Annual Inflow and Infiltration Mitigation Planning Keeps the City of Altamonte Springs Poised to Handle Storm Events

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The City of Altamonte Springs (city) owns and operates a 12-mil-gal-per-day (mgd) regional water reclamation facility (WRF), shown in Figure 1, that treats and reclaims municipal wastewater for the city and several adjacent communities.

The city is an innovative water utility leader, from Project APRICOT (A Prototype Realistic Innovative Community of Today) in the 1980s developing a citywide reuse system, to the 2017 PureALTA project, which is a model for converting reclaimed water to potable water without reverse osmosis (RO) and is setting the standard for future water resource management.

In a similar vein, this project is a proactive effort to help renew private and public wastewater infrastructure by prioritizing and coordinating construction efforts with other city programs. This project is specifically focused on reducing rain and groundwater from entering the city's wastewater system as inflow and infiltration (I&I), maintaining the city's capacity during storm events, and minimizing/eliminating wastewater overflows.

The I&I contributions to the city's wastewater collection system during the high rainfall season create significant additional flow that consumes available capacity at the city's WRF. More importantly, inflow contributions from large rainfall events have historically stressed the capacity of wastewater collection infrastructure for short periods of time. The unwanted I&I contributions incur increased annual operating expenses and potential discharges of highly treated effluent to the Little Wekiva River during major storm events.

The city's approach to addressing I&I issues is to evaluate, prioritize, and mitigate I&I within the wastewater collection system, while dovetailing with other city efforts, including neighborhood restoration initiatives.

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Figure 1. Altamonte Springs Regional Water Reclamation Facility

In prioritizing specific I&I projects, the city considered wastewater collection system infrastructure near the end of its useful life or in need of upgrade/improvement. A large portion of the city's gravity piping is made of vitrified clay, which is now nearing the end of its life. Replacement or structural lining of the clay gravity pipe will accomplish both infrastructure renewal and I&I reduction objectives. Other key collection system components include manhole structures and customer lateral lines.

Wastewater pump station repair/replacements are addressed by a different city program that also focuses on priority stations. The city uses investigations, including pump station run times, rainfall data, closed-circuit television (CCTV), smoke testing (defined later), and visual inspections, to prioritize I&I hotspots. The data analysis identifies the type of I&I and quantifies pump station basin I&I to determine the best mitigation solutions. Once the high-priority areas are determined, continuing contractors or other city construction initiatives are utilized to make necessary improvements.

This article presents the data analysis and fieldwork performed for I&I mitigation that could be useful to other utilities addressing the issue.

Background

The city's wastewater collection and transmission system (Figure 2) consists of nearly 150 mi of gravity sewer pipe, 72 active pump stations, over 3,600 manholes spread out over approximately 11 sq mi (28 sq mi, including wholesale sewer customers), and its 12-mgd WRF. With such a significant coverage area and potential for I&I, the city decided to act decisively in reducing its immediate I&I issues, as well as proactively planning to minimize future I&I with a more structured I&I mitigation program (program).

The city first needed to enhance its annual I&I budget in order to perform the more-structured and robust tasks associated with the I&I program. Costs for field work, pipe lining, engineering support, and infrastructure renewal were analyzed and compared to the cost of reactive emergency repairs, operating costs, Florida Department of Environmental Protection (FDEP) compliance regulatory costs, and costs associated with progress reporting, as well as previously established funds for sewer system repairs. Once the cost analysis was performed, the city allocated additional funding for the program.

The city and Reiss Engineering worked together to restructure the existing I&I program and establish a new base I&I program, which would regularly monitor the I&I data over a period of years and after major storm events. In addition to data analysis, field work would also be performed to further identify I&I contributions and a plan would be established annually to reduce I&I.

The program needed to be robust and rigid in mitigating I&I issues found within the system, yet flexible enough to be reviewed and updated annually based on new information found throughout the year.

Objective

The city's goals for the program were to reduce operating costs, as well as significantly minimize the potential of overflows through aggressive I&I mitigation measures. One of the key components of the program is annual updates to I&I mitigation strategies and periodic performance assessments. The annual updates to the program use engineering analyses to identify "priority areas" within the collection systems that are vulnerable to I&I. Engineering analyses include gravity piping condition assessments, groundwater-level comparisons to gravity sewer pipe elevations, and pump station operation comparisons during dry periods and rainfall events. The program developed strategic actions to cost-effectively reduce I&I in the prioritized areas.

Strategic actions involve investigative field work to identify and quantify I&I and corrective measures to reduce it. The investigative field work includes in-house CCTV inspection of sanitary sewer lines, smoke testing, and flow monitoring targeted by the engineering analyses to identify specific sources of I&I more efficiently. The corrective measures to reduce I&I are both preventative and restorative, such as gravity sewer lining, gravity sewer point repairs, installation of manhole caps, cleanout repair,

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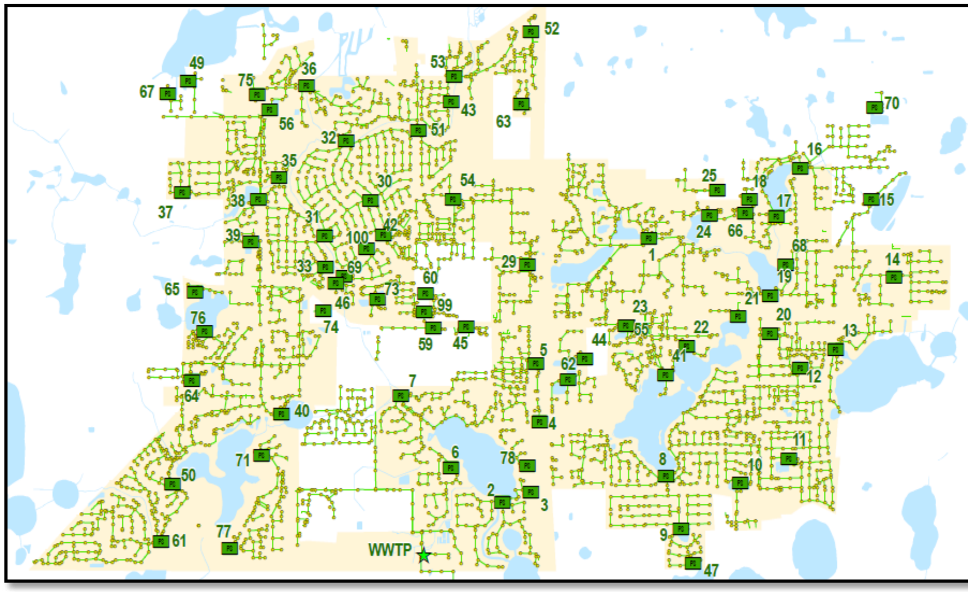

Figure 2. Altamonte Springs Collection and Transmission System

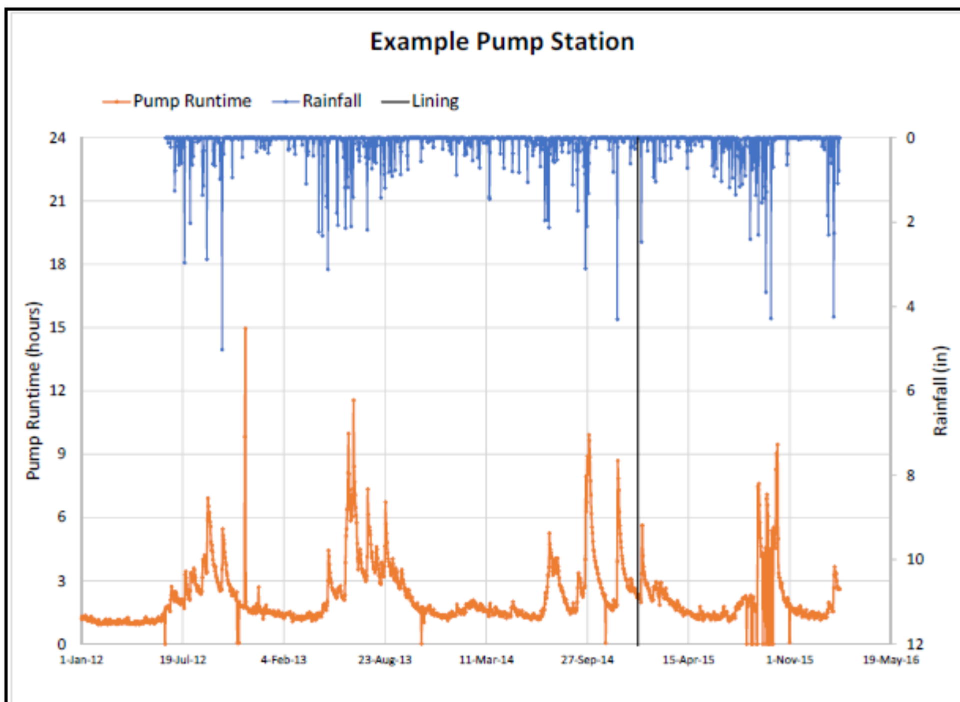

Figure 3. Example of Pump Run Time Versus Rainfall

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and notification to residents with damaged sewer components on private property. As I&I mitigation is an ongoing effort, the program is periodically evaluated for effectiveness based on wet weather flows and pump station operations, and adjusted accordingly.

Besides reducing I&I, the city wanted a more-structured way to breathe new life into its aging infrastructure and effectively deploy staff and resources to the sewer system. Some utilities may invest in I&I mitigation without clearly establishing a solid basis on how to deploy their resources in the most cost-effective manner. The city wanted to ensure that its annual I&I budget was used efficiently to keep costs down and effectively treat I&I.

Methodology

To develop the program, five years of supervisory control and data acquisition (SCADA) data, pump station run times, and CCTV inspections were reviewed. Current rainfall data were also collected using the city's local rainfall gauges. Next-generation radar (NexRAD) was provided by St. Johns River Water Management District (SJRWMD), and the National Oceanic and Atmospheric Administration (NOAA).

From the data, the following steps were performed to develop an I&I mitigation program:

- Correlate pump run times with rainfall.
- Determine a priority ranking based on strong or weak correlation between pump run time and rainfall. This priority ranking is established to determine which sub-basins should be prioritized for I&I mitigation.
- Perform CCTV inspections to qualify and quantify pipe defects in high-priority sub-basins.
- Determine a priority ranking based on type of defects and location of the pipes.
- In situations where CCTV cannot be performed in high-priority basins, smoke testing is performed.
- Based on smoke testing results, a priority ranking is established among the pipes tested in the high-priority areas.
- Evaluate the different alternatives to mitigate I&I on high-priority pipes, such as pipe lining, repair, or replacement.
- Hire a contractor to perform the work.
- Evaluate the data on an annual basis and adjust the program as necessary.

The next section presents in detail the different data analysis steps and results obtained for the city.

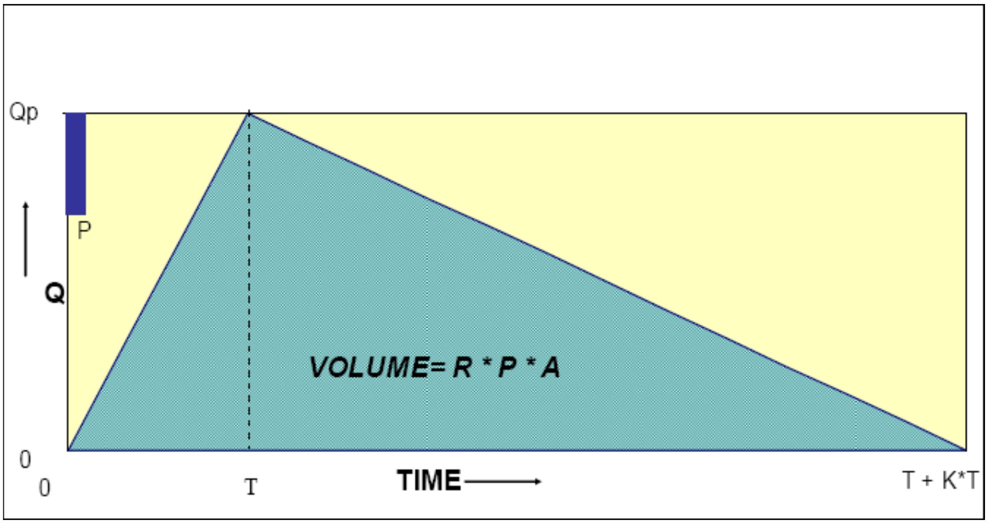

Figure 4. Triangular Unit Hydrograph

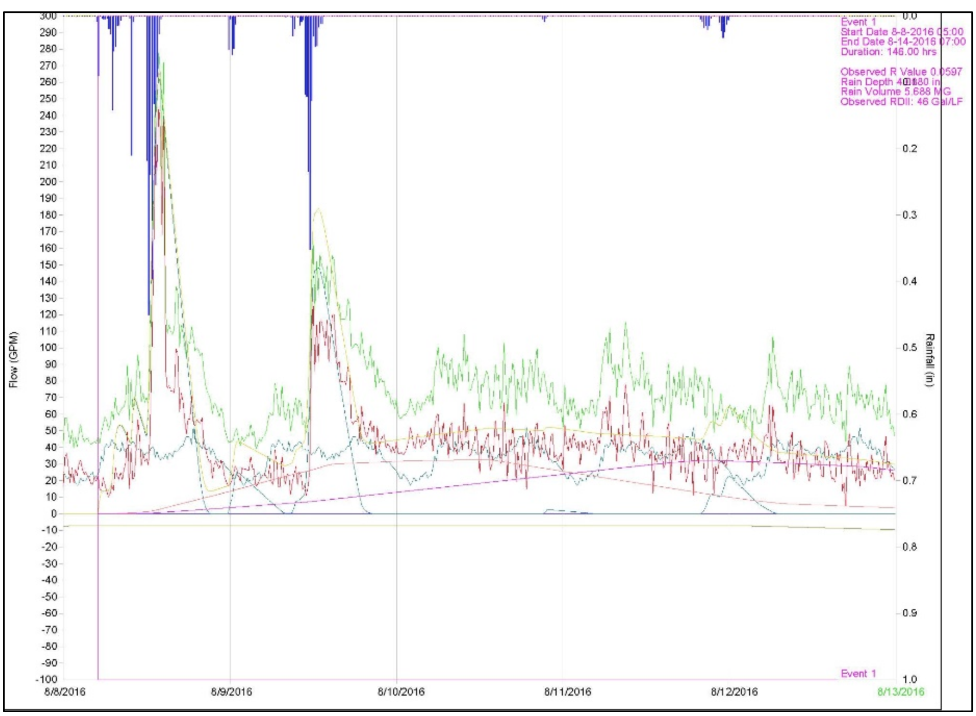

Figure 5. Unit Hydrograph Example

Data Analysis Results

Pump station pump run times were compared with rainfall data from the closest rainfall gauge to establish correlations, or lack thereof. Two separate methods were used to analyze the data to improve accuracy. The Q-versus-I method was used by graphically plotting pump station run time data versus rainfall data for the same period of time (Q) and comparing peaks in run times to peaks in rainfall (I), as presented in Figure 3. This example shows that the pump run times increased following a major rainfall, compared to run times during a relatively dry period.

Rainfall data were also examined using the U.S. Environmental Protection Agency (EPA) sanitary sewer overflow analysis and planning (SSOAP) toolbox. This toolbox uses the RTK method to derive the sanitary sewer system rainfall-derived inflow and infiltration

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Table 1. Pump Station Area Priority Level

Pump Station #	Average Hours/day Operated	Hours/in of rain
1	5.8	5.4
2	3.3	4.1
3	2.8	3.5
6	4.0	3.7
7	3.7	3.2
8	11.1	12.0
10	3.3	4.4
11	7.1	10.7
12	7.8	10.7
13	4.5	3.6
14	2.7	3.4
15	1.3	5.4
16	2.9	4.5
17	3.8	5.4
32	3.0	1.6
54	5.7	4.9

Table 2. Quantified Pipeline Defects by Pipe Segment

PS Area	MH Number	Length (ft)	Total Defects	Root	Crack	Joint	Deposits	Lateral
2	02-01-05	216	4	0	4	0	0	0
2	02-01-05	288	4	0	4	0	0	0
2	02-01-06	265	4	0	4	0	0	0
2	02-01-08	353	4	0	1	3	0	0
2	02-01-10	318	4	0	0	4	0	0
2	02-01-11	283	12	0	6	6	0	0
2	02-01-11	319	1	0	1	0	0	0
2	02-01-13	131	4	0	4	0	0	0
2	02-01-19	143	1	1	0	0	0	0
2	02-02-02	274	4	0	3	0	1	0
2	02-02-03	234	7	3	4	0	0	0
2	02-02-03	332	14	2	11	0	1	0
2	02-02-03	123	1	0	1	0	0	0
2	02-06-01	178	3	0	2	1	0	0
2	02-08-02	332	10	0	10	0	0	0
2	02-08-03	187	1	0	1	0	0	0
5	05-01-01	134	5	0	0	0	0	5
5	05-01-02	38	4	2	1	0	0	1
5	05-01-04	90	1	1	0	0	0	0

PS: pump station; MH: manhole

Table 3. Pipe Defect Point Values

Pipe Defect Type	Point Value
Deposits	N/A
Leaking Laterals and Root Infiltration	1.25
Cracks and Separated Joint	1.50

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(RDII) response using the associated rainfall and flow monitoring data. The RTK method compares the fraction of rainfall volume that enters the sewer system and equals the volume under the hydrograph (R), time from the onset of rainfall to the peak of the unit hydrograph (T), and the ratio of time to recession of the unit hydrograph to the time to peak (K). The RTK method also compares rainfall data to flow that comes from the pump station, but also considers the sub-basin area to establish unit I&I generation factors within each basin.

The following is an excerpt from the SSOAP toolbox manual:

> "The RDII unit hydrograph method is similar to the Q versus I method in that it compares rainfall data to lift station run times. This method also takes into account the area of the sub-basin and estimates the amount of I&I that enters the sub-basin and how much of that flow is seen as inflow versus infiltration. The three primary factors looked at (inflow, infiltration, and volume entering the basin) are assigned values R, T, and K parameters (RTK method) and are estimated using a hydrograph combining all three parameters."

Figure 4 depicts the triangular unit hydrograph in response to one unit of rainfall over one unit of time.

The unit hydrograph is described by the following parameters:

- R: The fraction of rainfall volume that enters the sewer system and equals the volume under the hydrograph.
- T: The time from the onset of rainfall to the peak of the unit hydrograph in hours.
- K: The ratio of time to recession of the unit hydrograph to the time to peak.
- A: The sub-basin area.
- P: Rainfall depth over one unit of time.
- Volume: Volume of RDII in unit hydrograph.
- Qp: Peak flow of unit hydrograph.

Figure 5 shows an example of one of the unit hydrographs.

Prioritizing the pump station sub-basins for repair or further investigation was then performed. By setting a priority to each of the sub-basins, a work plan could then be developed to establish regions within each sub-basin (or even an entire sub-basin) to ensure that areas with highest I&I contributions were corrected first. Areas were given priority numbers based on the rainfall and pump run time correlation, as well as pipe defects.

Pump run times versus rainfall correlation was first prioritized. A priority 1 through 4 scale was used, with priority 1 being the highest I&I priority. The correlation between pump run time and rainfall was established by calculating the number of hours the pumps were operated by in. of rain after subtracting the estimated baseline flow; therefore, the higher the run time per in. of rain, the more impact the I&I has on the pump station.

- Priority 1: Pump station with a run time above five hours per in. of rain (significant correlation with rainfall).
- Priority 2: Pump station with a run time between three and five hours per in. of rain (some correlation to rainfall).
- Priority 3: Pump station with a run time between one-and-a-half and three hours per in. of rain (less correlation with rainfall).
- Priority 4: Pump station with a run time less than one-and-a-half hours per in. of rain (no clear correlation with rainfall).

Table 1 presents an example of the priority levels for each pump station area.

Once priorities were established for each sub-basin, the pipelines themselves were then prioritized. The CCTV inspection footage was reviewed, which allowed for the visual inspection and identification of damage within the gravity sewer network. Defective sections of the pipe, such as root infiltration, cracks, joint separation, deposits, and damaged service laterals were identified. The damage type was noted and quantified for each pipe segment individually and summed for each pump station basin. Table 2 shows an example of pipeline defects.

Prioritization was then established based on the CCTV footage evaluation. The number of defects per pipe segment, the type of defect, the estimated relative amount of I&I associated with the specific defect, and the pipe proximity to groundwater/surface water were considered in the prioritization. For example, pipe segments with visible large cracks and separated joints could result in the most I&I, whereas leaking laterals and root infiltration would generate slightly less I&I and deposits (areas with slow leaks that build up minerals) and would yield no significant amount of I&I.

Point values were assigned to each defect based on the potential for I&I, as seen in Table 3. These values were then multiplied by the number of defects per pipe segment, with an additional 1.5 multiplier added to pipe segments near large bodies of water, high groundwater tables, and surface water bodies. The final values were then tabulated and placed into one of the four priorities. Deposits were not initially counted within the prioritization as the produced minimal inflow. Additionally, defects that showed substantial inflow upon visual inspection were automatically classified as priority 1.

- Priority 1: Pipe segments with point values greater than 7.
- Priority 2: Pipe segments with point values between 5 and 7.
- Priority 3: Pipe segments with point values between 2 and 5.
- Priority 4: Pipe segments with point values less than 2.

Priority maps for the pipe segments were then created for a visual representation of the priority areas, both for areas to be smoke-tested and the areas to be lined in cured-in-place pipe (CIPP). Work orders were then created based on the prioritization for smoke testing, flow monitoring, and CIPP lining, as well as additional visual checks, such as field assessment and CCTV inspection. Figure 6 shows an example of the prioritization map.

Smoke testing is a method to detect defects in pipes, pump stations, and laterals that could result in I&I. It consists of blowing a nontoxic smoke into a gravity sewer system. The smoke travels through the pipe under very low pressure and escapes through any opening in the line. These openings can be broken or open cleanouts, stormwater cross connections, damage manhole structures, or any number of defects in the pipeline. The smoke testing performed included fixing cleanout-related defects and other defects not requiring significant excavation, and creating work orders for defects requiring significant excavations/repairs.

Select pump station sub-basins were

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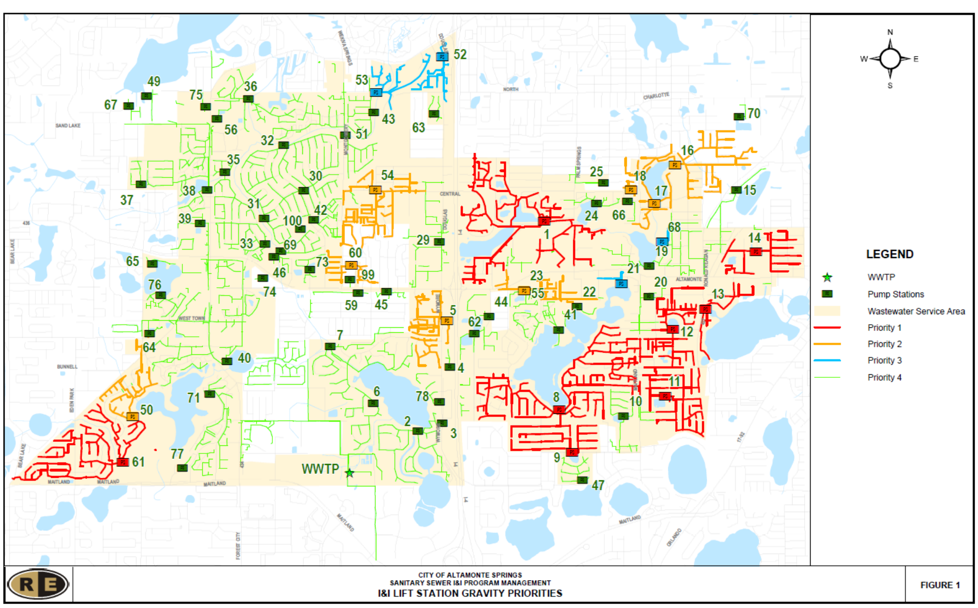

Figure 6. Pipeline Prioritization Map

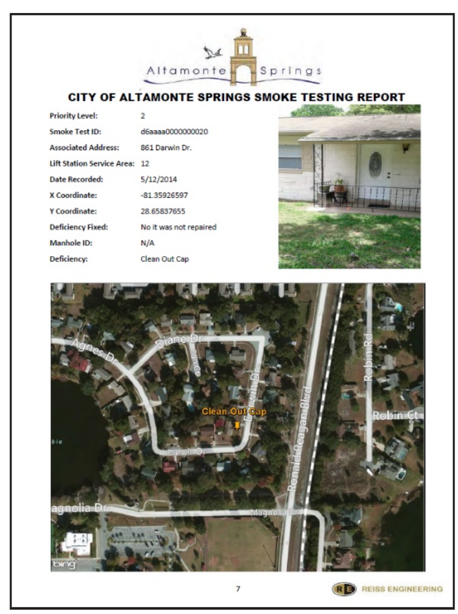

Figure 7. Smoke Testing Report Example Page

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smoke-tested based on the pump stations priority level. During the smoke testing, a field crew walked the pipeline being tested to look for smoke escaping the gravity sewer system. Each location where smoke was seen was noted using a global positioning system (GPS) mapping tool. The tool records the following attributes, as entered by the field crew:

- GPS X and Y coordinates
- Associated address
- Date recorded
- Type of deficiency
- The pump station sub-basin
- A priority level of 1 through 3 for repair
- Whether the defect was immediately repaired

The defects identified were also assigned a priority rating based on the estimated levels of I&I contribution as follows:

- Priority 1: Significant I&I contributions and requires immediate attention.
- Priority 2: Moderate I&I contributions and should be scheduled for repair and/or replacement as soon as possible.
- Priority 3: Low I&I contribution and should be scheduled for repair and/or replacement when resources are available.

The priority 1 defects were a mix of missing/damaged cleanout caps in low-lying areas or regions where direct water flow could take place, with damaged manhole structures, damaged laterals, and potential line blockages. The priority 2 defects included missing/damaged cleanout caps outside of low-lying areas, manhole lids with significant smoke emergence and/or in low-lying areas, and smoke rising from the ground without an identifiable source. Priority 3 defects consisted primarily of manholes with small smoke emergence and cleanouts not expected to receive drainage.

A report was generated for any defect that could not be repaired after testing. The report was used to then create new work orders to repair the pipe defect which, in turn, minimizes the locations in which rainfall can enter the sewer system. Figure 7 displays an example page from the smoke testing report.

Inflow and Infiltration Mitigation Alternatives

Lining of defective pipes can be a valuable alternative to minimize I&I, as well as expanding life expectancy of gravity sewer infrastructure using an economically effective approach. The CIPP lining utilizes a specifically sized sleeve covered in resin, which is inserted into a pipeline. The sleeve is then inflated via water or air pressure, and the resin is then cured using heat. Once the resin sets the sleeve, it's then structurally sound and has lined the interior of the pipe, thus covering pipe defects and reducing I&I.

During a period of time, several thousands of ft of gravity pipes were lined to reduce the I&I and renew aging infrastructure in the PS#11, PS#12, PS#13, and PS#14 areas. To help evaluate the effectiveness of the pipe lining, pump station run times were provided by the city from early 2012 to early 2016. For the pump station service areas that were recently lined, the data indicates that I&I is still occurring; however, the pump run time analysis shows that the run times were significantly reduced following the lining and smoke testing efforts.

During dry periods, the pump run time was estimated to establish a baseline, and then the pump run time over the baseline was assumed to be due to I&I; it was then normalized per in. of rain. As shown in Table 4, the run time per in. of rain was reduced to a range of 35 to 73 percent, depending on pump station.

This analysis suggests that the gravity pipe lining is having a positive impact on I&I, while some I&I is still occurring in the unlined pipes in these pump station areas, as well as in manholes and service laterals.

Table 4. Pump Run Time Comparison: Pre- and Post-Pipe Lining

	PS#11	PS#12	PS#13	PS#14
Start day for lining work	8/28/2014	1/15/2015	11/19/2014	1/5/2015
End day for lining work	9/25/2014	2/16/2015	12/15/2014	1/22/2015
Days (of data) before lining work	970	944	887	934
Days (of data) after lining work	501	357	420	382
Rain (in.) before lining work	126	139	130	136
Rain (in.) after lining work	114	62	69	65
Run time (hours/day) during dry periods (baseline)	5.0	5.0	2.5	1.5
Run time (hours) of pumps prior to lining	6,938	7,400	3,969	2,519
Baseline run time (hours)	4,850	4,720	2,218	1,401
Run time (hours) due to I&I	2,088	2,680	1,751	1,118
Run time (hours/in.) due to I&I prior to lining	16.57	19.32	13.49	8.21
Run time (hours) of pumps after lining	3,732	2,453	1,298	791
Baseline run time (hours)	2,505	1,785	1,050	573
Run time (hours) due to I&I	1,227	668	248	218
Run time (hours/in.) due to I&I after lining	10.74	10.76	3.61	3.39
Decrease in pump run time	35%	44%	73%	59%

Neighborhood Enhancement Program

The city has an ongoing neighborhood enhancement program to replace streets, sidewalks, and landscaping to help sustain a neighborhood's value and customer approval. Prioritized areas that were inside planned neighborhood enhancement areas were included in these projects to increase program efficiency and minimize cost and customer disruptions. Project components included gravity sewer and service laterals, pump station replacement/rehabilitations, and neighborhood drainage improvements.

Conclusions

The city's mitigation program is an example of a structured, pro-active, efficient, and cost-effective way to address I&I issues. Data compilation/review/analysis and strategic planning efficiently identify I&I budget requirements and opportunities to dovetail with other city programs. The creation of work plans based on I&I prioritization focuses on collection basins that will provide the most benefit to the city. Field data analysis before and after I&I mitigation efforts confirmed that targeted lining can significantly reduce I&I.

The city demonstrated that regular review of new data, CCTV inspections, smoke testing, and field inspections, and following through on needed repairs and annual workplan updates, is an effective program for mitigating a utility's I&I.