Acoustical leak detection survey of City of Orland Water DistributionSystem

City of Orland Acoustic Leak Detection Survey

Report Prepared by
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MC Enginnering, Inc.

June 2015

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Background

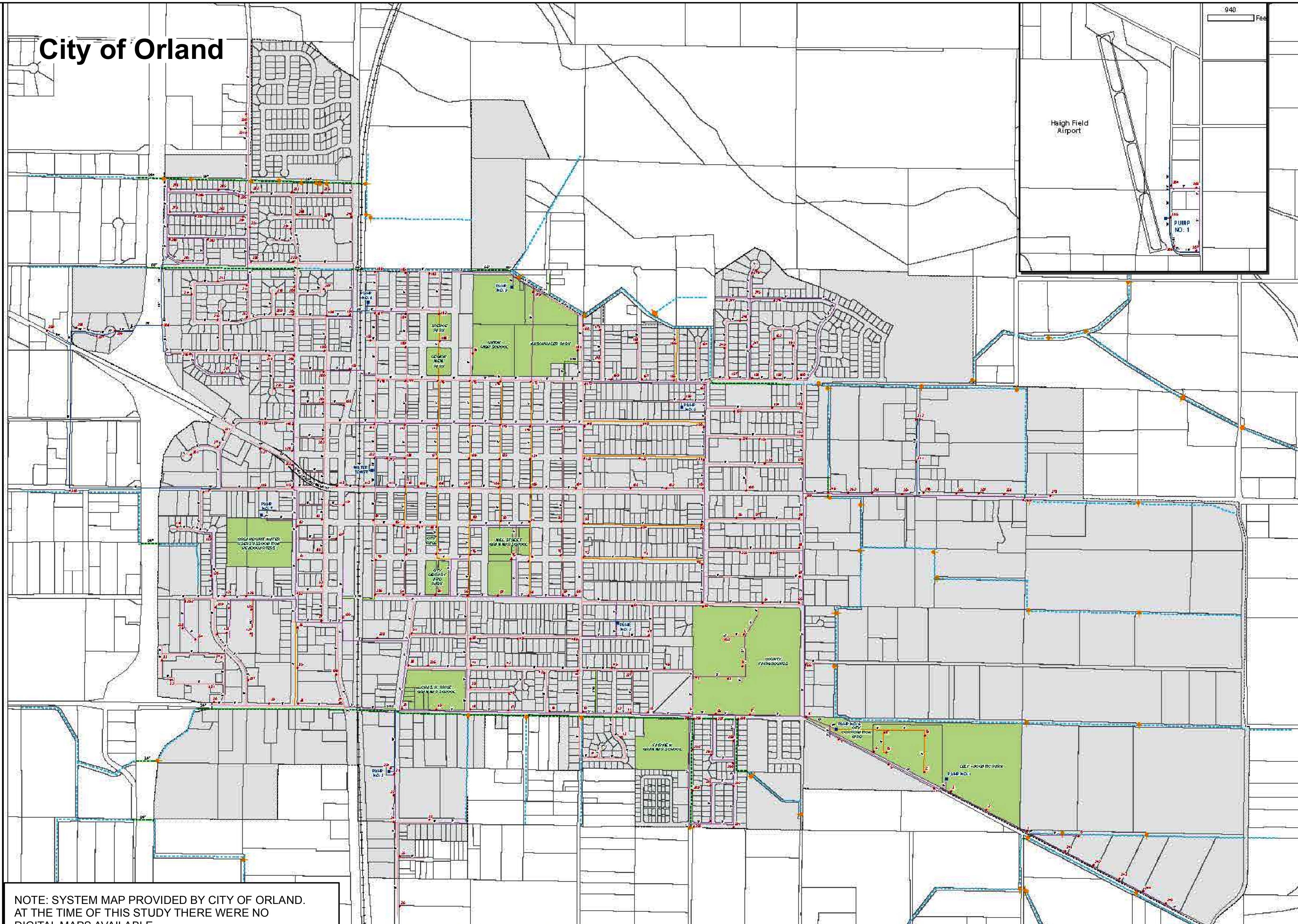
The City of Orland (City) originally retained MC Engineering in 2014 to conduct investigations related to water efficiency and metering. The resulting report, completed in November in 2014 titled “Meter and Water Loss Management System Report” included documenting existing suspected water losses and making recommendations for various investigations in metering, control system upgrades, and other water efficiency improvements, one of which included conducting an initial acoustic leakage survey. This study was prepared in response to the recommendation for an acoustic survey and includes results of an initial study focused on approximately 17 miles of older mains in the City’s distribution system network.

The previous study estimated overall non-revenue water in the City’s distribution system at 18.4% which is considered relatively high, particularly for California. This total is made up of both Real Losses (losses due to leaks) and Apparent Losses (losses due to meter inaccuracy) as discussed further in the 2014 initial study. The previous study estimated overall customer meter inaccuracy at 3% in order to distinguish between Real an Apparent Losses, however, no meter testing was conducted to confirm this and the 3% estimate was based on a combination of engineering judgement along with consideration of the age and type of existing meters. A summary of the performance indicators from the initial water audit findings are presented below in Table 1. A map of the distribution system is presented below in Figure 1.

Table 1
AWWA Water Audit Performance Indicators

PERFORMANCE INDICATORS		
Financial Indicators		
Non-revenue water as percent by volume of Water Supplied:	18.4%	
Non-revenue water as percent by cost of operating system:	9.1%	
Annual cost of Apparent Losses:	$19,098	
Annual cost of Real Losses:	$27,521	
Operational Efficiency Indicators		
Apparent Losses per service connection per day:	26.83	gallons/connection/day
Real Losses per service connection per day*:	54.84	gallons/connection/day
Real Losses per length of main per day*:	N/A	
Real Losses per service connection per day per psi pressure:	1.00	gallons/connection/day/psi
? Unavoidable Annual Real Losses (UARL):	13.00	million gallons/year
From Above, Real Losses = Current Annual Real Losses (CARL):	50.04	million gallons/year
? Infrastructure Leakage Index (ILI) [CARL/UARL]:	3.85	

* only the most applicable of these two indicators will be calculated



Water Infrastructure

Legend

- 10" WATER LINE
- 2 1/2" WATER LINE
- 2" WATER LINE
- 4" WATER LINE
- 6" WATER LINE
- 8" WATER LINE
- UKNOWN DIAM - WATER LINE
- HYDRANT
- WELL
- EXISTING OPEN CANAL OR LATERAL
- EXISTING UNDERGROUND PIPE
- EXISTING TURNOUT STRUCTURE

350 Feet

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NOTE: SYSTEM MAP PROVIDED BY CITY OF ORLAND. AT THE TIME OF THIS STUDY THERE WERE NO DIGITAL MAPS AVAILABLE.

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CITY OF ORLAND, CA
LEAK DETECTION STUDY

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FIGURE 1 - EXISTING DISTRIBUTION SYSTEM MAP

The information received to prepare the AWWA water audit listed a total length of mains of 34 miles. The infrastructure leakage index (ILI) for the City was estimated at 3.85 using the AWWA Water Audit software. An ILI of 1.0 would suggest the system is achieving results that are in line with expected best practices in the industry. The higher ILI suggests that Real Losses are having an impact on the City's NRW values.

To minimize costs, the City elected to survey up to 50% of the distribution system initially while focusing on the older mains in the core downtown area. Limited information was available related to maps, construction details, and exact locations of distribution system components. In the absence of this, City staff provided assistance for locating monitoring points and describing underground pipe materials and locations. Knowledge of underground materials becomes increasingly important when attempting to pinpoint suspected leaks.

Approach and Methodology

The acoustic surveys were conducted over a 3 week period from May 5th to May 22nd, 2015. The investigations were focused on potential leak areas located on the City side of the meter with an emphasis on distribution system main line leaks. The approach involved deploying initial noise logging devices with a maximum spacing of approximately 1,000 feet. The noise loggers were placed on top of operating nuts on valve boxes for mainline valves. The loggers were programmed to listen for leaks between the hours of 2 and 4 am. They were left in place a minimum of one night. If a leak, or suspected leak related noise, was detected, the logger was left in place for an additional night to confirm results. In cases were leaks were found, the sound files from the loggers were downloaded from the device onto the command unit via radio transmission and stored for subsequent recording and review with City staff. Follow-up pinpointing and correlating activities were conducted on suspected leaks as described further below.

Equipment

The team relied on technology manufactured by Vivax Metrotech, Inc. Metrotech is a leading supplier and manufacturer of acoustic leak detection devices and related equipment, providing related products to the water industry for over 50 years. A variety of tools were utilized which included:

1) **HL 5000 Electroacoustic Water Leak Locator**
   This equipment comes with various appurtenances including contact probes and a ground microphone. The HL 5000 is used to locate and listen to leaks in the field using either a contact probe at points of access (valves, meters, hydrants, etc.) or a ground microphone that is used on the surface.

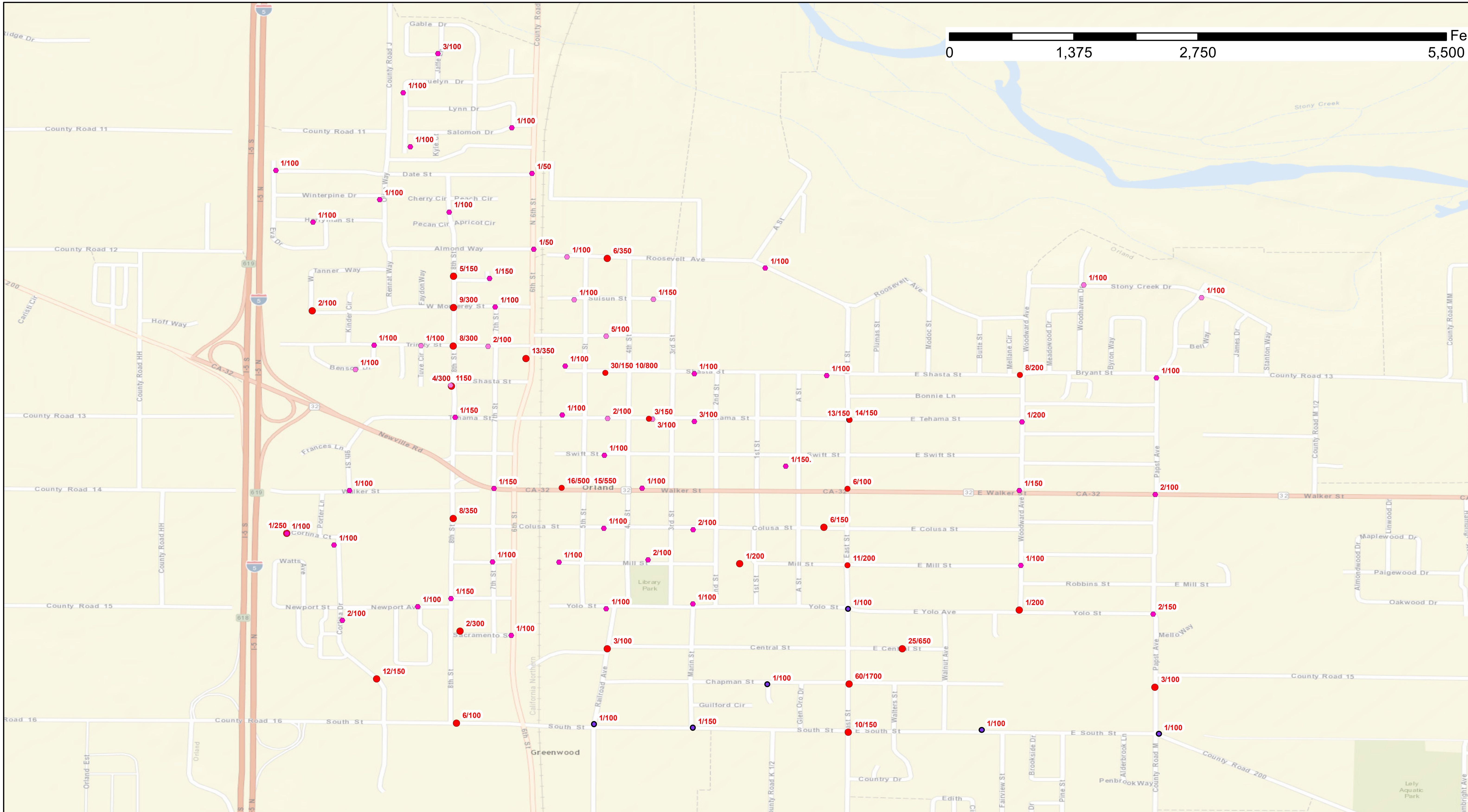
2) **Fifteen HL 7000 Noise loggers and associated Metrolog Commander:**
The noise loggers are deployed each day for subsequent listening and recording of sounds during quiet evening hours to minimize sound disturbances from normal water uses and/or surface noises.

3) **Metrolog HL 6000 Correlator:**
The correlator is used to help pinpoint the location of suspected leaks by apply noise transmitting algorithms based on the speed of sound in different pipe materials.

4) **Metrolog Correlating Loggers:**
The correlating loggers are deployed in groups of 3 to 4 devices around a point of suspected leakage. The loggers listen and record sound for subsequent analysis using a PC software program that compares the sound observed by each device in order to pinpoint source location/s. The correlating loggers are similar to the noise loggers in size and installation but include added features when coupled with PC software for pinpointing.

Initial Findings and Follow-up Requirements

Initially, the target coverage for the leak detection survey was 17 miles. The actual final survey coverage was 29 miles, or 85% of the entire system. The survey was performed based on deployment of 15 noise loggers, primarily on valves located on mains in City streets and alleys. The decibel readings and frequency of all recordings were noted and are plotted below in Figure 2.



LEGEND

4/650 POTENTIAL LEAK LOCATIONS/READING

1/100 NON-POTENTIAL LEAK LOCATIONS/READING

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METER REPLACEMENT AND AMI SYSTEM

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FIGURE 2 - CITY-WIDE LOGGER READINGS

China (Hong Kong), Esri (Thailand), TomTom, MapmyIndia, ©

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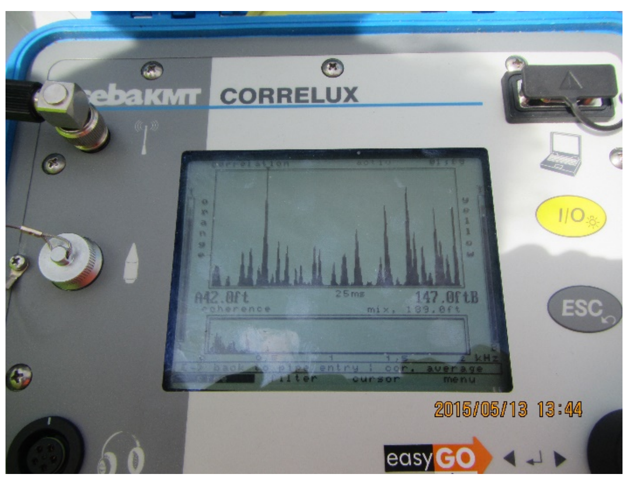
Following the initial readings of the daily loggers, further investigation was performed. Contact microphones, ground microphone, and correlators were used in an effort to actively pinpoint the leaks. Figures 3 & 4 below show the setup of the correlators and the initial output. Areas that were targeted as potential leaks were marked in the streets and are shown in Figure 5.

Figure 3
Correlator Setup

Figure 4
Correlator Results



Following the deployment of the daily loggers, the correlation of the potential leaks, and ground mic'ing the potential leak area, the area is targeted for further investigation. This is to be accomplished with potholing the potential leak location by City staff at a future date. During this leak detection survey, 5 areas were found to be candidates for further investigation and possible potholing. Table 1 below lists these suspected leak locations, the estimated magnitude of the leak, and recommendations for follow-up potholing and verification. Suspected leak number 5 below resulted in a valve leak that City staff was able to fix in the field curing the survey. Follow up contact mic'ing and a follow up daily logger showed that the leak had been fixed.

Table 1
Probable Leaks and Follow-up Required

Suspected Leak Number	Suspected Leak Location	Approximate Address	Decibels/Hz	Approximated Leakage (gpm)	Notes and Follow-up Recommendations
1	In Mainline in alley behind house	108 4th Street	6/350 6/400	10	There are potentially multiple leaks in this area. Targeted potholing followed up with contact and ground microphone survey is recommended in this area
2	In Mainline in Street at 2 Locations	218 8th Street	9/300 8/300 4/300	10	Pothole in targeted area and deploy contact microphone and ground microphone to pinpoint leak/leaks
3	In Mainline in Street in 2 Locations	36 E Central	26/650	15	Pothole in targeted area and deploy contact microphone and ground microphone to pinpoint leak/leaks
4	Multiple leaks in Mainline in Intersection	1130 East St.	60/1700	10	Pothole in targeted area and deploy contact microphone and ground microphone to pinpoint leak/leaks
5	Leak in Valve box in sidewalk	731 East Street	6/150	1.5	This was a visual leak discovery and the City staff was contacted and the leak was fixed
6	Possible Leaks in Mainline	731 East Street	16/500 15/550	10	Due to the traffic and inaccessibility of the area on Highway 32, no correlating took place. It is recommended that further analysis be done, possibly with a street shutoff

A Suspected Leak Area Field Form for each of the leaks identified in Table 1 above are included in Appendix A. These field forms are intended to be used as a field guide when potential leaks are discovered. The field forms contained in Appendix A include a location description and maps of the suspected leak, initial readings and description of follow up equipment used to pinpoint the leaks, a more detailed remarks and follow up recommendation section, and a hyperlink to the audio file of the suspected leak. Figure 5 below shows the 4 areas of potential leaks along with the leak that was located and addressed by City staff.

LEGEND

4/650 TARGETED LEAK LOCATIONS/READING

LIMIT OF CORRELATION/CORRELATION LOGGER LOCATION

LEAK LOCATED AND FIXED IN THE FIELD BY CITY STAFF

POTENTIAL POTHOLE LOCATIONS

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FIGURE 5 - POTENTIAL AND RESOLVED LEAK AREAS

AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS

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Estimating Leak and Break Flow Rates

Once a leak is located, the ability to estimate the size of the leak (flow rate in gallons/minute) is important for several reasons. First, knowing the approximate size of the leak can help operators prioritize which leaks to target for further monitoring and pinpointing, which leaks to target for potholing and verification, and to identify potential leaks to repair immediately.

Several methods can be deployed for estimating leakage rates including:

1) Estimating based on the nature of the sound and experience
2) Calculations performed by recording the amount of time required to fill a container with a known volume
3) Estimates that rely on calculations based on the orifice and crack sizes
4) Approximations based on recorded decibels and leak sound frequency
5) Providing realistic estimations based on the location, pipe size, pipe material, and known system pressure

Firm results for estimating leakage ultimately require that the leak be excavated and evaluated in detail. Appendix B is an excerpt from a larger report prepared in 1992 by the Department of Water Resources Titled "Water Audit and Leak Detection Guidebook". The DWR report was prepared in cooperation with AWWA and the EPA and it includes a summary of methods used for estimating the flow rates for various types of leaks. Appendix C contains graphics describing the nature of the frequency ranges for various types of leaks.

Appendix D contains information gleaned from a 2005 report prepared by Water System Optimization (WSO) Inc. The related work was funded by a grant from the AWWA Water Research Foundation (WRF). Table 10.4.5.6 from the report, which was prepared for the El Dorado Irrigation District, presented the recommended estimated leakage rates for Unreported leaks for various main sizes and service leaks. A FAVAD analysis was performed in order to modify the WRF study estimates to account for the lower system pressure in Orland (50 psi vs. 70 psi for EID). These values are summarized below in Table 2 and used as initial estimates for quantifying the leaks found during this study. More accurate estimates can be made once the leaks are potholed, confirmed, and repaired.

Table 2
Typical Leakage Rates for Various Conditions

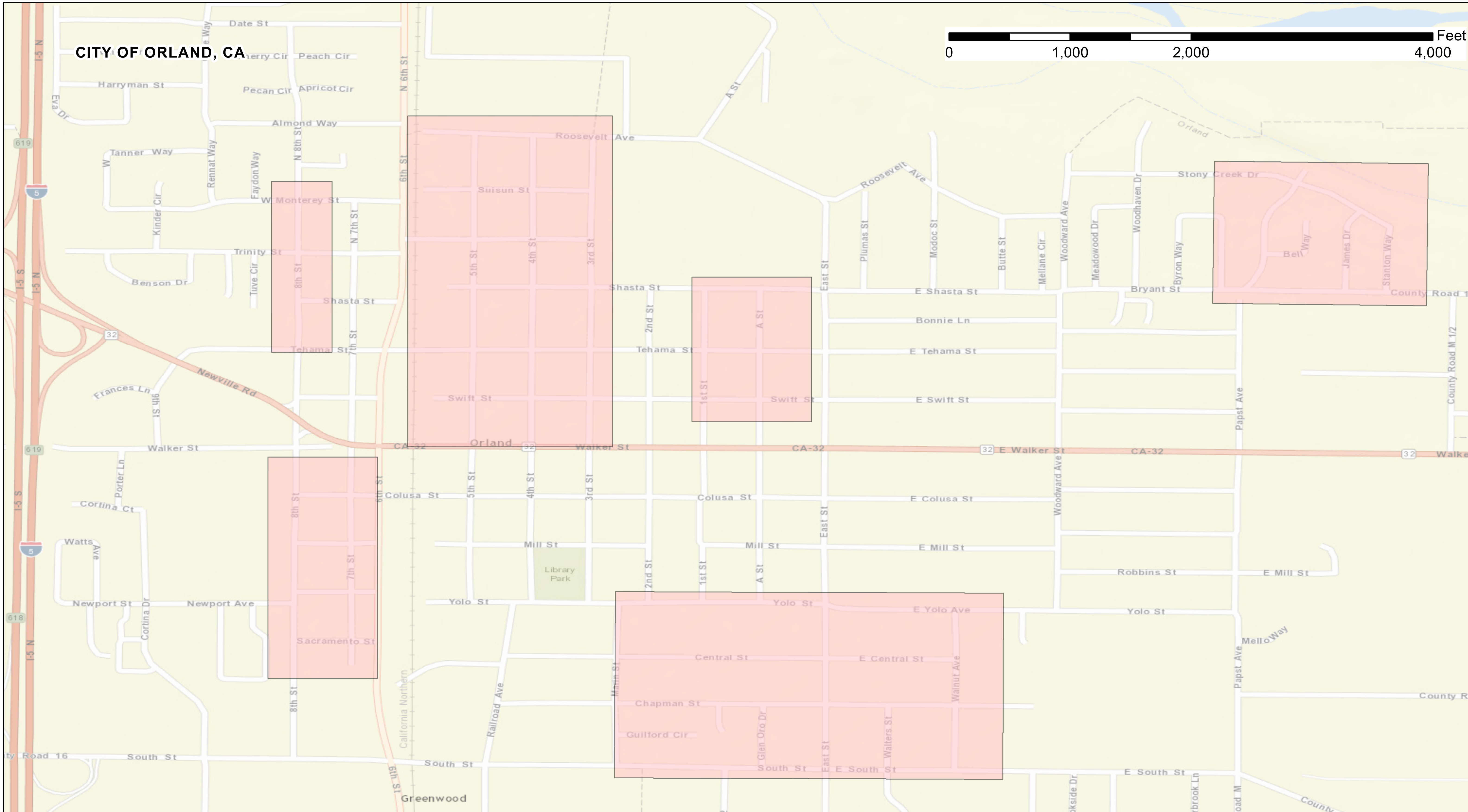
Type of Unreported Leak	Estimated Loss at 70 psi (gpm)	Estimated Loss at 50 psi (gpm)
Main Breaks		
Less than 4”	13.9	11.8
4 inch	22	18.6
6 inch	46	38.9
8 inch	46	38.9
10 inch	46	38.9
12 inch	111	93.8
Greater than 12 inch	111	93.8
Service Leaks		
Up to and Including 1 inch diameter	6.9	5.83
Over 1 inch diameter	13.9	11.8
Fire Hydrant Leaks	3.5	3.0
Valve Leaks	6.9	5.8

Conclusions and Recommendations

Pipes within the City of Orland are aging and the frequency of main breaks and leaks can be expected to increase with time. This study confirmed that leakage is an important consideration in the City’s overall water loss. However it provided only one snap shot into the condition of the City’s existing mains and should be followed by on-going verification. Several of the suspected leaks are considered worthy of potholing to verify prior to making repairs while leaks at some locations should be monitored to verify their presence and magnitude over time so repairs can be programmed as needed.

Estimated leakage rates for the leaks discovered during the course of this study are summarized above in Table 1 and they total 56.5 gpm assuming that the values are roughly 25 % of the magnitude of the estimates from Table. 2. The current annual real losses were estimated at approximately 50 MG/year in the AWWA water audit, or an average flow rate of 95 gpm. The 56.5 gpm estimated above is equal to 59% of that value. Once the above leaks are investigated and confirmed, more accurate estimates regarding their impact on the total City-wide water loss can be developed. Initial follow-up should include verifying the leak location through potholing along with subsequent repair activities.

During the Leak Detection Survey, approximately one-third of the fire hydrants in the system were surveyed with a contact probe microphone. It was determined that approximately 80% of the fire hydrants showed signs of leakage. There is the potential that this could be attributed to leaks in the service lines/main lines although many of the fire hydrant leaks were located in areas where there was no evidence of mainline/service leaks. It is recommended that follow-up investigation be performed on the fire hydrants during the winter months. This would eliminate the potential for irrigation activities contributing to the potential leak investigation. Figure 6 below shows a representative area of where the fire hydrant contact mic survey was performed.



LEGEND

FIRE HYDRANT/WATER VALVE AREAS SURVEYED WITH A CONTACT/GROUND MICROPHONE

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FIGURE 6 - FIRE HYDRANT-VALVE SURVEY AREAS

Appendices

Appendix A: Suspected Leak Area Field Forms

MC Engineering

LOCATION 1 - SUSPECTED LEAK AREA FIELD FORM – CITY OF ORLAND, CA

Date: **5/13/2015**	**Team Members:** Richard Relyea, John Bravo
Survey Location:	**Site Conditions:**
General Location: 4th & 5th Street Alley Between Suisun & Roosevelt Nearest Address: 108 4th Street Fire Hydrant: 184 & 185 GPS Coordinates: 39°45'15.1"N 122°11'41.3"W	Sunny – 70 degrees – No Wind

Survey Results:

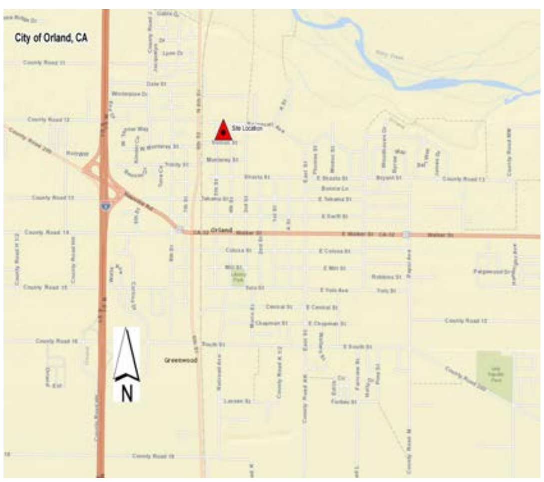
Daily Logger Readings (Decibels/Herz)	Day 1:	Day 2:	Day 3:
	6/350	6/400	

Additional Leak Detection Implemented:

- ☒ Contact Mic
- ☒ Ground Mic
- ☒ Correlator
- ☐ Correlating Logger
- ☐ Pothole

Audio File: [Report\Sound Files\Leak Location 1\Day 1_6-350_Location 1.wav]

Site Location	Leak Location



REMARKS:

This area was confirmed to have more than 1 leak within the alley between 4th and 5th Street, between Suisun and Roosevelt Ave. Daily loggers, correlators and contact/ground microphones were used to confirm the leak location. It should be noted that there is the potential for multiple leaks in these areas. City staff confirmed that garbage trucks use the alleys and typically the water mains and services contain only 1-2' of cover. Further investigation into water mains that are located in alleys is suggested and pothole investigation in the area shown above is highly recommended.

MC Engineering

LOCATION 2 - SUSPECTED LEAK AREA FIELD FORM – CITY OF ORLAND, CA

Date: 5/11/2015	**Team Members:** Richard Relyea, John Bravo
Survey Location:	**Site Conditions:**
General Location: 8TH Street between Monterey & Trinity Nearest Address: 218 8th Street Fire Hydrant: 205 & 206 GPS Coordinates: 39°45'09.1"N 122°11'58.8"W	Sunny – 70 degrees – No Wind

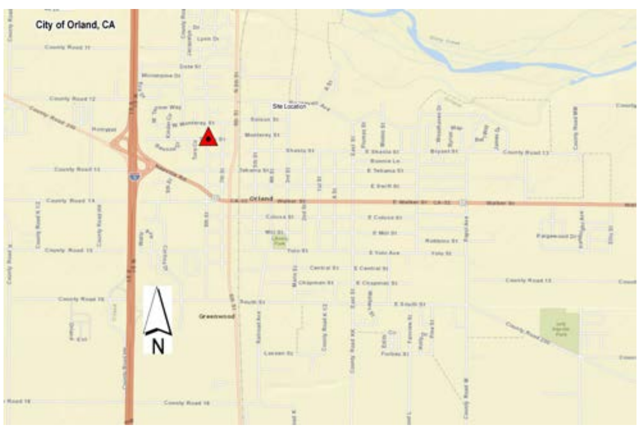
Survey Results:			
Daily Logger Readings (Decibels/Herz)	Day 1:	Day 2:	Day 3:
	9/300	8/300	

Additional Leak Detection Implemented:

- ☒ Contact Mic
- ☒ Ground Mic
- ☐ Correlator
- ☒ Correlating Logger
- ☐ Pothole

Audio File: ..\Sound Files\Leak Location 2\Day 1_9-300_Location 2.wav

Site Location | **Leak Location**



REMARKS:

This area was confirmed to have more than 1 leak on 8th Street between Monterey and Trinity. Daiy loggers were deployed and based on the decibel and Herz readings, it was decided that contact/ground mic analysis should be performed and also the deployment of the correlating loggers. The results of the correlators showed the possibility of 2 leaks. At this time, correlating loggers were deployed which also confirmed the leaks. It is recommended that potholing take place to pinpoint the leaks and fixes to the main line be implemented.

MC Engineering

LOCATION 3 - SUSPECTED LEAK AREA FIELD FORM – CITY OF ORLAND, CA

Date: 5/08/2015	**Team Members:** Richard Relyea, John Bravo
Survey Location:	**Site Conditions:**
General Location: Central St between Walnut & East Nearest Address: 36 E. Central St Fire Hydrant: 71 GPS Coordinates: 39°44'33.3"N 122°11'09.5"W	Sunny – 70 degrees – No Wind

Survey Results:

Daily Logger Readings (Decibels/Herz)	Day 1:	Day 2:	Day 3:
	26/650		

Additional Leak Detection Implemented:

- ☒ Contact Mic
- ☒ Ground Mic
- ☒ Correlator
- ☐ Correlating Logger
- ☐ Pothole

Audio File: [..\Sound Files\Leak Location 3\Day 1 26-550 Location 3.wav]

Site Location	**Leak Location**
	

REMARKS:

This area was confirmed to have more than 1 leak on E. Central between East and Walnut. Daiy loggers were deployed and based on the decibel and Herz readings, it was decided that contact/ground mic analysis should be performed and also the deployment of the correlators. The results of the correlators showed the possibility of 2 leaks. A It is recommended that potholing take place to pinpoint the leaks and fixes to the main line be implemented.

MC Engineering

LOCATION 4 - SUSPECTED LEAK AREA FIELD FORM – CITY OF ORLAND, CA

Date: 5/08/2015	**Team Members:** Richard Relyea, John Bravo
Survey Location:	**Site Conditions:**
General Location: Intersection of East St & E. Chapmen St. Nearest Address: 1130 East St. Fire Hydrant: 60 GPS Coordinates: 39°44'29.7"N 122°11'14.8"W	Sunny – 70 degrees – No Wind

Survey Results:

Daily Logger Readings (Decibels/Herz)	Day 1:	Day 2:	Day 3:
	60/1700		

Additional Leak Detection Implemented:

- ☒ Contact Mic
- ☒ Ground Mic
- ☐ Correlator
- ☒ Correlating Logger
- ☐ Pothole

Audio File: No Audio File Available

Site Location	Leak Location

REMARKS:

This area was first targeted for a potential leak when the daily loggers were being deployed. The valve box that was to be the location of the daily logger was 1/3 full of water, a sign that there was a leak in the vicinity. The daily logger received a definite potential for a leak. The correlating loggers were then deployed to pinpoint the leak and it was evident by the results of the correlating loggers that there was more than 1 hit in the intersection. It is recommended that the area be potholed. It is difficult to pinpoint the number of leaks along the main. This is due in part to the fact that there are not accurate records of how the mains and the valves are tied together. Further investigation is recommended.

MC Engineering

LOCATION 5 - SUSPECTED LEAK AREA FIELD FORM – CITY OF ORLAND, CA

Date: **5/08/2015**	**Team Members:** Richard Relyea, John Bravo

Survey Location:	Site Conditions:
General Location: Intersection of East St & E. Chapmen St. Nearest Address: 731 East St. Fire Hydrant: 93 GPS Coordinates: 39°44'46.5"N 122°11'14.6"W	Sunny – 70 degrees – No Wind

Survey Results:

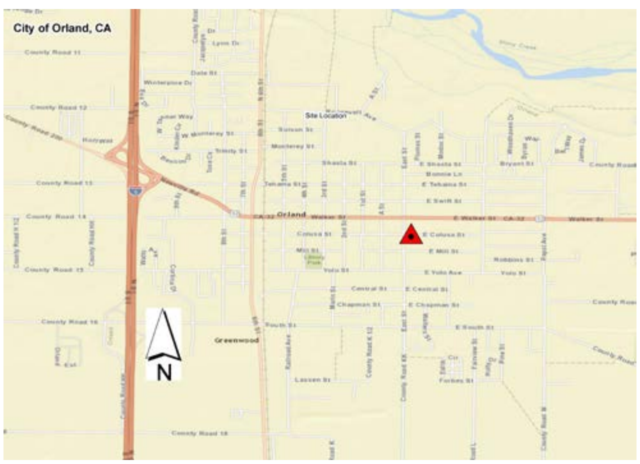
Daily Logger Readings (Decibels/Hertz)	Day 1:	Day 2:	Day 3:
	6/150	1/100	

Additional Leak Detection Implemented:

- ☒ Contact Mic
- ☐ Ground Mic
- ☐ Correlator
- ☐ Correlating Logger
- ☐ Pothole

Audio File: [..\Sound Files\Leak Location 5\Day 1 6-150 Location 5.wav]

Site Location	Leak Location



REMARKS:

This area received a moderate hit on the daily loggers. It was deemed a suspect area and therefore an investigation with the contact microphone was under taken. While opening a valve box, it was discovered that it was full of water and it was also evitdent that the water was running into the storm drain. City staff was contacted and the water was removed from the valve box. A valve exercise was performed and it seemed to fix the leaking water. Placing a daily logger at the same location was verification that was wan no mainline leak.

MC Engineering

LOCATION 6 - SUSPECTED LEAK AREA FIELD FORM – CITY OF ORLAND, CA

Date: 5/04/2015	**Team Members:** Richard Relyea, John Bravo
Survey Location:	**Site Conditions:**
General Location: Highway 32 East of 5th Street Nearest Address: 430 Walker St Fire Hydrant: 93 GPS Coordinates: 39°44'50.6"N 122°11'43.7"W	Sunny – 70 degrees – No Wind Loud busy intersection on Highway 32

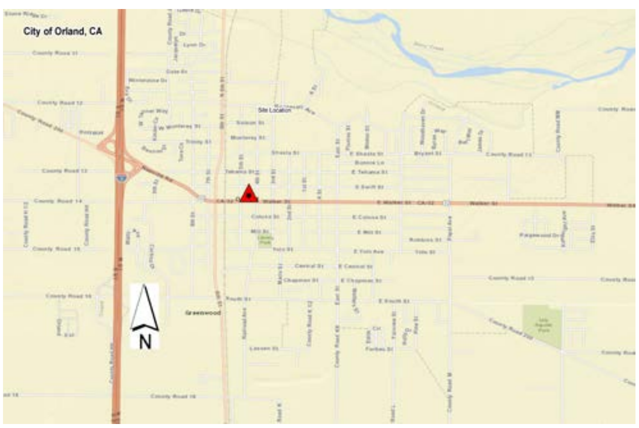
Survey Results:

Daily Logger Readings (Decibels/Hertz)	Day 1:	Day 2:	Day 3:
	16/500	15/550	

Additional Leak Detection Implemented:

- ☐ Contact Mic
- ☐ Ground Mic
- ☐ Correlator
- ☐ Correlating Logger
- ☐ Pothole

Audio File: ..\..\Sound Files\Leak Location 6\Day 1_6-150_Location 5.wav

Site Location	**Leak Location**
	

REMARKS:

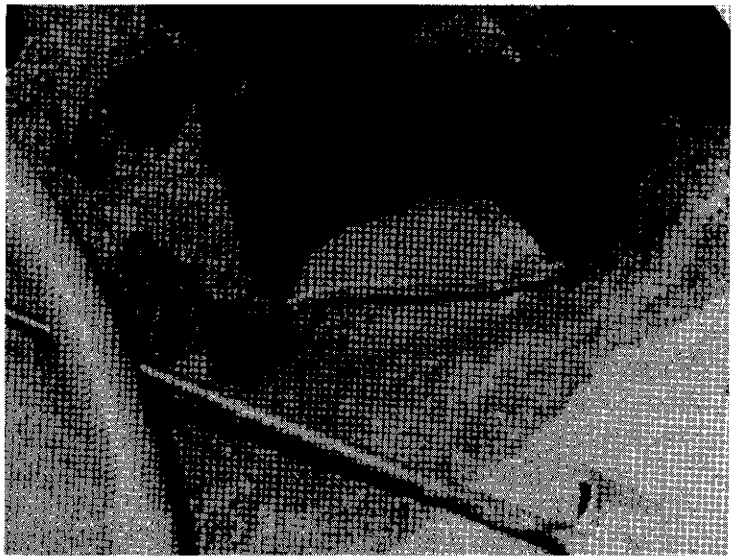
This area was surveyed using the daily loggers. The loggers were deployed for 2 days and each day there was evidence of a leak. Correlation and pinpointing was not possible for this location due to high traffic and safety concerns. It is recommended that further investigation take place using correlators and contact/ground microphones and possible potholing.

Appendix B: Water Audit and Leak Detection Guidebook Excerpt

Measuring and Estimating Losses from Discovered Leaks

Losses from leaks that are discovered and repaired should be measured to determine the rate of loss and the total volume lost during the life of the leak. Three methods are suggested (from "Leak Detection Productivity," by Douglas S. Greeley in Water Emergency and Management Reference Number 1981):

- o Use a container of known volume and a stop watch.
- o Use a hose and a meter.
- o Calculate losses using modified orifice and friction loss formulas.



36. Service–line leaks can be easily repaired by replacing a part of the service line. Some agencies place the damaged line in line with a test meter and measure the flow rate.

The first method, sometimes known as the bucket and stop watch method, is as simple as its name.

Hold a container against the leak for a predetermined time period. Measure the time with a stop watch. Measure the water captured with a measuring cup or other container of known volume. Then convert time and volume to gallons per minute.

Use time intervals that are easy to deal with.

Time in seconds:	6	10	15	30
Multiply volume in gallons by: to get gallons per minute.	10	6	4	2

The conversion factor to calculate acre-feet for a two year time period, from gallons per minute (gpm):

$$\frac{(60 \text{ min/hr})(24 \text{ hrs/day})(365 \text{ days/yr})(2 \text{ years})}{325{,}828 \text{ gallons per acre-foot}} = 3.23$$

1.0 gpm for 2 years = 3.23 acre-feet over the two-year average leak lifetime.

Large spraying-type leaks can be measured by draping an enveloping device (such as a large canvas, rain jacket, or large inverted pail) over the leak and diverting the water into a container.

The second method requires connecting a hose to the leak and directing the flow through a meter.

The third method is the simplest to perform in the field but requires calculations. This method is often helpful for large leaks where the flow is too great to measure and the main must be valved off. It requires that the size and shape of the hole be measured and the line pressure be determined. A pressure gauge or a hand-held blade pitotmeter could be used to determine the pressure of the water coming from the leak or a nearby fire hydrant. This method also uses some assumptions regarding the shape of the hole which may introduce error.

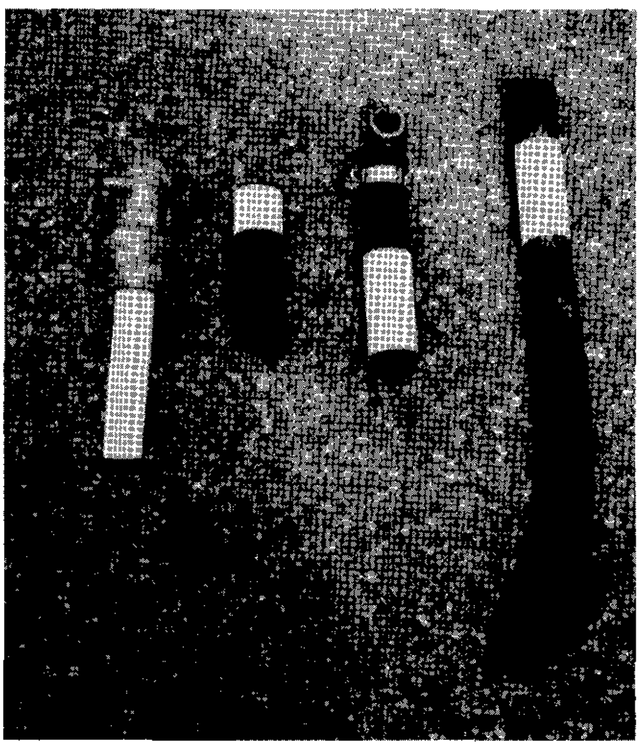
For losses from such items as pipes or broken taps, Greeley assumes an orifice coefficient of 0.80 and calculates flow in gallons per minute from the formula:

$$Q = (43{,}767/1440) \times A \times \text{square root of } P$$

where Q = flow in gallons per minute
A = the cross sectional area of the leak in square inches and
P = the pressure in pounds per square inch.

For example, if the hole in the pipe were roughly circular, then the area would be: $A = 3.14 \times r^2$. You need only measure the diameter of the hole and ascertain the pressure in the pipe.

For relatively small holes, the following leak rates in gallons per minute (Table 5) were calculated, assuming a circular hole and several pressures.



37. Plastic service line are also subject to deterioration from improper installation, thus resulting in leaks.

Calculating Leak Rates for Small Leaks

The following tables provide leak rates for typical meter box leaks. These tables can be used to convert drips per second and cups per minute to gallons per minute to be entered on the Leak Repair Report.

TABLE 4
LEAK LOSSES FOR CIRCULAR HOLES UNDER DIFFERENT PRESSURES
(losses in gallons per minute)

DIAMETER OF HOLE inches	AREA OF HOLE sq. in.	WATER PRESSURE IN POUNDS PER SQUARE INCH 20	40	60	80	100	120	140	160	180	200
0.1	0.007	1.067	1.510	1.850	2.136	2.388	2.616	2.825	3.021	3.204	3.337
0.2	0.031	4.271	6.041	7.399	8.544	9.522	10.464	11.302	12.083	12.816	13.509
0.3	0.070	9.611	13.593	16.648	19.224	21.493	23.544	25.430	27.186	28.835	30.395
0.4	0.125	17.087	24.165	29.597	34.175	38.209	41.856	45.209	48.331	51.263	54.036
0.5	0.196	26.699	37.758	46.245	53.399	59.702	65.400	70.640	75.518	80.098	84.431
0.6	0.282	38.477	54.372	66.593	76.894	85.971	94.176	101.721	108.745	115.341	121.581
0.7	0.384	52.331	74.007	90.640	104.662	117.010	128.184	138.454	148.014	156.993	165.485
0.8	0.502	68.350	96.662	118.387	136.701	152.840	167.424	180.839	193.325	205.052	216.144
0.9	0.636	86.506	122.338	149.833	173.012	193.434	211.896	228.874	244.676	259.519	273.557
1.0	0.785	106.798	151.035	184.979	213.596	238.807	261.600	282.561	302.070	320.394	337.725
1.1	0.950	129.225	182.752	223.825	258.451	288.957	316.536	341.898	365.505	387.676	408.647
1.2	1.131	153.789	217.490	266.370	307.578	343.882	376.704	406.887	434.981	461.367	486.323
1.3	1.327	180.488	255.249	312.615	360.977	403.584	442.104	477.527	510.498	541.465	570.755
1.4	1.539	209.324	296.028	362.559	418.648	468.062	512.737	553.819	592.057	627.972	661.941
1.5	1.767	240.295	339.829	416.203	480.590	537.317	588.601	635.762	679.658	720.886	759.880
1.6	2.011	273.402	386.649	473.547	546.805	611.347	669.697	723.355	773.299	820.208	864.575
1.7	2.270	308.646	436.491	534.590	617.292	690.153	756.025	816.600	872.983	925.938	976.024
1.8	2.545	346.025	489.353	599.333	692.050	773.736	847.585	915.496	978.707	1038.070	1094.220
1.9	2.836	385.540	545.237	667.776	771.081	862.095	944.378	1020.040	1090.470	1156.620	1219.180
2.0	3.142	427.191	604.140	739.918	854.383	955.230	1046.400	1130.240	1208.280	1281.570	1350.890

The above table of losses from roughly circular shaped holes in pipe is computed from the following formula established by Greeley:

Q = (30.394)(A)(square root of P) gallons per minute

where "A" is the cross sectional area of the leak in square inches and "P" is the pressure in pounds per square inch

TABLE 5
LEAK LOSSES FOR JOINTS AND CRACKS UNDER DIFFERENT PRESSURES

For leaks emitted from joints and cracked service pipes an orifice coefficient of 0.60 is used in the following equation.

Q = (22.796)(A)(square root of P)

"A" is the area in square inches and "P" is the pressure in pounds per square inch.

The following table of flow rates was computed in gallons per minute for four different leak dimensions under pressures ranging from 20 to 200 psi.

AREA LENGTH	AREA WIDTH	WATER PRESSURE IN POUNDS PER SQUARE INCH 20	40	60	80	100	120	140	160	180	200
1.0	1/32	3.2	4.5	5.5	6.4	7.1	7.8	8.4	9.0	9.6	10.1
1.0	1/16	6.4	9.0	11.0	12.7	14.2	15.6	16.9	18.0	19.1	20.1
1.0	1/8	12.7	18.0	22.1	25.5	28.5	31.2	33.7	36.0	38.2	40.3
1.0	1/4	25.5	36.0	44.1	51.0	57.0	62.4	67.4	72.1	76.5	80.6

TABLE 6
DRIPS PER SECOND CONVERTED TO GALLONS PER MINUTE

Drips per Second	Gallons per Minute
1	0.006
2	0.012
3	0.018
4	0.024
5	0.030

Note: Five drips per second amounts to a steady stream.

TABLE 7
CUPS PER MINUTE CONVERTED TO GALLONS PER MINUTE

8-ounce Cups per Minute	Gallons per Minute
0.25	0.016
0.50	0.031
0.75	0.047
1.00	0.062
1.50	0.094
2.00	0.125
2.50	0.156
3.00	0.188
3.50	0.219
4.00	0.250

Use the Leak Repair Report Form, to record all information regarding leak excavation, flow rates, and leak repair. (See Example 21 on page 79.)

Determining Leak Detection Effectiveness

An important and often neglected part of the leak detection project is the determination of whether the project was a cost-effective water conservation measure. To determine whether the leak detection project was cost effective, the agency must evaluate the completed leak detection project.

The Leak Detection and Repair Project Summary (see Example 22 on page 81) includes information needed for this evaluation.

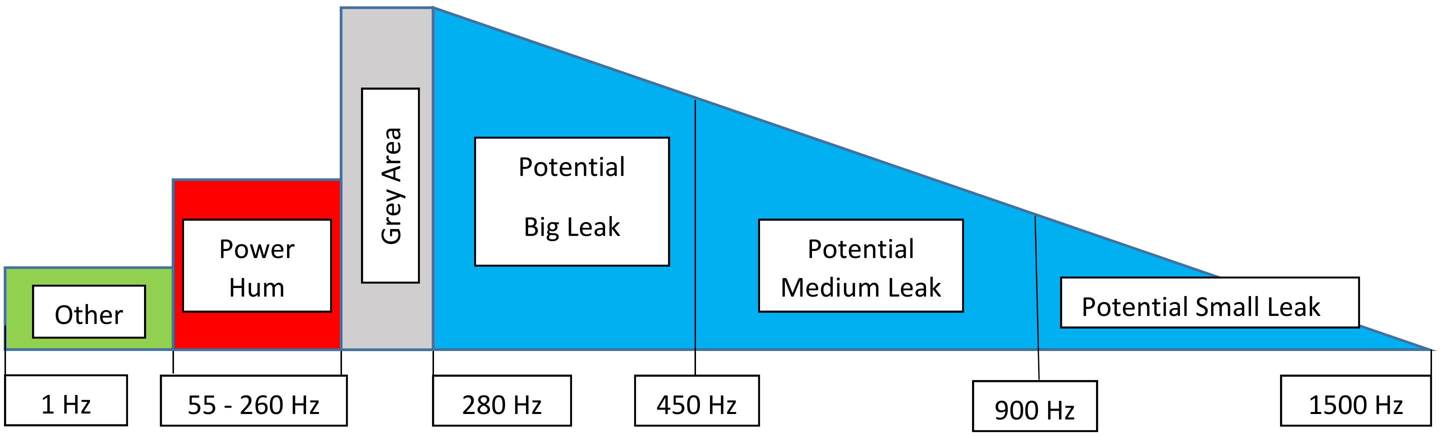
Appendix C: VXMT Acoustic Guideline

ACOUSTIC SPECIAL 2014

Using *piezzo sensor*s such as:

Noise loggers, Contact mics, Correlator mics (max spacing between two sensors about 900 – 1,200 ft)

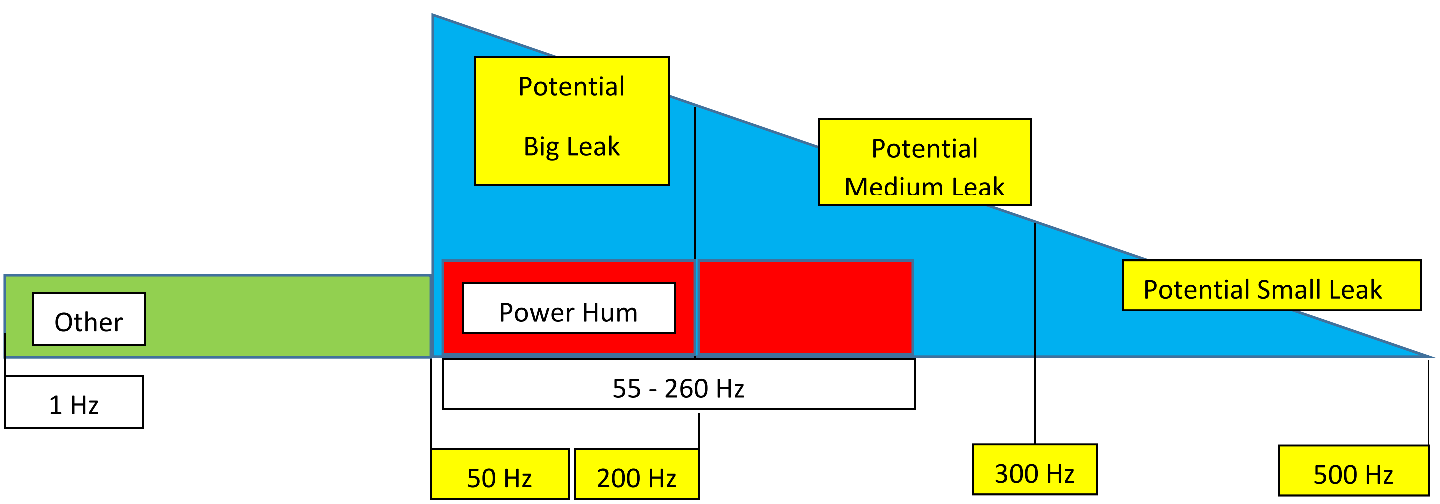
For NON-Plastic water pipes up to 24 inches in diameter – General rule of thumb



Using *piezzo sensor*s such as:

Noise loggers, Contact mics, Correlator mics (max spacing between two sensors about 300 – 500 ft)

For PLASTIC water pipes up to 24 inches in diameter – General rule of thumb

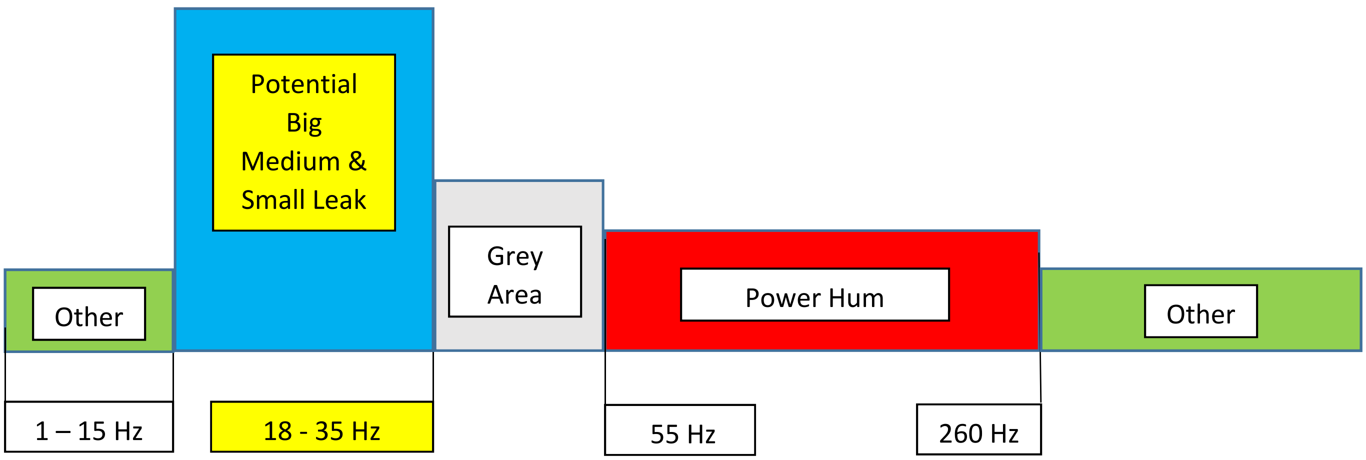


ACOUSTIC SPECIAL 2014

Using *Hydrophones* (pressure wave sensors – connected to water column)

In conjunction with Correlators, Noise Loggers or Correlating loggers (max. spacing between two sensors > 1,000 ft)

For ALL water pipes – General rule of thumb



Appendix D: WSO Report Excerpt

- **Location Duration** - for reported leaks and breaks, this is the time it takes for the water service organization to investigate the report of a leak or break and to correctly locate its position so that a repair can be effected; for unreported leaks and breaks, the location duration is zero since the leak or break is detected during the leak detection survey and awareness and location occur simultaneously.
- **Repair Duration** - the time it takes to make the repair once a leak has been located.

Reported breaks have extremely short combined awareness, location, and repair times - varying typically in the range of only a few hours up to a week. Therefore, the amount of water lost is relatively small. The time taken by the public to report a break will depend upon the degree of inconvenience caused, but would not generally be more than 5 days, and the break, once reported, is often repaired within 2 days.

However, unreported breaks, which can only be detected through active leakage control, run for much longer periods and, although the rate of leakage may be less than for reported breaks, the amount of water lost can be considerable. For example, a leakage detection technique may be the regular sounding of the system, followed by rapid repair of all located breaks. If the system is completely sounded once a year, then the average duration for which an unreported break will run on that system will be a half year, or approximately 185 days. This is derived from the sum of the average time taken to become aware of the break, i.e. half a year in this example, plus one day each to locate and then to repair the break. Doubling the intensity of active leakage control effort, i.e. completely sounding the system every six months instead of every year, would reduce the duration for which the break runs to an average of about 95 days, reducing the water loss by half. However, conversely, a reduction in activity to sounding the system every two years would allow breaks to run for an average of 365 days before their location and repair, doubling the losses resulting from sounding the complete system annually. This illustrates why the detection of unreported breaks can be of such importance to a water service provider.

The various intensities of sounding carry differing levels of cost – personnel, equipment, and materials - to implement, and these costs must be compared with the value of the water that would be either saved by a higher intensity of active leakage control activity or lost due to a lower level of activity. Night flow measurement techniques to achieve awareness of break existence, combined with advanced leak detection techniques to locate individual breaks, are more efficient than regular sounding alone, but also have a high capital cost to implement the systems that are needed.

The HANSEN data was analyzed to determine the average duration of each type of leak that has occurred.

10.4.5 Leak and Break Flow Rates

In systems where the flow rates of individual leaks and breaks cannot be individually monitored, it is necessary to make some realistic assumptions to estimate the volume of real losses arising from these events. The usual technique is to categorize and count events by: (1) whether they occurred on mains, services, valves or hydrants, (2) pipe size and material, and if appropriate by type of failure, (3) whether the events were 'reported' or 'unreported' events. System pressure is also a significant factor in the flow rate of individual leaks.

The consultants previously carried out research on established values of flow rates from various leak types used by water utility operators in the UK, Canada, Brazil, and the United States.

10.4.5.1 Calculation of Leak and Break Flow Rates

To calculate the volume of real losses from an individual leak or break on mains or services, two parameters are required: (1) duration and (2) flow rate.

In systems where the flow rate and duration of individual leaks and breaks cannot be individually monitored, it is necessary to make some realistic assumptions to estimate the volume of real losses arising from these events. The usual technique is to categorize and count events by:

- Whether they occurred on mains, services, valves or hydrants
- Pipe size and material, and if appropriate by type of failure
- Whether the events were 'reported' or 'unreported but found by distribution' events

The average flow rate assigned to each category of the above events also needs to be defined. This section of the report reviews typical values for average flow rates of leaks and breaks used in North America and elsewhere and suggests values that should be used by EID.

10.4.5.2 Typical Flow Rates Used in North America

The consultants recently carried out a leakage management assessment project for the City of Philadelphia Water Department (PWD), which has operated an active leakage control policy for many years. PWD had developed an estimated average flow rate for different types of leaks and breaks on services, mains, valves, and hydrants. These are listed in Table 10-6.

The Philadelphia average leak and break flow rate values were initially compared with the average values for flow rates of 500 reported and unreported events on service connections and mains up to 6 inch diameter standardized to 70psi pressure. The UK data was obtained from Appendix D of the UK Managing Leakage Report E[17].

The UK data partially supported the Philadelphia values in that:

- There was no significant difference between average flow rates for reported and unreported leaks on small service connections.
- Average flow rates from reported mains breaks were higher than those form unreported mains breaks.

For 6 inch mains, the flow rates being used in Philadelphia were similar to those for unreported 6 inch UK mains breaks, but around half those for reported 6 inch mains breaks. However, Philadelphia assumed flow rates for leaks on service connections (both reported and unreported) that were considerably higher than those found in the UK study.

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[17] WRc, "Managing Leakage Series", ISBN 1 898920 21 4, 1994

Type Of Leak Or Break	Diameter	Unreported Leaks and Breaks (gpm)	Reported Leaks and Breaks (gpm)
Mains Break			
Joint Leak or Repair Band Leak	6”	10.4	10.4
Joint Leak or Repair Band Leak	8”	17.3	17.3
Joint Leak or Repair Band Leak	12” to 24”	27.8	27.8
Round (circumferential) crack	6”	55.5	55.5
Round (circumferential) crack	8”	69.4	69.4
Round (circumferential) crack	10”	83.3	83.3
Round (circumferential) crack	12”	97.2	97.2
Longitudinal crack or split bell	6”	69.4	69.2
Longitudinal crack or split bell	8”	83.3	83.3
Longitudinal crack or split bell	10”	97.2	97.2
Longitudinal crack or split bell	12”	111.1	111.1
Service Leaks			
Active Services	½” to ⅝”	10.4	10.4
Active Services	¾”	17.3	17.3
Active Services	1”	24.3	24.3
Active Services	2” to 4”	34.7	34.7
Abandoned or vacant buildings	½” to ⅝”	17.3	17.3
Abandoned or vacant buildings	1”	31.2	31.2
Abandoned or vacant buildings	2” to 4”	34.7	34.7
Fire Hydrant Leaks		3.5	3.5
Valve Leaks		6.9	6.9

Table 10-6Average Water Loss Flow Rates for Specific Leak Types Previously Used in Philadelphia

10.4.5.3 Mains Break Flow Rates

The Philadelphia data set for mains breaks flow rates was assumed to relate most closely to Cast Iron mains, which is the predominant mains material type in Philadelphia. Table 10-7 shows the Philadelphia data, compared with data from four other recent projects:

- UK 'Managing Leakage' series values for reported and unreported bursts, 4 inch to 6 inch mixed pipe materials.
- Canadian average values for ring cracks on Cast Iron mains obtained from SCADA System flow data[18]
- German values for Cast Iron Mains[19] that may include corrosion events.

Mains	Philadelphia (unreported)			UK	UK	Canada	Germany
	Leak at Joint or Repair Band	Long. Crack or Split Bell	Ring Crack	Unreported Break at 70psi	Reported break at 70psi	Ring Cracks on Cast Iron Mains at 70psi	Breaks on Cast Iron Mains
4"	-	-	-	22	44	75	18.5
6"	10.3	69.4	55.5	46	92	132	18.5
8"	17.4	83.3	69.4	-	-	201	-
10"	-	97.2	83.3	-	-	300	-
12" – 48"	27.8	111.1	97.2	-	-	-	-

Table 10-7 Comparison of Average Flow Rates for Mains Breaks (all values in gpm)

It should be noted that, for the UK data, the average flow rates for reported breaks are twice the average flow rates for unreported breaks, for 4 inch and 6 inch mains.

Analyzing the flow rates used by PWD for pipes between 4" and 10" it was felt that they are overestimating the amount of water lost through those leaks and breaks. Since the UK average values relate to mixed materials with a significant proportion of non-metallic pipes, it is recommended that the UK values be used for 4-inch and 6-inch pipes. It is seen to be appropriate to apply the UK flow rates for 6" breaks to 8" and 10" mains breaks as well.

As very little data is available on average leakage flow rates size pies 12" and above form other utilities and countries the PWD average flow rates had to be used as representative average flow rates for North America.

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[18] Source: "Table of Typical Water Loss Rates based upon Pipe Size – Shear (70 psi)", from Halifax (Canada) Scada System. April 2000

[19] Source: "Typische Wassererluste der einzelnen Schadensarted", Table attributed to Dr Hoch, Stuttgart, Germany, circa 1992

10.4.5.4 Service Leak Flow Rates

Several leakage consultants, based in Canada, the USA, and Brazil (Brazilian values for mixed mains materials), experienced in the North American market were invited to comment on an anonym zed comparison of the Philadelphia, UK, and German averages for unreported leaks on ½ inch, ¾ inch and 3 inch metal service connections and for unreported breaks on 6 inch cast iron and ductile iron mains. The comparative values for average flows for unreported service pipe leaks are shown in Table 10-8.

A graphic comparison of the Philadelphia values for leaks on active service connections with the other data is presented in Figure 10-2.

Services Size (Inches)	Philadelphia (PWD)		UK (At 70psi)	Germany	USA	Brazil	Canada	Average (Of data exc. PWD)
	Active	Abandoned or Vacant						
½"	10.4	17.3	**5.0**	-	7.5	3.5	5.0	5.3
¾"	17.3	24.3	6.0	-	8.0	4.4	5.0	5.8
1"	**24.3**	31.2	-	7.5	-	-	-	7.5
2"	34.7	34.7	-	7.5	-	-	-	7.5
3"	34.7	34.7	-	7.5	-	22.2	10.0	13.2
4"	34.7	34.7	-	-	-	-	-	-

Table 10-8 Average Flows Rates for Unreported Service Pipe Leaks (all values in gpm)

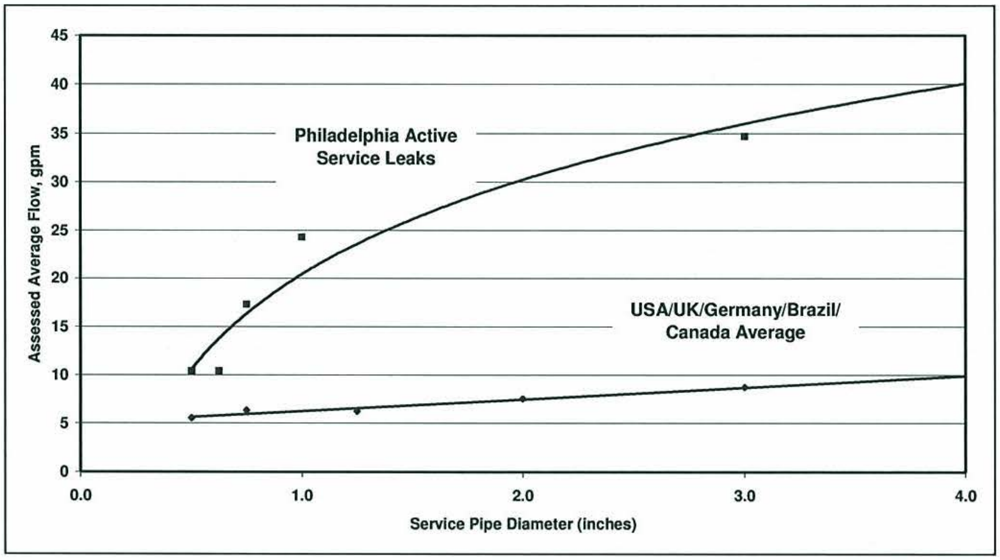

Figure 10-2 Average Flows for Unreported Leaks on Active Service Pipes

Table 10-8 and Figure 10-2 show that the more widely drawn international data set gives average values for flow rates on service pipe leaks substantially less than those being used in Philadelphia.

In reviewing the comparisons, it was noted that the UK, Canadian, and Brazilian data were generally based on changes in night flow measurements taken after leak detection/repair exercises, rather than estimates based on a sonic leak survey or measurement of the size of holes at the time of repair. One of the consultants commented that (in his experience) the sonic leak flow estimate always gave a higher estimate than that recorded by the night flow measurement method, pre and post leak repair.

Experience form the UK has shown that leakage flow rates for pipes with diameters between 1inch and 3 inch should be estimated at the same flow rate of 13.9gpm at 70 PSI (flow rate is equal for reported and unreported leaks and breaks).

For the purposes of calculating volumes of real losses from reported and unreported leaks on service connections, the Philadelphia study recommended that the following simplified average values be used in North American situations. A more detailed breakdown based on type of service pipe material or pipe diameter appeared to be unjustified, given the variability of the data. From the values in Table 10-9, it should be noted that:

- The flow rates for reported leaks are assumed to be the same as those for unreported leaks on services (based on the Philadelphia values and experience in UK).
- For abandoned or vacant smaller diameter services, the average flow rates are twice those for active service pipes.

Service Pipe Diameter	**Up to & inc. 1 Inch diameter (gpm)**	**Over 1 Inch diameter (gpm)**
Active Services - Reported and Unreported Leaks	6.9	13.9
Abandoned or Vacant Services - Reported and Unreported Leaks	13.9	13.9

Table 10-9 Recommended Average Flow Rates for Service Leaks

10.4.5.5 Hydrant Leak and Valve Leak Flow Rates

The PWD value for fire hydrant leaks (standard or high pressure) is 3.5gpm. The only available data for comparison is 0.7gpm for hydrant seat leaks from Halifax, Canada[20].

The PWD value for leaks on Valves is 6.9gpm. The only available data for comparison is 2.2gpm from Germany[21].

In the absence of other sets of comparative data, it is recommended that the PWD values for hydrant and valve leaks be used in EID, and that they be used for both reported and unreported leaks on these fittings.

[20] Source: "Table of Typical Water Loss Rates based upon Pipe Size – Shear (70 psi)", from Halifax (Canada) Scada System. April 2000

[21] Source: "Typische Wassererluste der einzelnen Schadensarted", Table attributed to Dr Hoch, Stuttgart, Germany, circa 1992

10.4.5.6 Recommended Leak and Break Flow Rates

The typical flow rates for unreported leaks and breaks currently being used in North America have been reviewed and compared with more recent data from UK, Germany, Brazil, and Canada, and by drawing on the experience of leak detection consultants in Canada, USA and Brazil. A list of recommended typical flow rates for Leaks and Breaks at 70psi pressure was developed and is presented in Table 10-10.

	Unreported Leaks and Breaks (gpm)	**Reported Leaks and Breaks (gpm)**
Mains Breaks		
Less than 4"	13.9	13.9
4"	22	44
6"	46	92
8"	46	92
10"	46	92
12"	111	222
Greater than 12"	111	222
Service Leaks		
Up to & including 1" diameter	6.9	6.9
Over 1" diameter	13.9	13.9
Fire Hydrant Leaks	3.5	3.5
Valve Leaks	6.9	6.9

Table 10-10 Recommended Leak and Break Flow Rates at 70psi