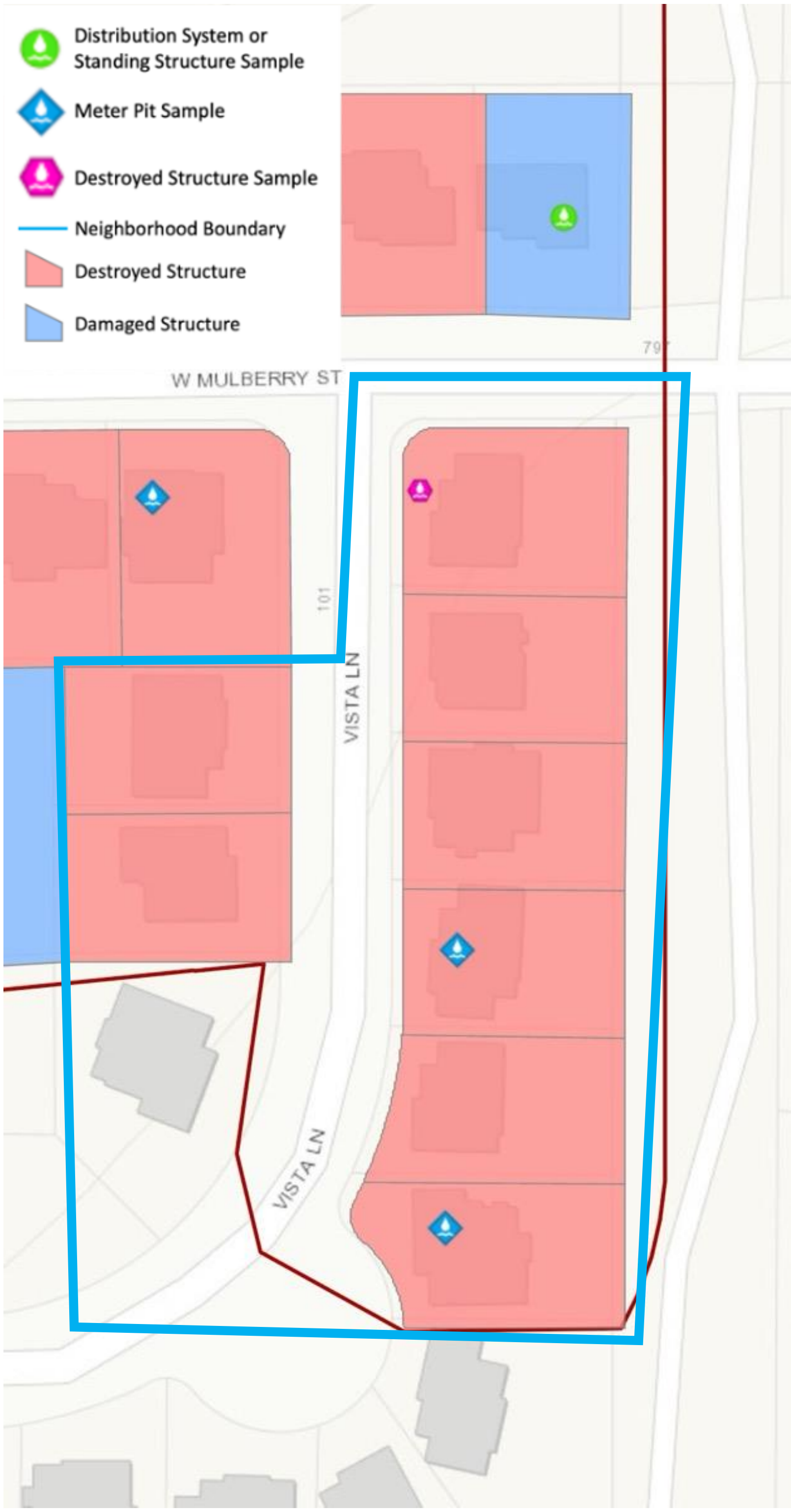

Figure 46. An overview of the sampling performed in the Vista neighborhood

A2.32 Warbler

Table 49. Summary of VOC/SVOC sampling performed in the Warbler neighborhood

Neighborhood	Sample Stage	Type	Number of Samples	Number of Total Analyses	Number of Total Analyses >MRL	Percent >MRL	Number of Total Analyses >MCL	Percent Exceeding the MCL
Warbler	Standing Structure	Stagnant	1	21	0	0%	0	0%
	Meter Pit	Stagnant	1	112	1	0.89%	0	0%
		Flushed	1	112	0	0%	0	0%

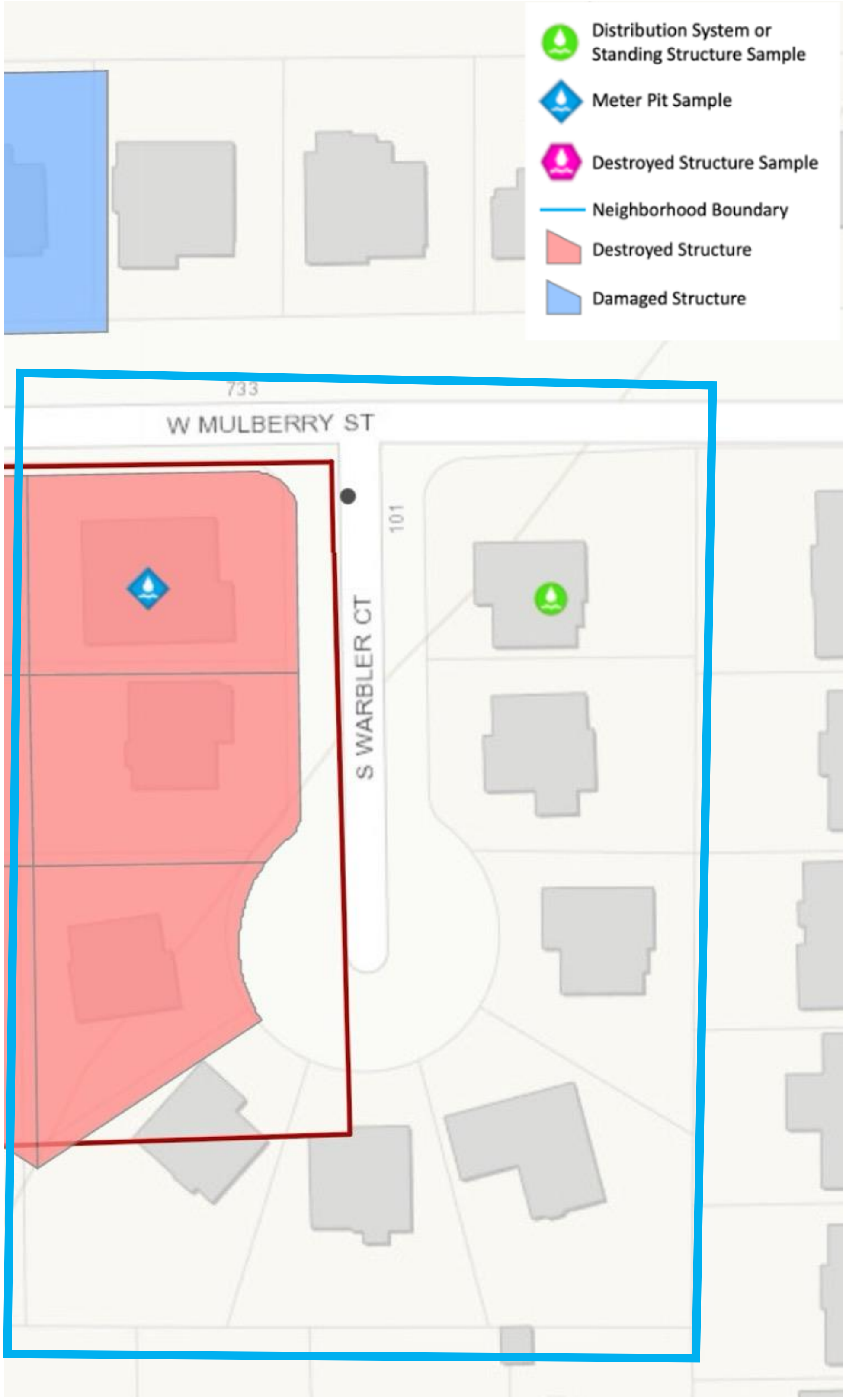

Figure 47. An overview of the sampling performed in the Warbler neighborhood

A3 All Compounds Analyzed in Marshall Fire Water System Sampling

Parameter	Number of Analyses	MCL (µg/L)	Minimum Result (µg/L)	Maximum Result (µg/L)	Average Result (µg/L)	Number >MRL	Number >MCL
1,1,1,2-Tetrachloroethane	5	NA	0	0	0	0	NA
1,1,1-Trichloroethane	878	200	0	0	0	0	0
1,1,2,2-Tetrachloroethane	245	NA	0	0	0	0	NA
1,1,2-Trichlor-1,2,2-Trifluoroethane	240	NA	0	0	0	0	NA
1,1,2-Trichloroethane	878	5	0	0	0	0	0
1,1-Dichloroethane	858	NA	0	0	0	0	NA
1,1-Dichloroethene	878	NA	0	0	0	0	NA
1,1-Dichloropropene	9	NA	0	2.6	0.29	1	NA
1,1`-Biphenyl	291	NA	0	0.3	0	2	NA
1,2,3,4-Tetrachlorobenzene	52	NA	0	0	0	0	NA
1,2,3-Trichlorobenzene	618	NA	0	0	0	0	NA
1,2,3-Trichloropropane	5	NA	0	0	0	0	NA
1,2,4,5-Tetrachlorobenzene	52	NA	0	0	0	0	NA
1,2,4-Trichlorobenzene	930	NA	0	0	0	0	NA
1,2,4-Trimethylbenzene	618	NA	0	4.1	0.01	2	NA
1,2-Dibromo-3-Chloropropane	240	NA	0	0	0	0	NA

Parameter	Number of Analyses	MCL (µg/L)	Minimum Result (µg/L)	Maximum Result (µg/L)	Average Result (µg/L)	Number >MRL	Number >MCL
1,2-Dibromoethane	245	NA	0	0	0	0	NA
1,2-Dichlorobenzene	765	600	0	29	0.57	27	0
1,2-Dichloroethane	882	5	0	4.8	0.01	2	0
1,2-Dichloropropane	878	5	0	0	0	0	0
1,2-Dinitrobenzene	52	NA	0	0	0	0	NA
1,2-Diphenylhydrazine	52	NA	0	9.3	0.18	1	NA
1,3,4,5-Tetrachlorobenzene	52	NA	0	0	0	0	NA
1,3,5-Trimethylbenzene	618	NA	0	1.1	0	2	NA
1,3,5-Trinitrobenzene	52	NA	0	0	0	0	NA
1,3-Dichlorobenzene	745	NA	0	0	0	0	NA
1,3-Dichloropropane	5	NA	0	0	0	0	NA
1,3-Dichloropropene	5	NA	0	0	0	0	NA
1,3-Dinitrobenzene	52	NA	0	0	0	0	NA
1,4-Dichlorobenzene	930	75	0	0	0	0	0
1,4-Dinitrobenzene	52	NA	0	0	0	0	NA
1,4-Dioxane	52	NA	0	0	0	0	NA
1,4-Napthoquinone	52	NA	0	0	0	0	NA
1-Methylnaphthalene	500	NA	0	0	0	0	NA
1-Naphthylamine	52	NA	0	0	0	0	NA

Parameter	Number of Analyses	MCL (µg/L)	Minimum Result (µg/L)	Maximum Result (µg/L)	Average Result (µg/L)	Number >MRL	Number >MCL
2,3,4,6-Tetrachlorophenol	500	NA	0	0	0	0	NA
2,3,5,6-Tetrachlorophenol	52	NA	0	0	0	0	NA
2,4,5-Trichlorophenol	739	NA	0	0	0	0	NA
2,4,6-Trichlorophenol	739	NA	0	0	0	0	NA
2,4-Dichlorophenol	739	NA	0	0	0	0	NA
2,4-Dimethylphenol	739	NA	0	0.52	0	1	NA
2,4-Dinitrophenol	739	NA	0	0	0	0	NA
2,4-Dinitrotoluene	739	NA	0	18	0.02	1	NA
2,5-Dimethylphenol	52	NA	0	0	0	0	NA
2,6-Dichlorophenol	52	NA	0	0	0	0	NA
2,6-Dinitrotoluene	739	NA	0	25	0.03	1	NA
2-Acetylaminofluorene	52	NA	0	0	0	0	NA
2-Aminonaphthalene	52	NA	0	0	0	0	NA
2-Butanone	853	NA	0	13	0.02	1	NA
2-Chloroacetophenone	52	NA	0	0	0	0	NA
2-Chlorobenzalmalononitrile	52	NA	0	0	0	0	NA
2-Chloronaphthalene	739	NA	0	0.83	0	1	NA
2-Chlorophenol	739	NA	0	0	0	0	NA

Parameter	Number of Analyses	MCL (µg/L)	Minimum Result (µg/L)	Maximum Result (µg/L)	Average Result (µg/L)	Number >MRL	Number >MCL
2-Hexanone	240	NA	0	0	0	0	NA
2-Methylnaphthalene	739	NA	0	8.2	0.01	4	NA
2-Methylphenol	739	NA	0	0	0	0	NA
2-Nitroaniline	739	NA	0	0	0	0	NA
2-Nitrophenol	739	NA	0	0	0	0	NA
2-Picoline	52	NA	0	0	0	0	NA
3&4-Methylphenol	739	NA	0	0	0	0	NA
3,3¬¥-Dichlorobenzidine	739	NA	0	0	0	0	NA
3,3¬¥-Dimethylbenzidine	52	NA	0	0	0	0	NA
3-Methylcholanthrene	52	NA	0	0	0	0	NA
3-Nitroaniline	739	NA	0	0	0	0	NA
4,6-Dinitro-2-Methylphenol	739	NA	0	0	0	0	NA
4-Aminobiphenyl	52	NA	0	0	0	0	NA
4-Bromophenyl Phenyl Ether	739	NA	0	0	0	0	NA
4-Chloro-3-Methylphenol	739	NA	0	320	1.51	8	NA
4-Chloroaniline	739	NA	0	0	0	0	NA
4-Chlorophenyl Phenyl Ether	739	NA	0	0	0	0	NA

Parameter	Number of Analyses	MCL (µg/L)	Minimum Result (µg/L)	Maximum Result (µg/L)	Average Result (µg/L)	Number >MRL	Number >MCL
4-Chlorotoluene	618	NA	0	3	0.01	2	NA
4-Methyl-2-Pentanone	853	NA	0	0	0	0	NA
4-Nitroaniline	739	NA	0	0	0	0	NA
4-Nitrophenol	739	NA	0	0	0	0	NA
4-Nitroquinoline 1-Oxide	52	NA	0	0	0	0	NA
5,5-Diphenylhydantoin	52	NA	0	0	0	0	NA
5-Nitro-O-Toluidine	52	NA	0	0	0	0	NA
6-Methyl Chrysene	52	NA	0	0	0	0	NA
7,12-Dimethylbenz(A)Anthracene	52	NA	0	0	0	0	NA
A,A-Dimethylphenethylamine	52	NA	0	0	0	0	NA
Acenaphthene	739	NA	0	3.2	0.01	4	NA
Acenaphthylene	739	NA	0	0.76	0	2	NA
Acetone	853	NA	0	1200	2.39	38	NA
Acetonitrile	613	NA	0	0	0	0	NA
Acetophenone	291	NA	0	9.2	0.05	6	NA
Acrolein	613	NA	0	24	0.04	1	NA
Acrylonitrile	613	NA	0	31	0.07	2	NA
Aniline	500	NA	0	5	0.01	1	NA

Parameter	Number of Analyses	MCL (µg/L)	Minimum Result (µg/L)	Maximum Result (µg/L)	Average Result (µg/L)	Number >MRL	Number >MCL
Anthracene	739	NA	0	0.37	0	5	NA
Aramite	52	NA	0	0	0	0	NA
Atrazine	291	3	0	0	0	0	0
Azobenzene	448	NA	0	0	0	0	NA
Benz(A)Anthracene	739	NA	0	0.3	0	2	NA
Benzaldehyde	291	NA	0	23	0.15	10	NA
Benzene	882	5	0	221	0.55	31	15
Benzenethiol	52	NA	0	0	0	0	NA
Benzidine	52	NA	0	0	0	0	NA
Benzo(A)Pyrene	739	NA	0	0	0	0	NA
Benzo(B)Fluoranthene	739	NA	0	0	0	0	NA
Benzo(G,H,I)Perylene	739	NA	0	0.14	0	2	NA
Benzo(K)Fluoranthene	739	NA	0	0	0	0	NA
Benzoic Acid	500	NA	0	73	0.15	1	NA
Benzophenone	52	NA	0	0	0	0	NA
Benzyl Alcohol	500	NA	0	48	0.45	6	NA
Bis(2-Chloro-1-Methlethyl) Ether	739	NA	0	0	0	0	NA
Bis(2-Chloroethoxy)Methane	739	NA	0	0	0	0	NA
Bis(2-Chloroethyl)Ether	739	NA	0	12	0.35	43	NA

Parameter	Number of Analyses	MCL (µg/L)	Minimum Result (µg/L)	Maximum Result (µg/L)	Average Result (µg/L)	Number >MRL	Number >MCL
Bis(2-Chloroisopropyl)Ether	52	NA	0	0	0	0	NA
Bis(2-Ethylhexyl)Phthalate	739	NA	0	18	0.13	66	NA
Bromobenzene	5	NA	0	0	0	0	NA
Bromochloromethane	618	NA	0	0	0	0	NA
Bromomethane	245	NA	0	0	0	0	NA
Butyl Benzyl Phthalate	739	NA	0	8	0.02	5	NA
Caprolactam	291	NA	0	0	0	0	NA
Carbazole	739	NA	0	1.5	0	2	NA
Carbon Disulfide	853	NA	0	0	0	0	NA
Carbon Tetrachloride	878	5	0	9.6	0.03	3	3
Chlorobenzene	882	100	0	9.5	0.03	8	0
Chlorobenzilate	52	NA	0	0	0	0	NA
Chloroethane	245	NA	0	0	0	0	NA
Chloromethane	858	NA	0	3.6	0.01	2	NA
Chrysene	739	NA	0	0.18	0	1	NA
Cis-1,2-Dichloroethene	878	NA	0	0	0	0	NA
Cis-1,3-Dichloropropene	240	NA	0	0	0	0	NA
Cyclohexane	240	NA	0	0	0	0	NA
Di-N-Butyl Phthalate	739	NA	0	6.2	0.01	7	NA

Parameter	Number of Analyses	MCL (µg/L)	Minimum Result (µg/L)	Maximum Result (µg/L)	Average Result (µg/L)	Number >MRL	Number >MCL
Di-N-Octyl Phthalate	739	NA	0	5.2	0.01	5	NA
Diallate	52	NA	0	0	0	0	NA
Dibenz(A,H)Anthracene	739	NA	0	0.11	0	1	NA
Dibenzo(A,H)Acridine	52	NA	0	0	0	0	NA
Dibenzofuran	739	NA	0	2.3	0	3	NA
Dichlorodifluoromethane	245	NA	0	0	0	0	NA
Diethyl Phthalate	739	NA	0	0	0	0	NA
Diisopropanolamine	52	NA	0	0	0	0	NA
Dimethoate	52	NA	0	0	0	0	NA
Dimethyl Phthalate	739	NA	0	0	0	0	NA
Dinoseb	52	7	0	0	0	0	0
Diphenyl Oxide	52	NA	0	0	0	0	NA
Diphenylamine	52	NA	0	0	0	0	NA
Disulfoton	52	NA	0	0	0	0	NA
Ethanol	613	NA	0	220	0.36	1	NA
Ethyl Methanesulfonate	52	NA	0	0	0	0	NA
Ethyl Tert-Butyl Ether	613	NA	0	0	0	0	NA
Ethylbenzene	882	700	0	1600	3.99	40	2
Famphur	52	NA	0	0	0	0	NA
Fluoranthene	739	NA	0	3.4	0.01	6	NA

Parameter	Number of Analyses	MCL (µg/L)	Minimum Result (µg/L)	Maximum Result (µg/L)	Average Result (µg/L)	Number >MRL	Number >MCL
Fluorene	739	NA	0	2.8	0.01	7	NA
Hexachlorobenzene	739	1	0	0	0	0	0
Hexachlorobutadiene	744	NA	0	0	0	0	NA
Hexachlorocyclopentadiene	739	50	0	0	0	0	0
Hexachloroethane	739	NA	0	0	0	0	NA
Hexachlorophene	52	NA	0	0	0	0	NA
Hexachloropropene	52	NA	0	0	0	0	NA
Indene	52	NA	0	0	0	0	NA
Indeno(1,2,3-Cd)Pyrene	739	NA	0	0.11	0	1	NA
Iodomethane	613	NA	0	0	0	0	NA
Isodrin	52	NA	0	0	0	0	NA
Isophorone	739	NA	0	16	0.02	2	NA
Isopropylbenzene	862	NA	0	190	0.31	18	NA
Isosafrole	52	NA	0	0	0	0	NA
Kepone	52	NA	0	0	0	0	NA
M,P-Xylene	853	NA	0	7.4	0.03	9	NA
Methapyrilene	52	NA	0	0	0	0	NA
Methyl Acetate	240	NA	0	1.5	0.01	2	NA
Methyl Methanesulfonate	52	NA	0	0	0	0	NA

Parameter	Number of Analyses	MCL (µg/L)	Minimum Result (µg/L)	Maximum Result (µg/L)	Average Result (µg/L)	Number >MRL	Number >MCL
Methyl Parathion	52	NA	0	0	0	0	NA
Methyl Tert-Butyl Ether	853	NA	0	3.7	0.01	2	NA
Methylcyclohexane	240	NA	0	0	0	0	NA
Methylene Chloride	878	NA	0	0	0	0	NA
Methylphenol, Total	52	NA	0	0	0	0	NA
N-Butylbenzene	618	NA	0	3.5	0.01	3	NA
N-Nitroso-Di-N-Butylamine	52	NA	0	0	0	0	NA
N-Nitrosodi-N-Propylamine	739	NA	0	0	0	0	NA
N-Nitrosodiethylamine	52	NA	0	0	0	0	NA
N-Nitrosodimethylamine	500	NA	0	0	0	0	NA
N-Nitrosodiphenylamine	739	NA	0	0	0	0	NA
N-Nitrosomethylethylamine	52	NA	0	0	0	0	NA
N-Nitrosomorpholine	52	NA	0	0	0	0	NA
N-Nitrosopiperidine	52	NA	0	0	0	0	NA
N-Nitrosopyrrolidine	52	NA	0	0	0	0	NA
N-Propylbenzene	9	NA	0	1.4	0.32	3	NA
Naphthalene	910	NA	0	42	0.17	25	NA

Parameter	Number of Analyses	MCL (µg/L)	Minimum Result (µg/L)	Maximum Result (µg/L)	Average Result (µg/L)	Number >MRL	Number >MCL
Nitrobenzene	739	NA	0	0	0	0	NA
O,O,O-Triethylphosphorothioate	52	NA	0	0	0	0	NA
O-Chlorotoluene	5	NA	0	0	0	0	NA
O-Phenylphenol	52	NA	0	0	0	0	NA
O-Toluidine	52	NA	0	0	0	0	NA
O-Xylene	853	NA	0	6.8	0.02	5	NA
P-Dimethylaminoazobenzene	52	NA	0	0	0	0	NA
P-Isopropyltoluene	5	NA	0	0	0	0	NA
P-Phenylenediamine	52	NA	0	0	0	0	NA
Parathion	52	NA	0	0	0	0	NA
Pentachlorobenzene	52	NA	0	0	0	0	NA
Pentachloroethane	52	NA	0	0	0	0	NA
Pentachloronitrobenzene	52	NA	0	0	0	0	NA
Pentachlorophenol	739	1	0	0.76	0	1	0
Phenacetin	52	NA	0	0	0	0	NA
Phenanthrene	739	NA	0	3.9	0.02	10	NA
Phenol	739	NA	0	0	0	0	NA
Phorate	52	NA	0	0	0	0	NA

Parameter	Number of Analyses	MCL (µg/L)	Minimum Result (µg/L)	Maximum Result (µg/L)	Average Result (µg/L)	Number >MRL	Number >MCL
Pronamide	52	NA	0	0	0	0	NA
Pyrene	739	NA	0	3.3	0.01	7	NA
Pyridine	739	NA	0	0	0	0	NA
Quinoline	52	NA	0	0	0	0	NA
Safrole	52	NA	0	0	0	0	NA
Sec-Butylbenzene	618	NA	0	4.2	0.02	3	NA
Styrene	882	100	0	8300	23.19	30	11
Sulfolane	52	NA	0	0	0	0	NA
Sulfotepp	52	NA	0	0	0	0	NA
Tert-Butanol	613	NA	0	0	0	0	NA
Tert-Butylbenzene	618	NA	0	0	0	0	NA
Tetrachloroethene	878	NA	0	0	0	0	NA
Tetrahydrofuran	613	NA	0	20	0.08	10	NA
Thionazin	52	NA	0	0	0	0	NA
Toluene	882	1000	0	511.6	1.78	39	0
Trans-1,2-Dichloroethene	878	NA	0	0	0	0	NA
Trans-1,3-Dichloropropene	240	NA	0	0	0	0	NA
Trichloroethene	878	NA	0	0	0	0	NA
Trichlorofluoromethane	245	NA	0	0	0	0	NA

Parameter	Number of Analyses	MCL (µg/L)	Minimum Result (µg/L)	Maximum Result (µg/L)	Average Result (µg/L)	Number >MRL	Number >MCL
Vinyl Chloride	882	2	0	0.7	0	1	0
Xylenes, Total	269	NA	0	5	0.04	3	NA