saturated by treated water to a depth of twelve feet in the ground by detecting its spectral signature. The entire process takes approximately six weeks from the time of ordering the service. The deliverables one receives are; access to a GIS Cloud map with the leaks, individual reports on each leak including a map and the result files in multiple standard formats like shape files, KMZ files and an Excel spreadsheet. Examples of these are shown in Fig. 2 and Fig. 3.

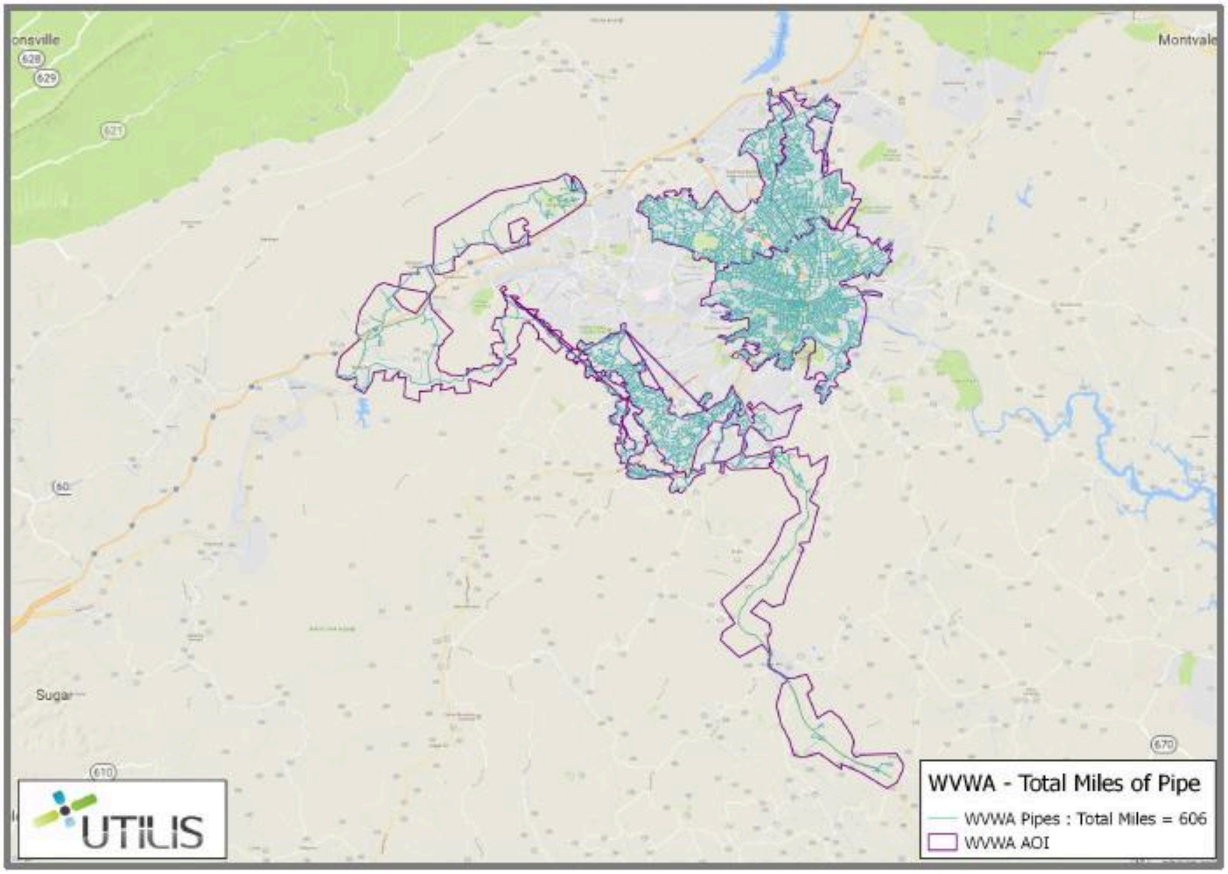

Fig. 4 – Areas Surveyed by SLD (Image used with permission)

Probability	Count
Very High	15
High	71
Medium	71
Low	18
Total	175

Fig. 5 – SLD Results

SELECTION OF PROJECT AREAS

As this technology was intriguing, the Authority investigated it further and spoke to references provided by SLD. Those clients said that they had seen a hit-rate of about 65%. The Authority procured the services of SLD to evaluate approximately half of its pipes or 606 miles in early October 2017. The areas to be surveyed are shown in Fig. 4. As this was an experiment, both densely populated areas such as the City of Roanoke were selected along with rural stretches of the system extending out into Roanoke and Franklin Counties.

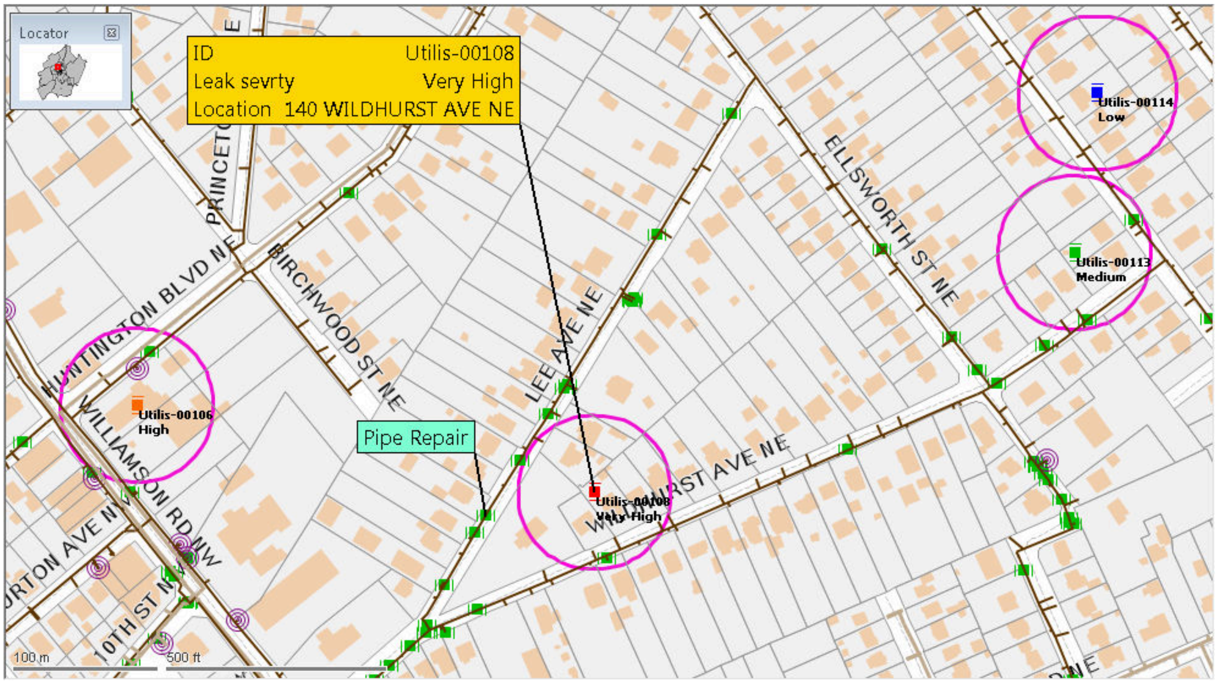

Fig. 6 – SLD Results in AMS

RESULTS

The results were provided to the Authority by SLD in mid-November 2017 based upon an image capture on 10/23/2017. 175 leak locations were identified. Based upon the spectral signature, SLD assigns a leak probability of low to very high. The results are shown in Fig. 5. SLD presented the results to the Authority and explained some of the finer points of their evaluation process. As shown in Fig. 3, a circular polygon is provided with a radius of 160 feet. SLD indicates that the saturated soil is most likely within this polygon. This does not necessarily mean that the leak is also within this polygon. It indicates that the resultant saturated soil is within the area. The location could be the low point of the area and the leak could be on a pipe uphill in any direction. The location is an indicator to the leak detection crew in the field to use their judgment as to where the water could be coming from.

MANAGEMENT OF LEAK DETECTION WORK ORDERS

The SLD results were directly imported into AMS as Leak Detection work orders so they could be viewed relative to the pipe network and all previous work orders in the area. As shown in Fig. 6, there were multiple pipe repairs already in the vicinity of many of the identified leaks.

The Authority has been using four main types of leak detection equipment over the years, namely geophones, ground microphones, correlators and acoustic data loggers. The leak detection work order was designed in AMS Mobile to accommodate the equipment used and data gathered during the investigative work. An example of a work order is shown in Fig. 7.

DEPLOYMENT OF LEAK DETECTION CREWS AND INITIAL CREW RESULTS

The work orders were grouped geographically, and a leak detection crew was deployed to investigate leaks in that area. SLD staff visited in the first week and accompanied the crews and managers as they investigated. A number of leaks were found in the first few days while other leak locations were deemed to be inconclusive.

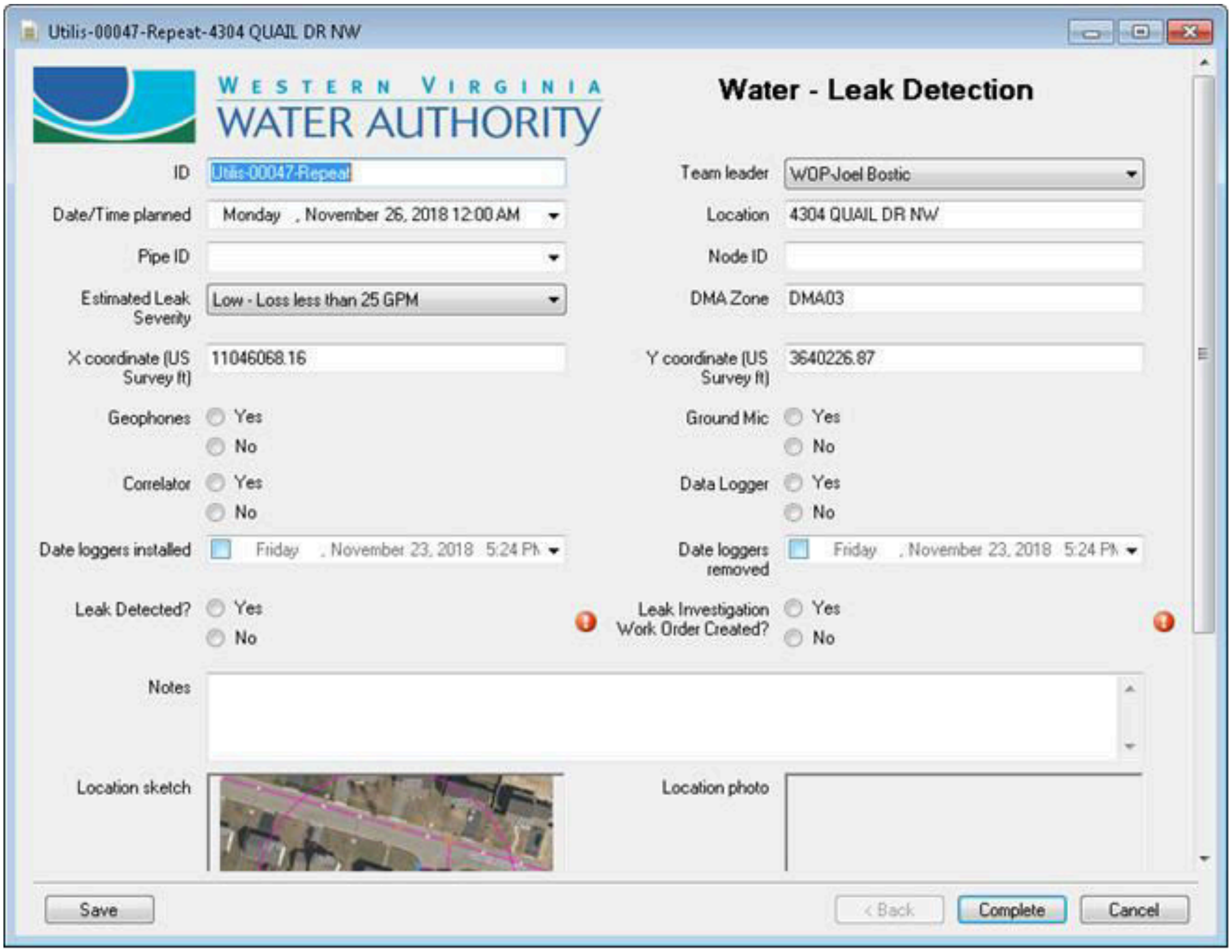

Fig. 7 – Leak Detection Work Order in AMS Mobile

As time went on, the initial results from the crew were reviewed. The first few weeks of investigations had approximately a 55% success rate. In January and February 2018, the overall success rate for the program dropped to 29%. Something was amiss.

The first clue was found in reviewing the work orders in AMS. The crew had been indicating no leaks but didn't use any equipment per their work orders as shown in Fig. 8. It transpired that the crew leader had not been using equipment but had been visually looking for leaks. They were not proficient in the use of the equipment and this may have contributed to their lack of interest and trust in using it.

This crew had used acoustic data loggers in the area of the "Very High" leak on Wildhurst Avenue shown in Fig. 6 in addition to ground microphones but claimed there was no leak. A week later, a 6" water main break surfaced at the edge of the SLD polygon. This occurred in a few other locations. As a result, pipe repairs were cross referenced against the SLD leak detection polygons and nine surfacing water breaks that would likely drain to the polygon boundaries were found.

Sewer Network | Water Network | Leak detection-Water Network | Pipe repair-Water Network | Leak detection-Water Network | Leak detection-Water Network

ID	Location	Leak severity	Geophones Used	Ground Mic Used	Correlator Used	Data Logger Used	Leak Detected?	Leak Investigation Work Order Created?	Pipe Repair Completed Nearby?	Completed	Date completed
Utilis-00013	5962 VILLAGE LN	High	No	No	No	No	No	No		☒	12/13/2017
Utilis-00014	726 GREENWICH DR	Medium	No	No	No	No	No	No		☒	02/15/2018
Utilis-00016	4541 NELMS LN NE	Medium	No	No	No	No	No	No		☒	02/26/2018
Utilis-00017	1147 TREVINO DR NE	High	No	No	No	No	No	No		☒	02/09/2018
Utilis-00018	4929 PINE GLEN RD NE	Medium	No	No	No	No	No	No		☒	02/26/2018
Utilis-00019	5932 HARWICK DR	High	No	No	No	No	No	No		☒	02/14/2018
Utilis-00020	5030 GLENVAR HEIGHTS BL	Medium	No	No	No	No	No	No		☒	03/08/2018
Utilis-00021	5349 YALE DR	Medium	No	No	No	No	No	No		☒	03/08/2018
Utilis-00022	4787 POOR MOUNTAIN RD	Medium	No	No	No	No	No	No		☒	03/09/2018
Utilis-00023	4858 YATEMAN LN	High	No	No	No	No	No	No		☒	02/14/2018
Utilis-00024	5132 POOR MOUNTAIN RD	Medium	No	No	No	No	No	No		☒	03/09/2018
Utilis-00025	4518 MORGAN CONNER LI	High	No	No	No	No	No	No		☒	02/14/2018
Utilis-00026	Near 2673 WILDWOOD RD	High	No	No	No	No	No	No		☒	02/14/2018
Utilis-00027	1661 SKYVIEW RD	Very High	No	No	No	No	No	No		☒	02/14/2018
Utilis-00028	1819 SAWMILL BRANCH RD	High	No	No	No	No	No	No		☒	02/14/2018

Fig. 8 – Leak Detection Work Orders in AMS

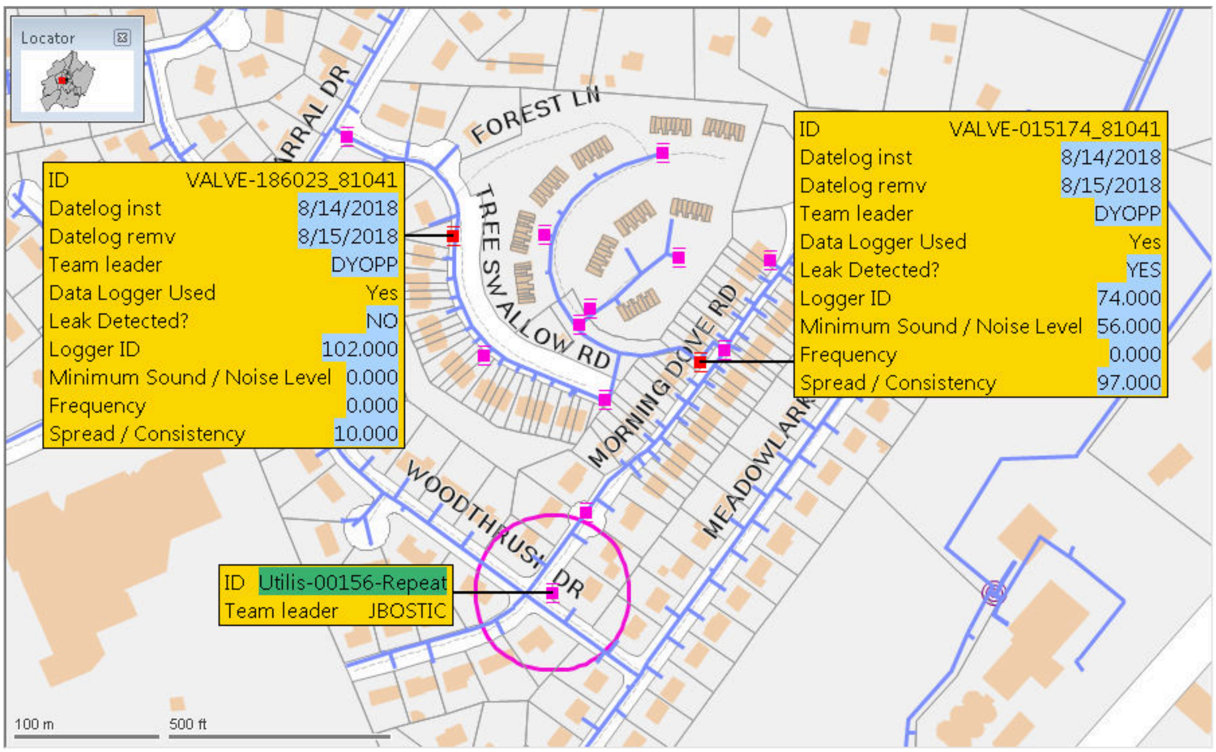

Fig. 9 – Leak Detection Data Logger Results

CHANGE OF CREW PERSONNEL

These issues were recognized by management and after a number of months, the right team was pulled together which had the skills, drive and attention to detail to effectively perform thorough leak detection activities. One of the critical elements was to dedicate this crew to leak detection and nothing else.

It was determined that, with staff changes, the crew needed adequate professional training in the use of the equipment. If one setting is ignored or misunderstood on a unit, the results may be misleading and the crew's time may be wasted. The new crew leader spoke directly to the manufacturers and gained a thorough understanding of the functionality of the equipment prior to using it. Some areas that had been investigated by the previous crew and determined to be leak-free were re-evaluated by the new crew and leaks were found.

Fig. 9 shows some of the results of acoustic monitoring data loggers in an area near a SLD leak location. These units are placed upon valves or meters overnight and "listen" for leaks. The results on each are recorded when the units are picked up the next day. It is critical to understand the output from the devices noted here as "Minimum Sound / Noise Level", "Frequency" and "Spread / Consistency". In the case on the right, the noise level coupled with the consistency of the signal was sufficient to convince the team leader that a leak had been detected.

CONCLUSIONS

At the time of writing, not all 175 of the SLD locations have been investigated. Of those that have been, as shown in Fig. 10, leaks have been discovered or have surfaced prior to field investigation in 51% of cases. The majority of the leaks were small with many being on services. However, there were two known areas that had saturated soil within the project scope that were not identified by SLD. One was adjacent to a tall building where there was a leaking 16" valve and the other was in a rural area at the end of the system where an automatic flushing valve released water for two hours every night. SLD said that buildings can interfere with signal accuracy. Another factor that may have played a role in this is the fact that some portions of the system are in karst topography. Water can disappear down to sinkholes and never surface.

Status	Count
Leak Found	65
Leak Not Found	62
Not Investigated	48
Total	175

Fig. 10 – SLD Leak Detection Results

While these results were not as good as those of other SLD clients, there were other benefits associated with the experiment. At the very least, crews were forced to leave the office and search for leaks in specific areas. The overall leak detection program took a more defined shape and it became clear that proper professional training and standardized data collection would be key to its success. The lessons learned in the first year of focused leak detection activities will benefit all future work in this regard.

Utilizing Sewer Flow Monitoring and Depth Sensors in a Mid-Size Utility

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ABSTRACT

The Western Virginia Water Authority is a mid-sized utility located in Southwest Virginia providing water and sewer service to approximately 250,000 people. Similar to most municipalities in the mid-Atlantic region, the Authority's sewer system experiences wet weather overflows due to inflow and infiltration. Multiple sewer flow meters were installed capturing flow from large sewersheds. When it was realized that the resultant data did not provide much value, the sewersheds were broken into smaller zones called sewer metering areas (SMAs) in 2012. The SMAs were prioritized for metering based upon the normalized quantity of wet weather overflows. Due to the difference between summer and winter flows, the meters were only installed for six months between October and April. Additionally, the Authority experimented with sewer depth and temperature sensors for early warning of surcharging at siphon manholes and known overflow locations. This in turn revealed surprising results to better plan our reactive and additional investigative efforts. With six years of metering data, this paper will examine the prioritization methodology, the purpose and use of the data for hydraulic model calibration, capital improvement planning, and additional unexpected characteristics of the SMAs revealed by the data. The lessons learned along with the challenges and realities of the hardware and analysis in addition to the results will be discussed in detail.

INTRODUCTION

The Western Virginia Water Authority was formed from the amalgamation of the water and sewer departments from the City and County of Roanoke in 2004. The majority of their system maintenance activities, investigations and repairs are done in-house and spread among four divisions, Sanitary Sewer Evaluation and Rehabilitation (SSER), Field Operations, Water Operations and Engineering.

Similar to most municipalities in the Mid-Atlantic region, the Authority's sewer system experiences wet weather overflows due to inflow and infiltration. There were known problem areas that had been identified by the staff from the City and County. During wet weather events, staff would visit the locations to record overflows and to cordon off the area if necessary.

ORIGINAL SEWERSHEDS

In the early years of the Authority, multiple sewer flow meters were installed capturing flow from large sewersheds. The upstream mileage of these sewersheds varied from 15 miles to 82 miles. The sewersheds are shown in Fig. 1.

The metering company provided monthly data to the Authority along with an annual report identifying the worst sewersheds. It was found that the same offenders were identified every year. This practice occurred each year for five years. When this author began work at the Authority in 2008 and began to build a sewer hydraulic model, it was found that the available flow data was not very useful for model calibration. The WAPUG manual recommends a maximum upstream mileage of two miles for accurate model calibration. With approximately

1,000 miles of mainline pipes, this would require 500 flow meters. That was an expensive proposition. It was decided to settle instead on an optimum upstream mileage of four miles.

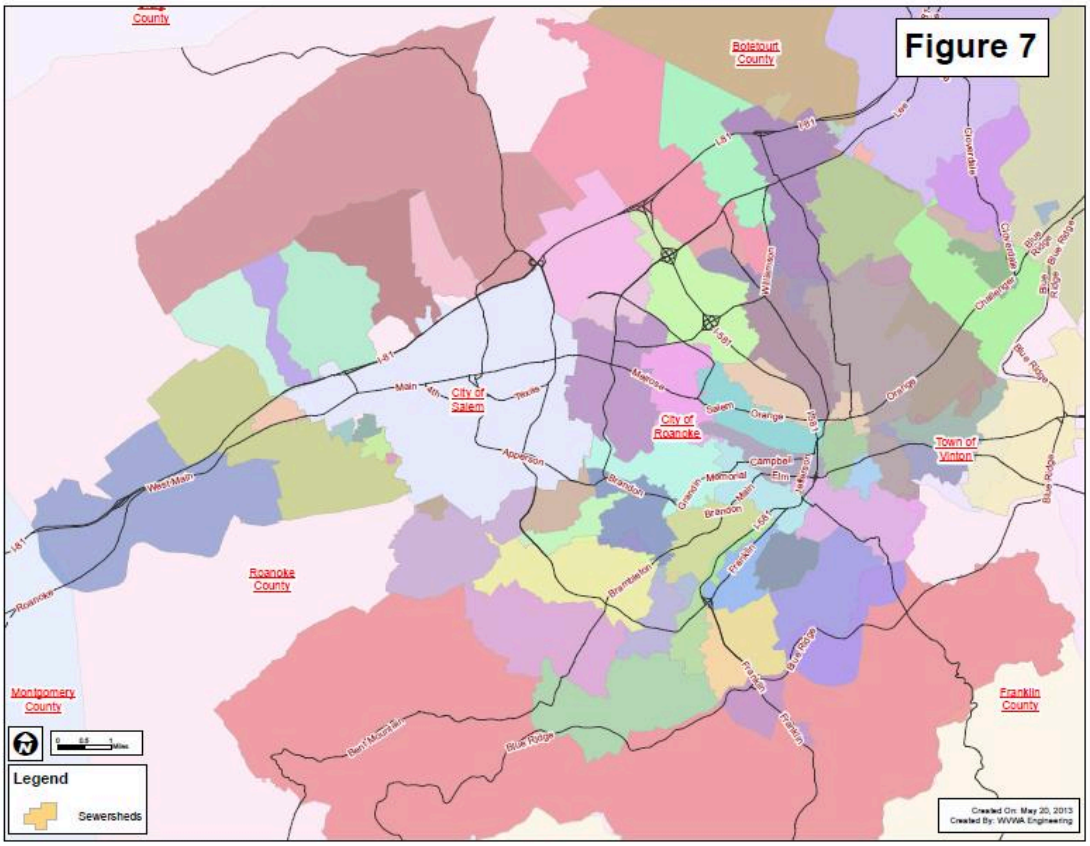


Fig. 1 – Original Sewersheds (from WVWA Engineering)

SOFTWARE

The Authority uses an asset management software (AMS) since 2009 for mapping and for Computerized Maintenance Management System (CMMS) purposes for both their water and sewer assets. In addition to having standard sewer mapping assets such as pipes, manholes and valves etc., the software also has all standard inspections such as CCTV, acoustic and manhole surveys; incidents such as blockage, flooding and odor incidents; and interventions such as pipe repairs, pipe cleans and manhole repairs. In addition to the asset management software, the Authority uses an integrated catchment model for sewer hydraulic modeling.

SEWER METERING AREAS

When it was realized that the resultant flow metering data did not provide much value, the sewersheds were broken into smaller zones called Sewer Metering Areas (SMA’s) in 2012. This was a relatively straightforward process. As AMS is by default a geometric network, a simple query was run to calculate the upstream mileage on every pipe. The pipes were color coded or themed by upstream mileage with mileages between four- and five-miles colored light green. When viewed, it was easy to identify the starting point of the DMA’s. An upstream trace was run on each light green pipe at a logical metering location to highlight the contributing pipes and a polygon was drawn around the highlighted pipes thus creating the SMA. This SMA was given the same name as the furthest downstream node in the polygon. An example of this is shown in Fig. 2. The SMA polygon is themed with a light brown color.

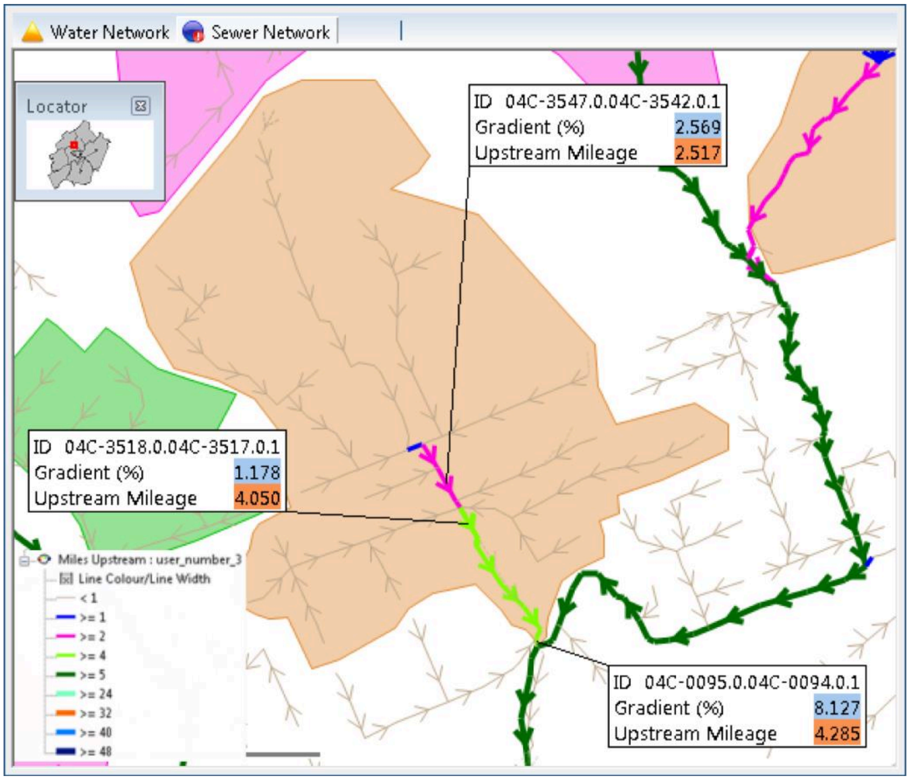


Fig. 2 – Sewer Metered Area Example

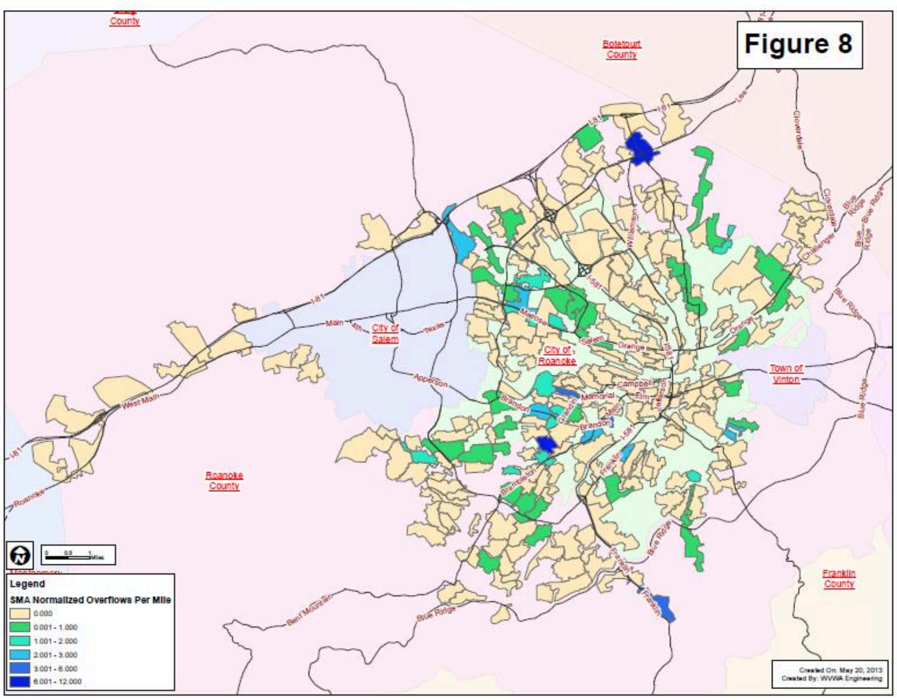


Fig. 3 – Resultant Sewer Metering Areas (SMA's) (from WVWA Engineering)

This process was repeated for all upstream mileages between three and four miles and continued for remaining smaller areas until we had SMA's ranging in size from one to five miles. We had to go over four miles in some cases for the sake of practicality. We currently have 257 SMA's as shown in Fig. 3. Within AMS, the number of incidents, repairs and surveys etc. were assigned to each individual SMA. We determined that we should rank the SMA's based upon Wet Weather Overflows. We normalized the Wet Weather Overflows per mile of Upstream Mileage by dividing the No. of Wet Weather Overflows by the Upstream Mileage. In order to choose the most likely candidate for flow monitoring, we simply sorted descending on this field.

USE OF SMA'S

As we had prioritized SMA's by the number of wet weather overflows, we used this to choose locations for flow metering. SMA's with a high number of overflows were immediately obvious candidates for flow monitoring. Those that had no overflows would not have been good candidates as clearly, they would be less likely to have hydraulic issues due to infiltration and inflow.

For the worst SMA's with multiple overflows, extensive inspection was undertaken to identify sources of I/I. CCTV inspection was done to detect storm connections. Manhole inspections were done to identify vented lids and brick manholes.

Earlier flow meter results revealed that runoff from a winter storm was found to be approximately two to two and a half times that of a summer storm. As a result, flow meters were installed from October to April each year instead of year-round.

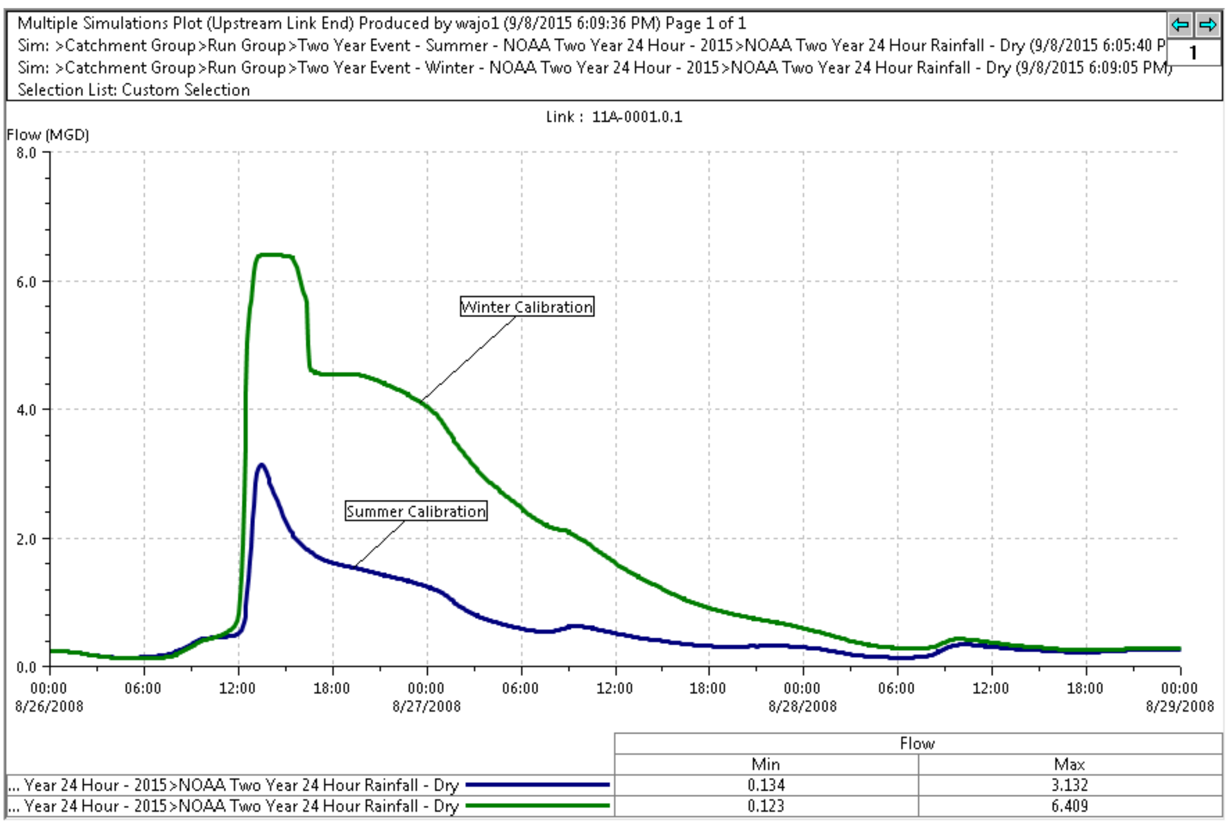
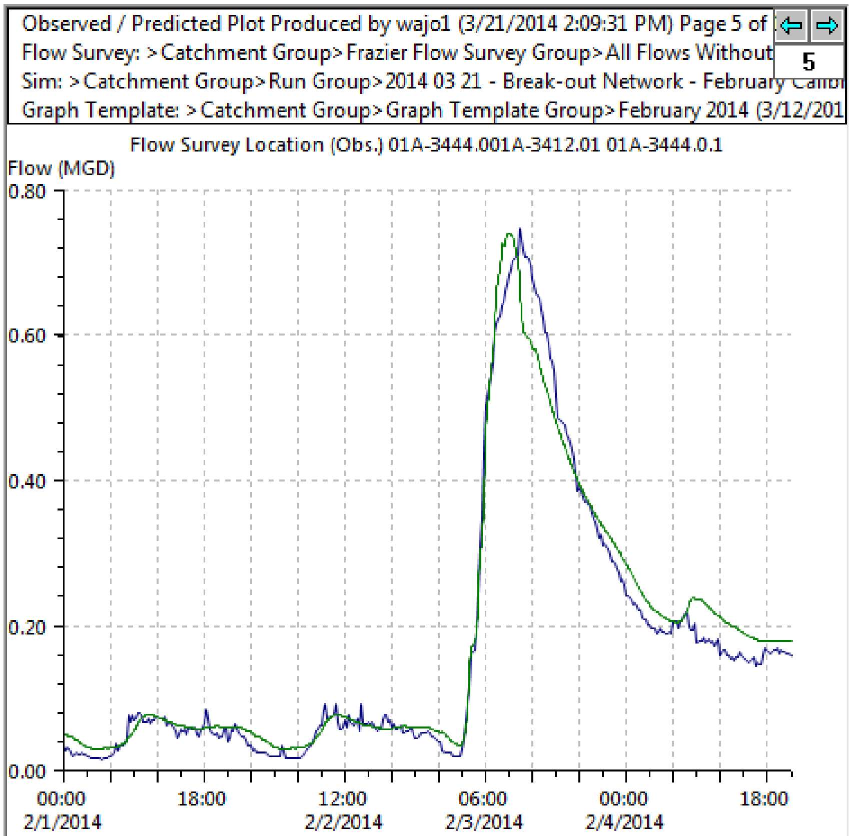


Fig. 4 – Flow Meter Calibration – Winter vs. Summer – Two Year Event

Following a number of storms, the flow data was used for hydraulic model calibration and verification, an example of which is shown in Fig. 5. Even without a hydraulic model, one can simply calculate the capacity of pipe immediately upstream and downstream of the flow meter and compare it to the peak flow observed during the storm event.



	Flow (MGD)		
	Min	Max	Volume (US Mgal)
Obs.	0.016	0.747	0.664
... Gauges - February 2014	0.030	0.741	0.691

Fig. 5 – Flow Meter Calibration

As one of the primary objectives of flow monitoring and hydraulic modeling was to mitigate wet weather overflows, the model was used to identify the appropriate pipe size to convey the flow and eliminate wet weather overflows. This in turn became an essential element in the Authority's Capital Improvement Planning program.

At the time of writing, flow monitors have been installed in over sixty SMA's. The worst SMA's with multiple overflows have all been monitored. Flow meters were installed in SMA's that contributed to pipes downstream that had overflows. The dry weather to peak weather flow ratio was calculated for each SMA. Some SMA's didn't have overflows themselves due in part to the rolling topography that provided sufficient steep pipe slopes which naturally would have increased pipe capacity. What was notable was that the ratio of dry to peak flow was over 20 in some of these SMA's.

This gave inspection personnel a new focus. With capital plans in place to mitigate wet weather overflows by conveyance projects, the SMA's with the highest dry to peak flow ratios