

# Water Quality Modeling Targets and Innovative Nitrification Strategies for City of St. Petersburg

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The City of St. Petersburg (City), like almost all other chloramine disinfectant water systems in Florida, faces the challenge of controlling nitrification in its distribution system during warmer months. The City feels that the negative customer service issues associated with standard nitrification control (free chlorine burns) outweighs its consideration as a nitrification mitigation tool. Therefore, the City needed an “outside the box” approach to meet this challenge.

The City selected water quality modeling to test innovative strategies to help control nitrification and accomplish the following objectives:

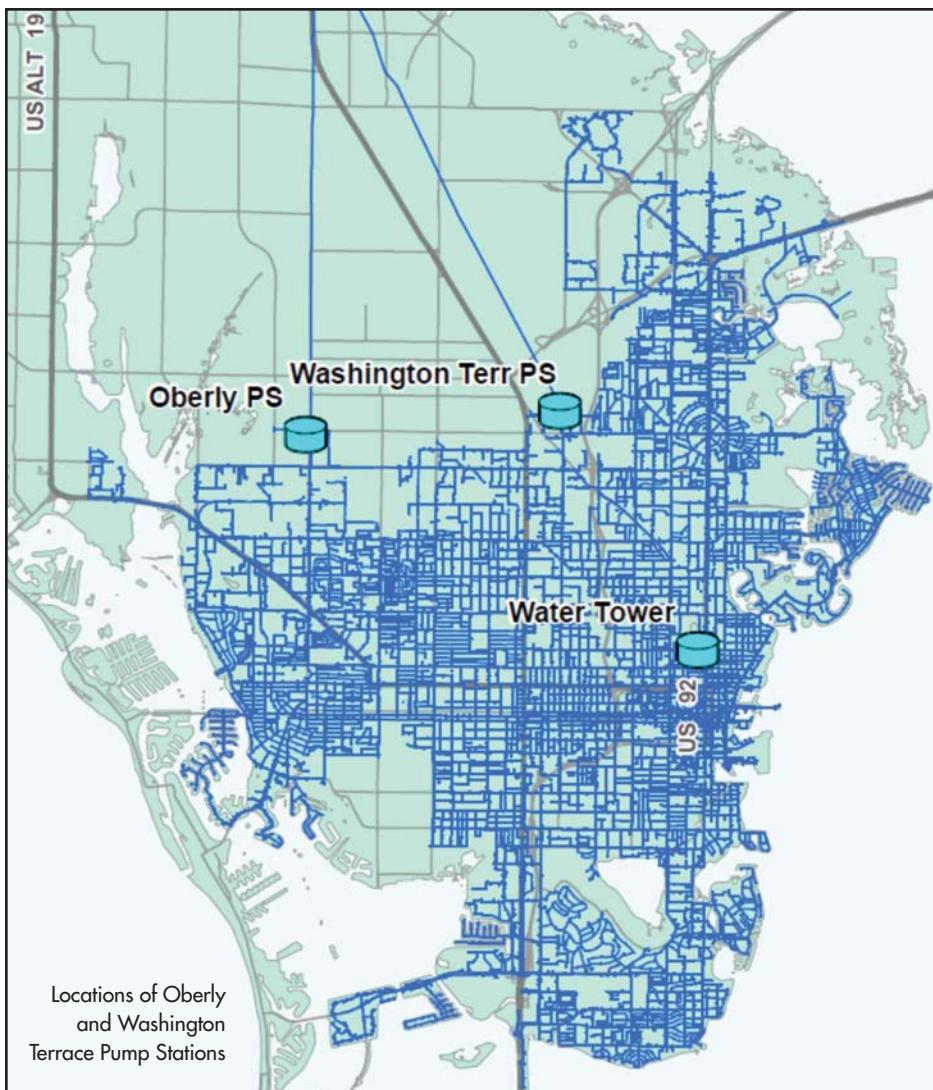
- ◆ Improve disinfectant residuals in the south end of its distribution system.
- ◆ Reduce operational flushing volumes.
- ◆ Reduce customer complaints associated with flushing.

A 98,000-pipe water quality model was developed and field-calibrated to assist the City. Extensive literature was reviewed to summarize nitrification conclusions from Tampa Bay Water’s historical research. Nitrification control strategies were tested with the water quality model to predict effectiveness. Innovative strategies, including conversion of reclaimed irrigation demand to potable water, auto flusher water reclamation, abandonment of water mains, thermo cooling stations, and enhanced unidirectional flushing, were considered. Based on the water quality modeling and operational judgment from the City staff, a nitrification control plan was developed for implementation.

## Existing Conditions

The City’s Water Resources Department currently receives, treats, and distributes potable water at the Cosme Water Treatment Plant (WTP) located north of the city. Finished water from the Cosme WTP is pumped through two large transmission pipelines, a 22-mi, 36-in. transmission main and a 24-mi, 48-in. transmission main, for storage and re-pumping at two pump stations: Oberly and Washington Terrace. The two stations then deliver service pressure supply to customers via an extensive transmission and distribution system. Part of the distribution system includes the Crescent Lake Elevated Tank in the eastern part of the city that provides peak flows and pressure surge stability.

The Cosme WTP receives its source water from Tampa Bay Water (TBW). Source water blends vary during the year and can come from groundwater well fields, treated surface water, and seawater treated by reverse osmosis (RO).



Locations of Oberly and Washington Terrace Pump Stations

The City utilizes chloramines to disinfect the water and maintain a disinfectant residual in the distribution system. The City applies the chlorine and ammonia dosage at the Cosme WTP and does not currently boost chloramine residual in the distribution system. The City prefers to maintain the distribution system with chloramines and has not historically performed free chlorine “burns” for distribution water quality maintenance.

The City currently uses remote water quality monitoring stations, including 13 Hach APA 6000 units, located throughout the distribution system and at its two pump stations, to monitor distribution system water quality. The monitoring stations, also known as online analyzers, monitor temperature, monochloramine residuals, free ammonia, conductivity, dissolved oxygen, and pH. Water quality instruments at both pump stations monitor influent total chlorine residual and turbidity, effluent monochloramine residual, free ammonia, and turbidity.

### Concerns in the Existing Distribution System

The key issue that is currently facing the City is low chloramine residuals in the south and southwest portions of its distribution system. The low chloramine residuals cause the City to flush high volumes of potable water to keep residuals in desired ranges. The high flushing volumes have also resulted in a negative perception from the City’s customers.

In response to low chloramine residuals and low public approval of high flushing, the City contracted with Reiss Engineering Inc., as a subconsultant through George F. Young Inc., to optimize water distribution operations, maintenance, and flushing activities.

### Chloramine Residuals

Chloramine (a combination of chlorine and ammonia) is the current disinfection method being used in the City’s distribution system. The City maintains a chloramine residual above 5.5 mg/L at the point of entry (POE). The distribution system residuals have historically varied from approximately 6.0 to less than 0.6 mg/L. These historical distribution system chloramine residuals show a stable and high chloramine residual of approximately 4-5 mg/L for the period of January through April 2010. Chloramine residuals are significantly lower for the remaining eight months of the year, for many of the locations recorded.

Residuals drop rapidly in warmer months. This decline in chloramine residuals is consistent with the City’s objectives for the project, which include assessment of methods to ensure higher, more stable chloramine residuals.



One of 13 water quality monitoring stations.



Previous field flushing arrangement.

### Historic Flushing

The City currently flushes during weekdays at approximately 39 locations, with eight of them being auto-flushers, also known as Hydroguards™. Auto-flushers are used to reduce work hours and public disruption. Flushing is currently performed in the southside and southwest portions of the City’s distribution areas.

The City’s current method to maintain water quality and keep chloramine residuals within compliance limits requires the City to flush significant quantities of potable water. Potable supply water is purchased from Tampa Bay Water. These high flushing quantities reiterates the main goal of this project: reduce flushing, which will save money and minimize potable water use.

### Chloramine Decay Evaluation

Low chloramine residuals in water distribution systems can be caused by high water age, nitrification, tuberculation or sedimentation in pipes, corrosive water, specific source water conditions, or other specific conditions. Therefore, analysis of high water age, nitrification, pipe condition, corrosive water, and source water conditions was performed for this project using historical data, targeted field data collection, bulk chloramine decay tests, calibrated hydraulic model results, and potable water chemistry calculations. Chronic low chloramine conditions were correlated to the City of St. Petersburg water distribution system to identify the potential causes.

The City’s 98,000-pipe hydraulic model was water quality-enabled and calibrated to field-measured conditions using pump station SCADA data and targeted distribution chloramine sampling data. The model was upgraded with the following data:

- ◆ Latest GIS pipes and structure
- ◆ Cosme WTP water sources
- ◆ June 2010 demand customer points

- ◆ Topo files from Southwest Florida Water Management District (SWFWMD)
- ◆ Bulk chloramine decay coefficients
- ◆ Calibrated chloramine pipe wall decay coefficients
- ◆ Pipe connectivity geometric network check
- ◆ SCADA pump operation information for September 2010

Following calibration, including adding existing water flushing locations, the model indicated that water leaving the pump stations ranged from 50 to 70 hours, and maximum water ages in the south section of the distribution system ranged from 130 to 220 hours (five to nine days).

The City’s existing model calibration included bulk residual decay rate coefficient determination and entry as a model input. The hydraulic model was then used to simulate chloramine residuals with normal pipe wall decay coefficients, and then compared to actual targeted chloramine sampling results. The model, under normal pipe wall decay, predicts significantly higher chloramine residual than actually observed in the field, indicating that conditions within the distribution piping are causing accelerated chloramine residual decay. The model was also used to determine the feasibility of hydraulic improvements, including reducing pipe diameters, reducing no flow zones, and flushing optimization.

The chloramine decay evaluation also included evaluation of the Langelier Saturation Index (LSI) and the Calcium Carbonate Precipitation Potential (CCPP) on the finished waters leaving the pump stations for two different events. Both LSI and CCPP indexes were positive and were in desired or recommended ranges.

Nitrification was evaluated through historical field data, targeted field data, and remote water quality monitoring stations using APA 6000 on-line analyzers to analyze water quality parameters. The historical water quality monitor stations’ chloramine data also indicated that

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the summertime period has accelerated chloramine decay, while the wintertime experiences minimal chloramine decay, as shown in Figure 1.

After a review of historical data, targeted field data collection and analyses, bulk chloramine decay determination, calibration of the City's hydraulic model, and water chemistry review, it was concluded that nitrification was occurring and was the likely cause of low chloramine residuals in the south portion of the system as follows:

- Water age is not the cause of dramatic chloramine decay, as indicated in bulk decay chloramine residual at 37 days at 90°F and 93°F measured at 2.31 mg/L when the hydraulic model showed maximum water age of approximately nine days.
- Pipe condition is not the cause given internal reviews with City staff stating that pipes are relatively newer in the southside portions of the city.
- Corrosive pipes are not the cause, since both LSI and CCPP indexes were positive

for the pump stations, and as long as LSI and CCPP are in recommended ranges, the water entering the distribution system from Cosme WTP is not corrosive.

- Nitrification is the primary reason for chloramine decay, with nitrite being above the American Water Works Association (AWWA) recommendation of 0.05 mg/L and ammonia oxidizing bacteria (AOB) and nitrite oxidizing bacteria (NOB) occurring in the distribution system.

## Nitrification Mitigation Options

Nitrification has been identified to be the primary cause of the dramatic chloramine decay in the southside portion of the distribution system. Specified nitrification mitigation options available to the City were identified based on the water quality evaluation. Nitrification control begins with the removal and/or deactivation of nitrifying bacteria, and continues with a nitrification control operating procedure to minimize nitrification in the distribution system.

### Distribution System Hydraulics

Flushing at high velocities can temporarily control nitrification by removing the water, biofilm, and sediment containing nitrifying bacteria. Systematic flushing to reduce detention time is also a preventive measure. Flushing requires bringing unaffected water that has a high total chlorine residual (e.g., > 1.5 mg/L Cl<sub>2</sub>) and low nitrite/nitrate levels (< 0.010 mg/L N nitrite) into the affected area. Unidirectional flushing effectively accomplishes this and moves the affected water and sediment out of the system, rather than downstream to other areas where it can spread the problem. After the total chlorine residual increases, and nitrite-N level decreases below the alert level, flushing can be reduced or discontinued.

### Hydraulic Model Tool

The City's hydraulic model, as discussed, was upgraded to include water age and quality modeling capabilities. The upgraded model was compared with field-collected data to verify its predictive abilities. The verified model was then used to compare hydraulic strategies with the status quo and target levels of water quality in the distribution system. Once updated and verified, the model was a useful tool to analyze the movement of water in the distribution system and potential hydraulic improvements. The hydraulic improvements tested included location and optimization of flushing locations and elevated tank operation.

### Hydraulic Nitrification Mitigation Options

Longer water distribution residence times allow nitrifying bacteria to grow and metabo-

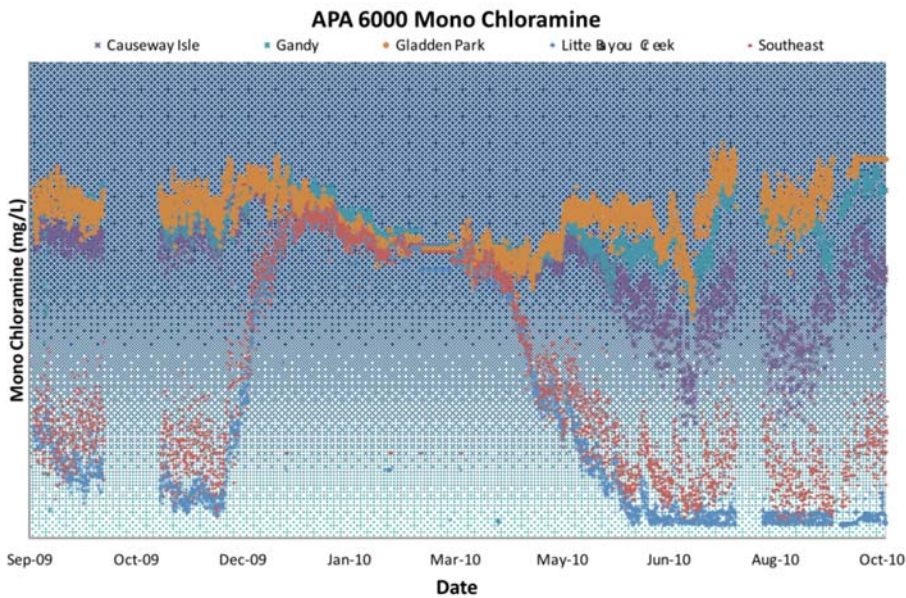


Figure 1. APA 6000 On-Line Analyzers – Remote Distribution Locations

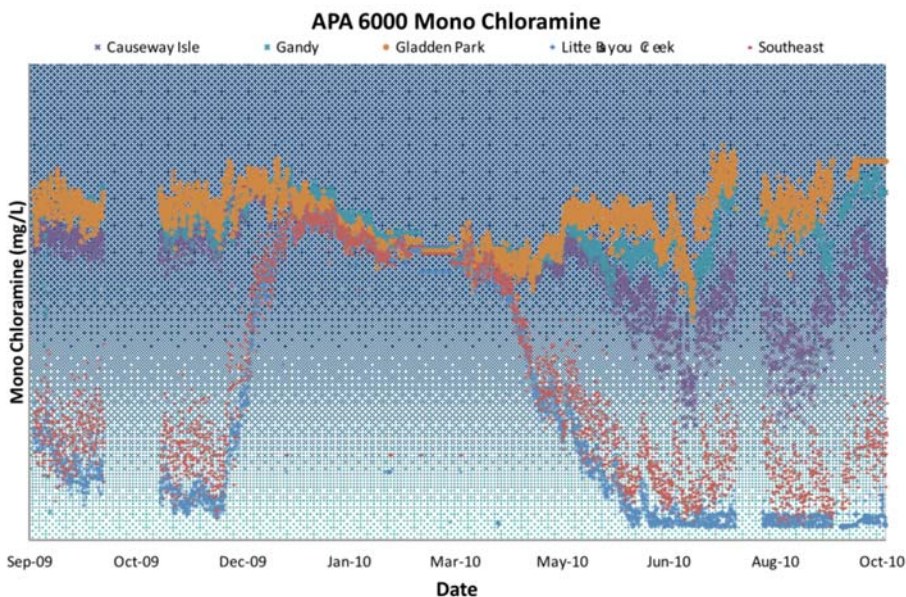


Figure 2. Water Age vs. Chloramine Residuals

lize. Adjustment of water storage operating levels, water demand, and pumping schedules may be necessary to minimize the water residence time or age.

To quantify possible nitrification water age reduction-related mitigation options for the City, its potable hydraulic model was calibrated with field chloramine data, field pressure data, and historical pressure data. Using the calibrated model, water age targets were set using a comparison of field chloramine residuals levels versus current water age from the City's hydraulic model as shown in Figure 2. Target water ages were set at 130 hours for the status quo system, and set at 178 hours for a cleaned pipe-distribution system (distribution system with nitrifying bacteria removed from the pipes). Because infeasible flushing quantities (>5.5 mgd) were required for the 130 hour target water ages, an intermediate target water age of 154 hours was developed to use as an intermediate step between status quo and a cleaned pipe distribution system. Hydraulic scenarios were then run in an attempt to achieve targeted water ages and determine optimized quantities of potable water that would need to be flushed to achieve those water ages, for various improvement alternatives as shown in Table 1.

Based on the hydraulic modeling, regular flushing rates in excess of 6 million gallons per

day (gpd) would be necessary to meet a targeted water age of 130 hours. The target water age of 130 hours was deemed infeasible based on the flushing volume, and an intermediate, more feasible target water age of 154 hours was utilized to bridge the span between status quo and a cleaned pipe distribution system. It should be noted that a water age reduction by itself will not control nitrification in areas experiencing nitrification unless coupled with a bacteria removal/deactivation option.

#### **Booster Station**

The possible addition of a new booster station in the southside portion of the City could give it the potential to increase low chlo-

ramine residuals, raise the low pH, trim elevated ammonia levels, and possibly even cool the water to reduce AOB and NOB.

#### **Temporary Change from Chloramine to Free Chlorine**

Temporarily changing the type of disinfectant residual from a combined to a free chlorine residual might be necessary when nitrification causes a Total Coliform Rule violation, or when other options are not effective. If done properly, a residual change is an effective measure to control nitrification. Some utilities change over the disinfectant in their entire distribution system for a period of time each year as a preventative measure. This method is

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Table 1. Required Flushing/New Demands

Water Age (hours)	Required Flushing/ New Demands for September (mgd)
Status Quo-Current Flushing (low residuals)	0.6
Status Quo-Optimal Flushing (Target 130)	6.0+
Remove 20-Optimal Flushing (Target 130)	5.5+
Add Booster Station-Optimal Flushing (Target 130)	5.8+
Convert 0.5 mgd major South Reclaimed (Target 130)	5.5+
Intermediate Target-Feasible Flushing (Target 154)	1.7
Cleaned Pipe-Optimal Flushing (Target 178)	0.5



Table 2. Nitrification Mitigation Summary

Nitrification Step	Method
Distribution System Hydraulics	Flush sufficient water through the southside portion of the city's distribution system to restore a high total chlorine residual.
	Conduct a unidirectional flushing (UDF) program.
	Addition of new auto-flushers at indicated locations to reduce no flow areas.
	Place parallel 20-in. or 16-in. line out of commission to possibly increase water circulation in southside area of city.
	Convert large reclaimed users to potable water.
Storage Tank Operation and Maintenance	Add new areas for public citizens to increase potable water usage.
	Introduce a stronger oxidant, soak and flush, or pig to kill nitrifying bacteria.
	Trim ammonia at pump stations by adding chlorine at Washington Terrace and Oberly pump stations.
	Trim ammonia at the elevated tank.
Booster Station	Increase mixing in elevated tank by modifying the filling and dumping procedures.
	Modify piping in elevated tank to have an influent pipe and a separate discharge pipe -
	Add a remote booster station on southside portion of distribution system to increase residuals.
Periodic Change from Chloramine to Free Chlorine	With new booster station increase pH and alkalinity.
	With new booster station, add chlorine to trim ammonia.
	With new booster station, add a cooling unit to reduce potable water temperature.
Optimized Pipe Corrosion	Use a free chlorine or chlorine dioxide burn to kill nitrifying bacteria.
	Add a remote booster station to inject additional chlorine into the system during a chlorine burn.
Switch disinfectant	Continue to replace old ferrous-based distribution system piping (DI and galvanized) -
	Use chlorine dioxide in addition to mono chloramine and start process when nitrification is not occurring.
Monitor at Point of Entry	Continue to minimize free ammonia leaving Cosme WTP target to 0.05 mg/L if possible.
	Continue optimal residual/ammonia ratio.
	Raise pH if possible.
Enhance the Nitrification Monitoring Procedure	Raise chloramine levels (already optimized).
	Continue City's extensive ongoing nitrification monitoring procedure.
	Expand or relocate monitoring locations near key proposed auto-flushers.
	Add pH and ORP to distribution analyses.
	Create water quality monitoring dashboard computer application.
	Continue assessing the water quality results and enacting nitrification control measures as needed.

Table 3. Action Plan

Action		Pros	Cons
Step	Method		
1	Conversion of reclaimed to potable	-Raises residuals -Would reduce labor and recapture flushed water	-Partial solution
2	Auto-flusher grid	-Raises residuals -Auto-flushers would reduce labor and optimize volume	-Partially effective -Flush 1.67 mgd year 1/0.4 mgd after UDF -City construction labor for auto-flusher installation
3	South UDF	-Successful for other utilities -Physically removes debris -South portion only	-Increased city labor -Cost
3a	Enhanced UDF pilot with oxidant	-Potentially disinfect pipe -Potentially avoid system burn	-New method
4	Valve off 20-in. & 16-in. diameter pipe from service	-Reduce water age and flushing requirements	-Reduce hydraulic and fire flow capacity -Reconnect customers
5	Enhance nitrification monitoring procedure	-Distribution water quality manager to execute -Computer-based application would provide useful tool	NA
6	Optimize elevated tank water age/quality	-Successful for other utilities	-Increased labor -New piping -Potential closed valves in system
I	Free chlorine burn	-Accepted practice for similar utilities	-Increased public notification -Customer complaints
II	Add new water demands	-Reduce flushing	-Increased city labor
III	Trim ammonia at elevated tank	-Successful for other utilities	- Unfamiliarity -Increased city labor

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used as a nitrification mitigation tactic by utilities within the state using chloramines as a disinfectant.

**Optimized Pipe Corrosion Control Program**

Corrosion control will reduce the reaction between chloramine and corrosion products and reduce chloramine demand. Corrosion control, secondary disinfection, and nitrification control programs should be integrated to ensure water quality objectives are met.

**Switch Disinfectant**

A switch of disinfection methods has been studied in depth, including pilot- and full-scale tests. Studies indicate that chlorine dioxide, or using chlorine dioxide in combination with monochloramine, have a beneficial effect in controlling nitrification (*Prevention of Nitrification Using Chlorite Ion*, JAWWA, 2009). In addition, chlorine dioxide does not react with ammonia, so it can be combined with the current chloramine practice. Studies have shown that the reduction byproduct of chlorine dioxide is chlorite ion, which has been shown to inhibit AOB and NOB in the distribution system.

Special caution should be made when using chlorine dioxide. The U.S. Environmental Protection Agency (EPA) has established a maximum contaminant level (MCL) of 1.0 mg/L and a maximum contaminant level goal (MCLG) of 0.8 mg/L for chlorite in drinking water, though in studies that were conducted, chlorite concentrations did not exceed the EPA standard. In addition, studies have shown chlorine dioxide produces intense oxidation, which shortens the life of polyolefins, and special caution should be used when using chlorine dioxide in distribution system containing polyethylene pipe.

**Point-of-Entry Monitoring**

Potable water leaving the Cosme WTP is currently stable with regards to corrosion potential, and it meets standard water quality goals and requirements. The City is currently operating the facilities at very close to optimum conditions.

**Enhance Nitrification Monitoring Procedure**

The City currently has an extensive ongoing nitrification monitoring procedure that includes state-of-the-art remote distribution water quality monitoring stations. The sites are constantly monitored by City operations staff via SCADA.

**Summary of Viable Nitrification Mitigation Options**

A summary of the possible nitrification mitigation options considered feasible for the City of St. Petersburg is shown in Table 2.

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## Water Quality Optimization Action Plan

Based on input from City staff, an alternative action plan was developed, as shown in Table 3. The recommended action plan includes innovative hydraulic and pipe cleaning methods to mitigate nitrification. The innovative approach is designed to potentially avoid the primary bacteria deactivation method of a full chlorine burn, which has resulted in significant customer dissatisfaction in the past. Auto-flushing devices and a new enhanced unidirectional flushing (UDF) program will be utilized in the south portion of the service area to combat seasonal nitrification activity. Should these innovative measures fall short of the City's needs, the full-system chlorine burn was included as a future consideration as needed. The recommended action plan is based on the evaluation of the City's water quality issues, in comparison with standard practices being deployed by similar utilities in Florida, and potential innovative measures.

### Primary Steps

While a system-wide free chlorine burn is typically the first step to deactivate nitrifying bacteria, the City may attempt an innovative localized bacterial inactivation method

(enhanced UDF) to avoid the customer dissatisfaction issues associated with a system-wide free chlorine burn. The burn will be reserved as a future consideration should the enhanced UDF not be fully successful. The primary steps for the recommended action plan are as follows:

1. Convert reclaimed water users back to potable water in the south portion of City, starting with large users, such as the golf course. These conversions could also be seasonally alternated (potable in the spring and summer, reclaimed in winter) to minimize potable water consumption during cooler periods.
2. Add new auto-flushers at indicated locations (shown in Figure 4) to mitigate high water age areas in the system, thereby hindering the nitrifying bacteria growth and metabolization. This step reduces required flushing volumes and field labor and makes flushing invisible to the public.
3. Conduct a UDF program in the south portion of the service area, and at other high water age extremities, to move the affected water and sediment out of the system, rather than downstream to other areas where it can spread the problem.
  - a. Pilot an enhanced UDF by adding an oxidant, (free chlorine, chlorine dioxide, ozone, hydrogen peroxide, or mixed oxidant blend) to the UDF process to scour with oxidized water. The oxidized water

would then sit in the pipe for 20 minutes and be flushed out to complete the process. This innovative process would require piloting to gauge effectiveness and identify costs.

4. Place parallel 20-in. and 16-in. lines out of service to possibly increase water circulation in the southside area of city (dependent on fire flow). Preliminary engineering is required to ensure system fire flow requirements are still maintained.
5. Enhance the City's ongoing, extensive nitrification monitoring procedure to include the following:
  - a. Expand monitoring to key sites near proposed auto-flushers to help seasonally optimize flush settings to conserve potable water.
  - b. Provide City treatment/distribution management and operators real-time maps to rapidly observe changing water quality conditions to respond with nitrification mitigation steps. The creation of a water quality monitoring dashboard, via an application module to the City's GIS, will allow City staff to overlay and spatially view water quality data, flushing locations/rates, SCADA data, pipe materials, customer complaints, and water quality model predictive output.
  - c. Better track nitrification activity, including oxidation-reduction potential (ORP) and pH monitoring.

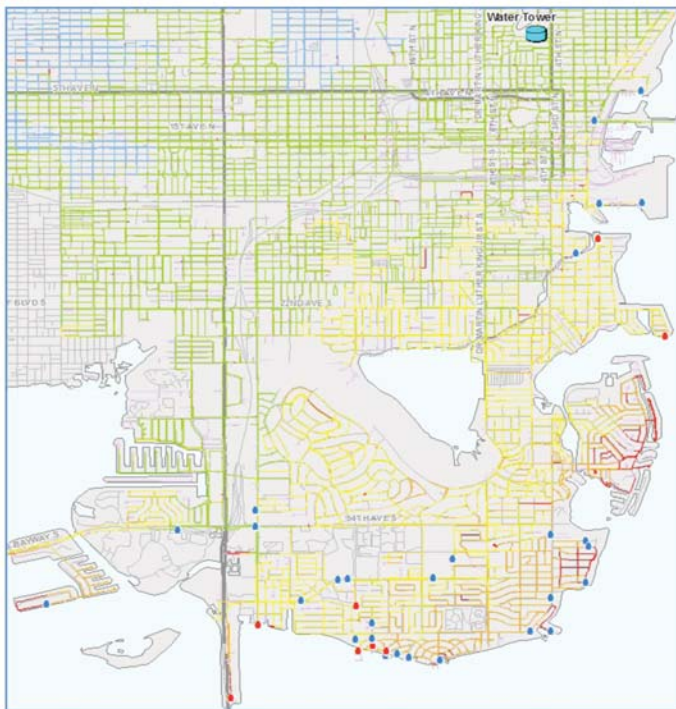


Figure 3. Water Age with Existing Flushing

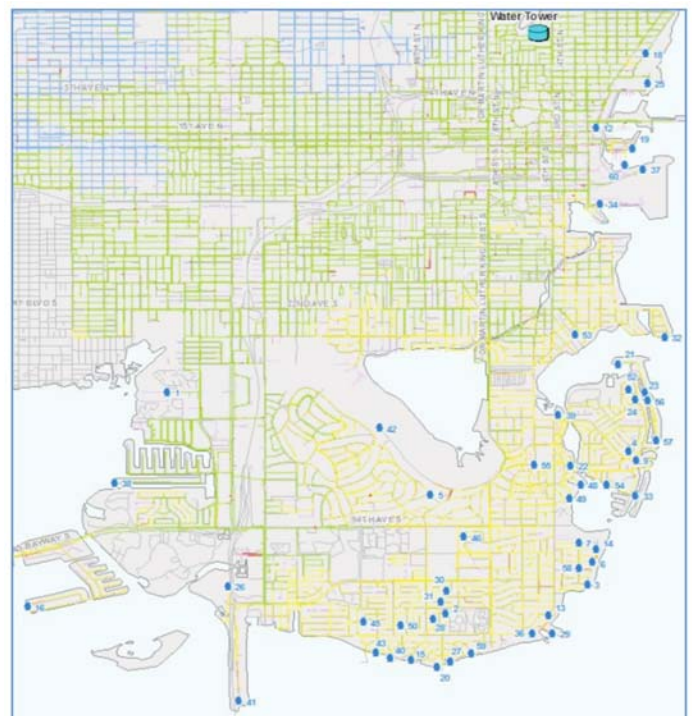


Figure 4. Water Age with Optimized Flushing

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6. Increase mixing in the elevated tank by modifying the filling and drawing of potable water procedures, and potentially by modifying the feed piping to the elevated tank to have separate influent and a discharge piping to the base of the tank.

## Future Considerations

Possible future considerations that the City can further investigate to add additional nitrification prevention methods include the following:

- ◆ System-wide free chlorine burn should the previous measures be ineffective.
- ◆ Add new areas for public citizens, which could include a children's splash park, water parks, vegetable farm, plant nursery, etc., to increase potable water usage and therefore increase circulation.
- ◆ Trim excess ammonia concentrations at the elevated tank to reduce free ammonia levels.

## Results

The City has implemented a portion of the plan and already reaped significant improvements. Implementation of new automatic flushing assemblies, and seasonal conversion of four of the city's parks from reclaimed to potable water for irrigation purposes, has showed the following benefits in 2011 compared with the previous year:

- ◆ 9.3 percent annual reduction in flushing quantities, discounting annual variations in weather.
- ◆ 25 percent average reduction in monthly nitrification sampling requirements.
- ◆ 400 percent reduction in customer complaints regarding flushing activities.
- ◆ 40 percent average annual lower City water distribution manpower and equipment usage.

The use of potable water by the parks has helped to decrease water age and increase chloramine residuals in historical low residual areas. As a result of this, and directing a portion of the new auto-flushers (Figures 3 and 4) to discharge directly to the sanitary collection system, additional reclaimed water quantities are now available for other areas of the city where the potable demand that is offset will not contribute to nitrification issues.

Nitrification in chloramine systems is an ongoing challenge, but this project demonstrates one utility's use of technologically advanced tools and innovation to improve distribution water quality. Full implementation of the recommended plan is expected to occur over the next five years. ◊