Distribution System Water Quality Improvements & Challenges after Ozonation/Biofiltration Steps are Added to Tampa's Surface Water Treatment Plant

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The David L. Tippin Water Treatment Facility produces potable water for about 600,000 customers in and around the city of Tampa. Its source water is the Hillsborough River water impounded in the Hillsborough Reservoir, and the majority of its watershed is swampy lowland in west central Florida.

The reservoir water quality changes dramatically from annual dry to wet seasons on short notice. They are closely correlated with the intensity of rainfall that signals the start of the wet season (June-September) from the dry season (December-May).

In a normal dry season, the color of the river water dwindles down from around 150 platinum color units (cu) to below 50 cu in May and June. As sudden heavy showers usher in the wet season in late June or early July, the color sharply rises from around 50 cu to more than 200 cu within a few days or weeks, and the corresponding organic matter content rises from below 6 milligrams per liter (mg/L) to above 20 mg/L.

The rise of color and organic matter is due to the sudden increase of the highly humified organic matter from the river's swampy watershed that is washed off by the intense rainfalls. The showers also dilute the alkalinity of the water from above 120 mg/L down to below 70 mg/L.

In the past, the David L. Tippin Facility, a conventional water treatment processes facility, has gone through many improvements and adjustments to handle these fluctuations of source water quality, treating the water to meet quality standards using ferric sulfate as a coagulant, free chlorine as a primary disinfectant, and chloramine as a secondary disinfectant.

The management, however, recognized that the existing treatment processes might not be enough to meet all upcoming water quality standards, such as the Stage 2 Disinfectants and Disinfection Byproducts Rule and the Long-Term 2 Enhanced Surface Water Treatment Rule. Other concerns were the plant's capacity to meet the demand of the population increase in the region, the persistent customer complaints on taste and odor, and the possible algal toxins during the dry season.

Water Quality 2000 Project

Management carried out an extensive study to solve these concerns and developed the Water Quality Master Plan. This plan identified and recommended adding the extra treatment processes of ozonation/biological activated carbon (BAC) filtration for the water quality improvement and the sand ballasted clarifier (Actiflo® System) and a new Post Filter Junction Box (PFJ Box) for capacity increase.

To implement the master plan recommendation, management quickly organized the Water Quality 2000 Project to carry out the design and construction of these facilities to be added to the treatment plant; the project was finished in December 2001.

After these improvements, the conventional sedimentation system treated 70 to 80 percent of the total flow, and the remaining flow was treated by the Actiflo® System. Ferric sulfate was used as a primary coagulant for both the conventional and Actiflo® processes. Settled waters from both processes were combined and the pH was increased to between 6.5 and 7.0 by adding lime and NaOH. This pH was carefully monitored and adjusted to minimize the formation of bromate during the subsequent ozonation process.

Ozonation was performed by two trains of ozone contactors, each train having eight cells and an overall hydraulic residence time of 34 minutes at 85 million gallons per day. The residual dissolved ozone concentration was maintained from 0.4 to 0.6 mg/L at the second cell and from 0.1 to 0.2 at the fourth cell, depending on the raw water quality.

The BAC filtration process is composed of 30 filters, each having two cells. All 30 filters were rebuilt with air scour underdrain systems as part of the plant expansion project. The maximum hydraulic loading rate for the filters is 3.5 gpm/sq ft. All filters were constructed with 12 inches of sand and 22 inches of granular activated carbon.

Ammonia was added right after filtration, and the ammoniated water received the chlorine addition at the PFJ Box to form chloramine. The chloraminated water was introduced directly into the clearwell.

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Initial Operations & Challenges

The simple schematic drawing of the initial treatment processes is shown in Figure 1. The new treatment plant started its operation in December 2001, but we immediately encountered an unusual drop in chloramine formation efficiency and its stability in the clearwell and in the distribution system.

Before the new processes, more than 90 percent of added chlorine was converted to chloramines, but the conversion ratio dropped down to only 40 percent at the PFJ Box. As a matter of operational protocol, operators started adding more chlorine and ammonia to produce and maintain the desired chloramine level in the finished water, but the significant drop of chloramine formation efficiency triggered intensive investigation and studies to find the causes.

After reviewing all operational data and several bench scale chlorine ammonia kinetic studies, we traced the cause back to the sequence of ammonia and chlorine application and the mixing at the PFJ Box. Corrections to the chemical application sequence and flow path changes were made in late April 2002 to improve the chloramine formation efficiency, shown in Figure 2. These operational adjustments restored chloramine formation efficiency, as shown in Figure 3, but the filtered and

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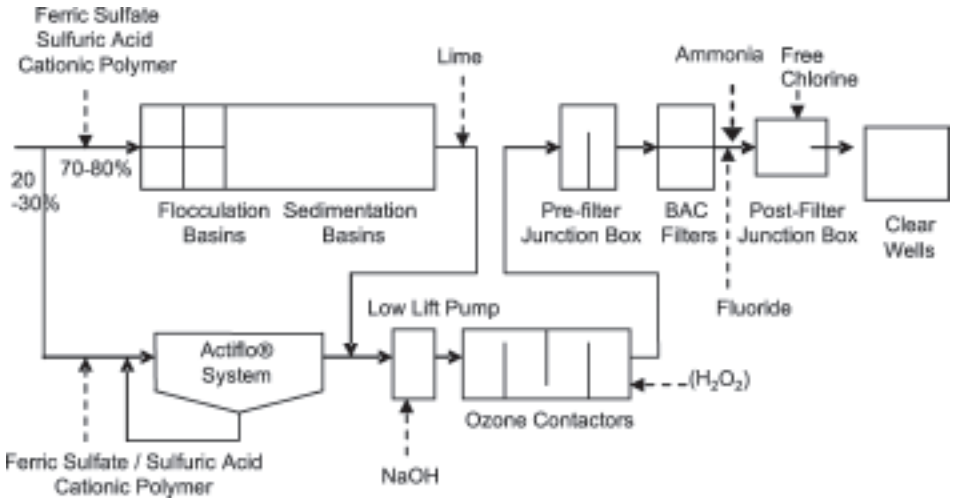

Figure 1: Schematic diagram of treatment processes in the David L. Tippin Water Treatment Facility after the completion of the Water Quality 2000 Project.

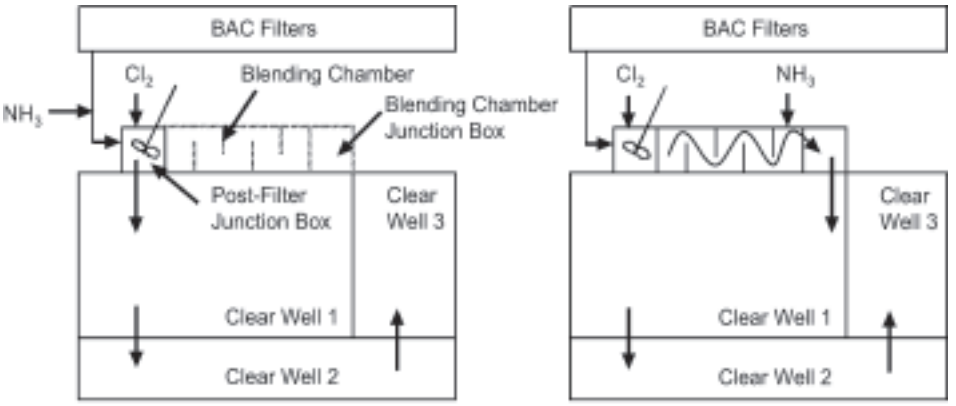

Figure 2: (a) Before the change and (b) after the change.

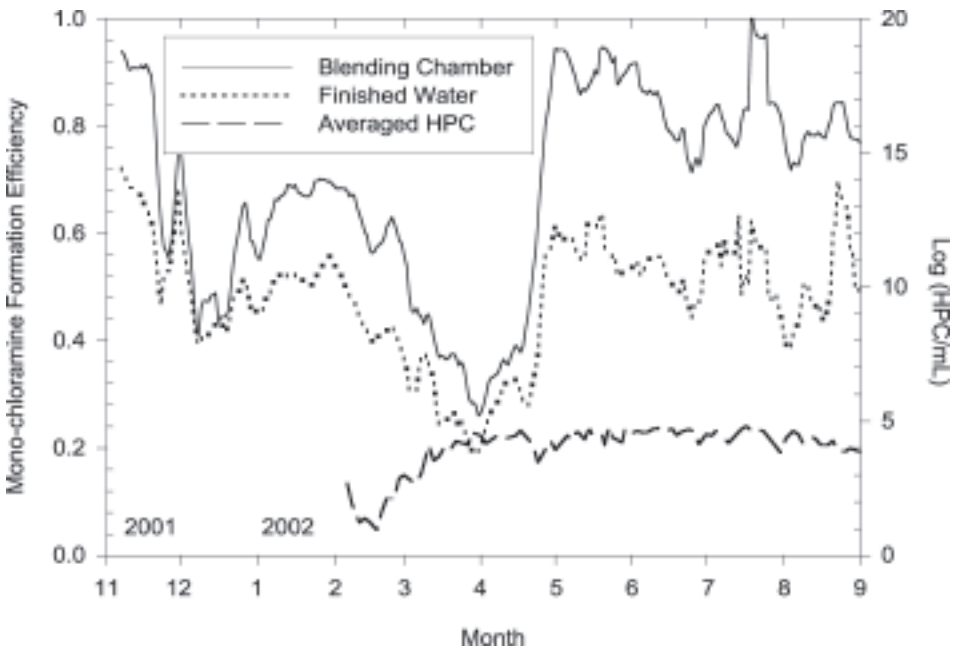

Figure 3: Chloramine formation efficiency.

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chloraminated water exhibited an unusually high chloramine demand, contrary to the common understanding on BAC filtration (LeChevallier et al, 1992), as shown in Figure 3.

The increase in chloramine demand after ozone/BAC filtration was similar to the findings reported by other researchers (Wilczak et al 2003). Two years of subsequent intensive studies showed that our BAC filter depth might be too shallow and was not adequate for filtering out all chloramine demand materials from the ozonated water or biologically produced materials in the BAC filters (Marda et al, 2008).

The studies recommended some operational adjustments on back washing and increasing chloramine concentration in the finished water to meet the extra chloramine demand. With this recommendation, the plant has been maintaining higher-than-normal filtered water chloramine to make up for the finished water chloramine demand. This practice stabilized the residual water quality, and two successful performance evaluations were carried out in 2002 and 2003 to finalize the Water Quality 2000 Project.

Distribution System Water Quality

As stated previously, chloramine formation problems encountered during the initial start-up of the new treatment processes with ozone/BAC filtration were corrected by operational adjustments (chlorine dosage and flow-path change). The subsequent problems of filtered water chloramine demand were partially corrected with 1.0 to 2.0 mg/L higher than normal filtered water chloramine concentration.

With these improvements, the treatment processes and finished water distribution have been stabilized. For the last seven years, we have collected several water quality parameters to assess the effect of our new treatment processes with the adjusted operational practices on the finished water quality and its change in the distribution system.

Customer Complaints

Figures 4 and 5 show the total customer complaints, as well as color, taste, and odor. As seen in Figure 4, the new processes dramatically reduced the total and water color/dirty-water complaints.

In the year 2000 before ozone/BAC filtration, there was a drought that intensified the change in water quality and altered corrosivity of the treated water, dramatically increasing customer complaints on water color to almost 2,000. The new treatment processes with the ozone/BAC filtration, together with corrosion control measures, lowered the color/dirty-water complaints to less than 200 in 2004. The

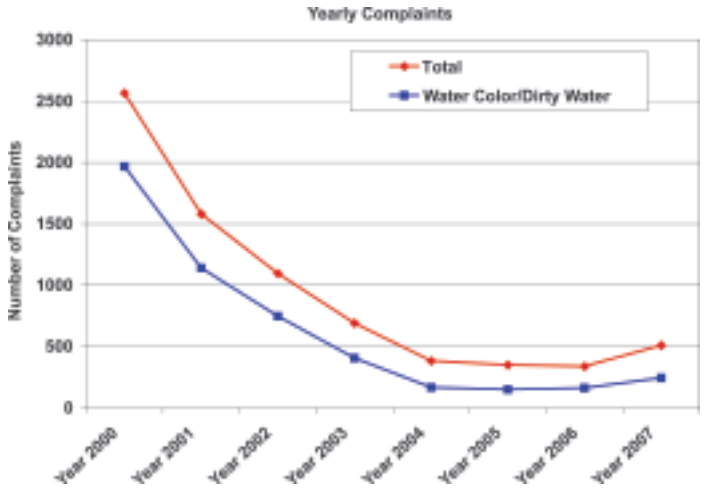

Figure 4: The total and color/dirty-water customer complaints.

Figure 5: Taste and odor complaints.

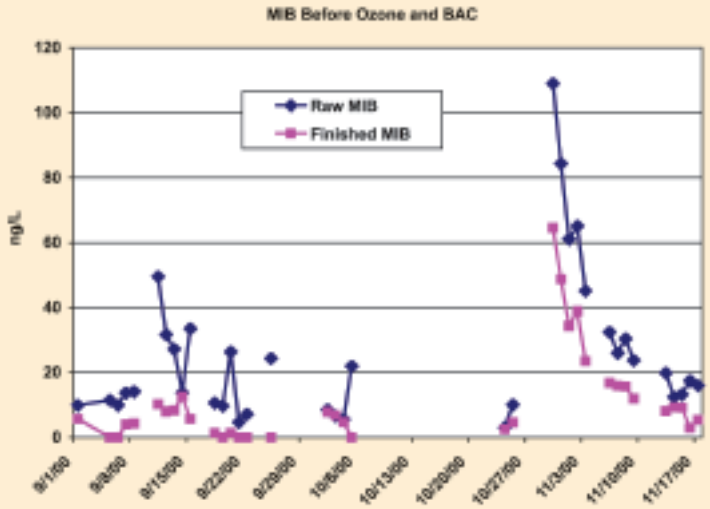

Figure 6(a): MIB before ozonation/BAC filtration.

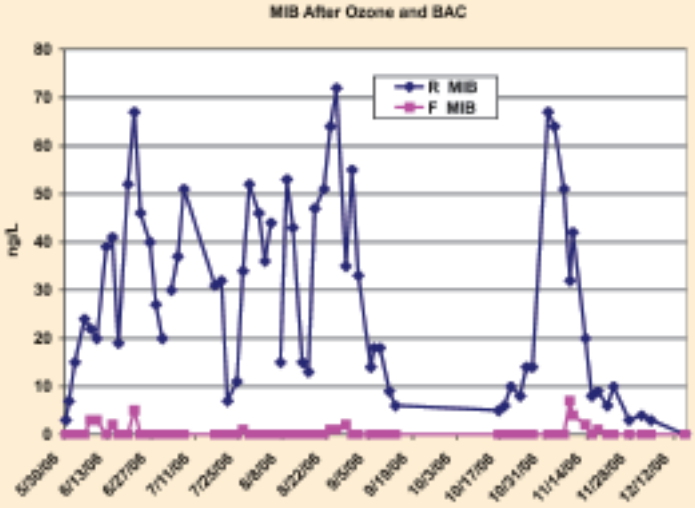

Figure 6(b): MIB after ozonation/BAC filtration.

annual average reduction of complaints on taste and odor was more than 50 percent as soon as ozone/BAC processes were implemented and maintained the reduced level as shown in Figure 5.

Taste & Odor Chemicals

Figures 6(a) and (b) are trend charts of the taste and odor chemical 2-Methylisoborneol (MIB) in the finished water before and after ozonation. As shown in the Figures, MIB in the finished water was reduced below odor threshold level after ozonation. Geosmin showed a similar trend. This reduction has been reflected in the overall reduction of taste and odor complaints.

Distribution System Chloramine Residuals & Demand

As shown in Figures 7 and 8, steady improvements in the distribution system chloramine residual have been observed. As mentioned, the initial ozone/BAC filtration

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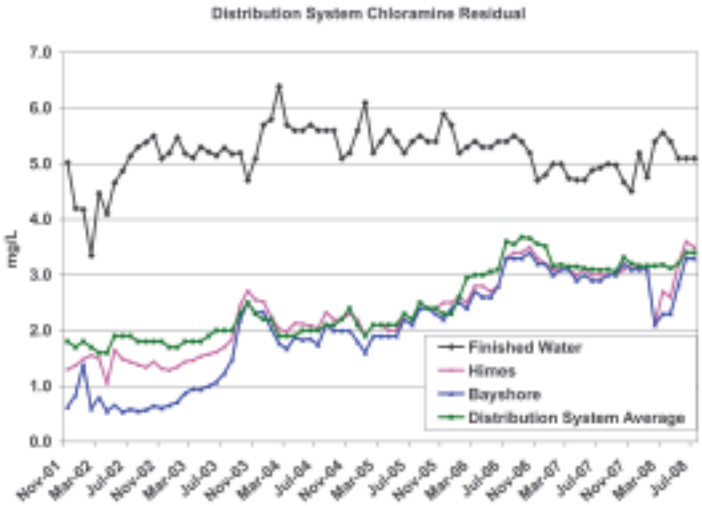


Figure 7: Distribution system chloramine residuals.

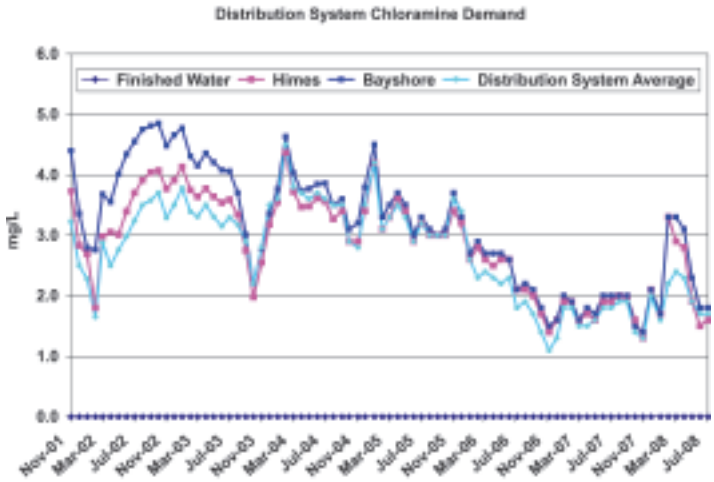
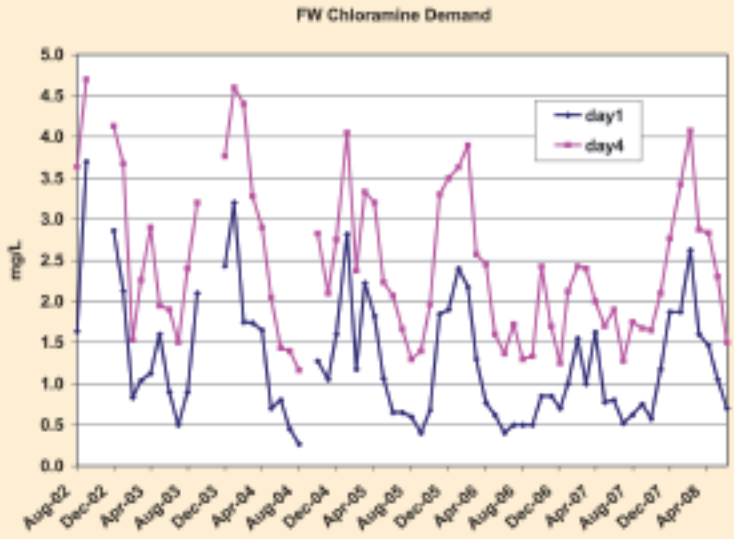


Figure 8: Distribution system chloramine demand.

Figure 9: Chloramine demand of incubated finished water.



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processes sharply reduced chloramine formation of the filtered water, and we corrected it by changing the flow path and chemical dosage sequence.

The chloramine formation percentage returned to normal, but chloraminated filtered water at the blending chamber still exhibited higher chloramine demand as it passed through the clearwell and was pumped into the distribution system. To compensate this demand, more chlorine was applied to produce finished water with a chloramines level 1 to 2 mg/L higher than normal.

This operational adjustment lasted more than a year and slowly improved the chloramine levels at the outskirt sampling points of Himes and Bayshore.

By the end of 2003 and two years after the new ozone/BAC processes, the gap in chloramine demand between the average and the outskirts sampling locations began narrowing, even though the overall demand remained high. At the beginning of 2005, the chloramine demand was around 3.5 mg/L; it was reduced to about 2.0 mg/L by the end of 2006 until the early part of February 2008.

As shown in Figure 8, each year during the dry season (around February), there was a spike in demand—except in the year 2007. For two to four weeks each year during that period of time, except in year 2007, our ozone contactor and the sedimentation basins had to be shut down for maintenance.

This interruption caused the higher organic load in the ozonated water, and the BAC filters were not able to remove the organic matter effectively, resulting in finished water with higher-than-normal organic matter and a higher chloramine demand at the clearwell and in the distribution system. This demand spike prompted us to do the chloramine demand study.

Finished Water Chloramine Demand (Incubation Study)

Starting in August 2002, the finished water samples were collected weekly and incubated for five days to measure their chloramine demand. Figure 9 is the chloramine demand chart of monthly average of the weekly demand data.

As illustrated in the chart, chloramine demand of the finished water produced during the ozone shut-off was 2-3 mg/L higher than that of ozonated finished water.

Effect of Finished Water Chloramine Demand on the Distribution System

Figures 10 and 11 show the finished water incubation demand compared with distribution system samples' chloramine demand. As shown in these figures, the effect of the finished water chloramine demand on the distribution system chloramine demand exhibit similar patterns.

The finished water chloramine demand improved quickly as soon as ozonation was resumed, but the distribution system chloramine demand lingered higher. This phenomenon indicated that other factors such as distribution system biofilms could be contributing to the additional demand in the distribution system.

This lingering recovery of the distribution system chloramine residual seems consistent with each episode of our annual ozone contactor maintenance activity during the dry season when the raw water color was low. Even with these fluctuations of the finished water chloramine demand, the overall demand trend shows a gradual reduction, resulting in the gradual increase of chloramine residual in the distribution system, manifesting an overall positive effect of ozone/BAC filtration on the chloramine residual of the distributed water.

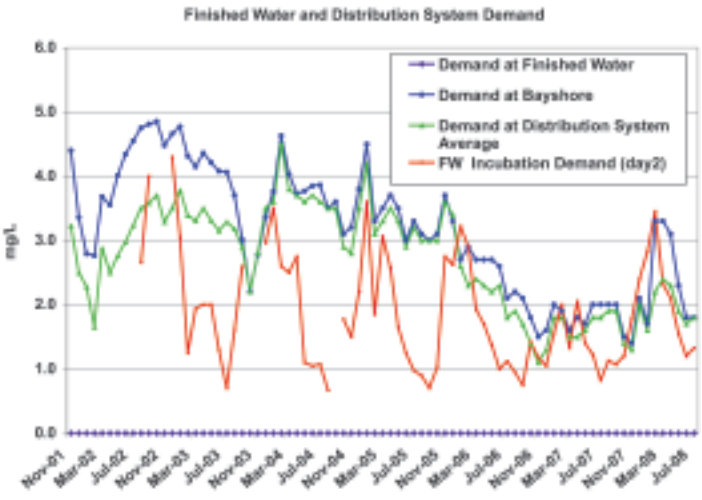

Figure 10: Chloramine demand trends of finished water and the distribution system.

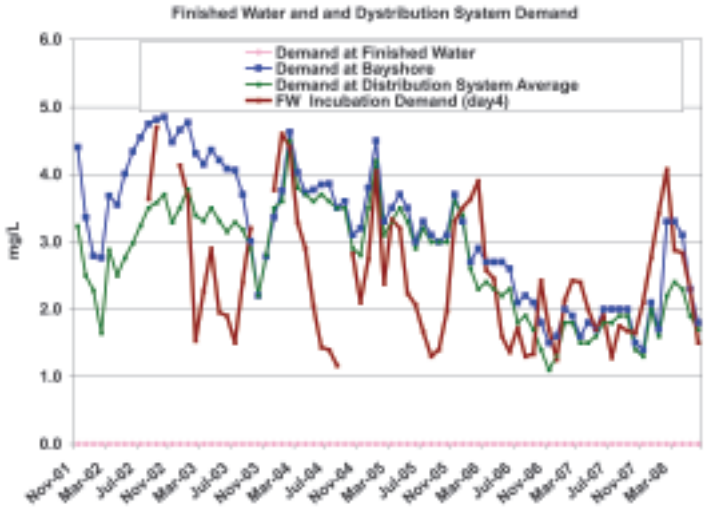

Figure 11: Chloramine demand trends of finished water and the distribution system.

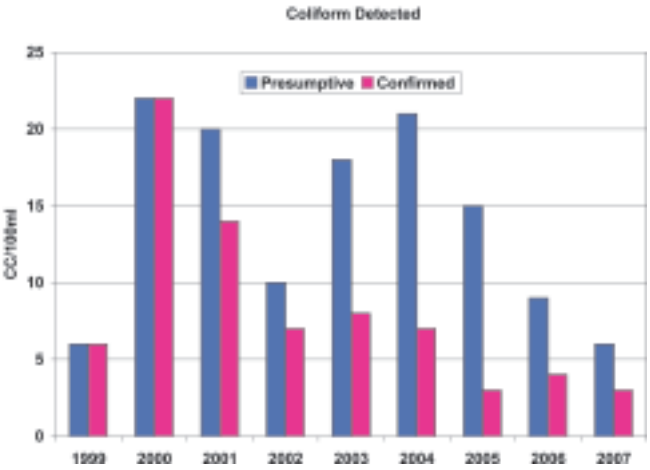

Figure 12: Coliform positives data.

Figure 13: Confirmed coliform positives and the chloramine level in the distribution system.

Total Coliform Rule Compliance Data

The positive effect of the Ozone/BAC treatment processes on the chloramine residual of the finished water and in the distribution system are shown clearly in Figures 12 and 13.

The figures clearly show that as the chloramine residual was increased gradually, the number of detected total coliform positives were reduced in the distribution system.

Disinfection Byproducts

Trihalomethanes (THMs) and Haloacetic Acids (HAAs) of the finished water were analyzed twice a week in addition to the quarterly compliance monitoring of the distribution system. The running annual averages (RAAs) of the finished water THMs and HAAs were compared with that of the quarterly compliance monitoring data of the distribution system in Figures 14, 15, 16, and 17.

As shown in Figures 14 and 15, both sets of data gradually have been reduced to current RAA of below 40 and 30 µg/L for total THM and total HAA respectively.

Figures 16 and 17 illustrate the similarities between distribution system and finished water THMs and HAAs levels, except for THMs in 2000 and 2001, when distribution system THMs were lower than those of finished water.

Ammonia, Nitrite and Nitrite in the Distribution System

Chlorine is added to the filtered water at the PFJ Box and it flows through the blending chamber. Ammonia is added at the middle of the blending chamber to produce chloramine, the secondary disinfectant for our distribution system. To ensure the formation and stabilization of monochloramine, a slight excess of ammonia (0.1-0.3 mg/L) normally is added.

It has been, however, operationally impractical for the David L. Tippin Water Treatment Facility to maintain free ammonia below the 0.3 mg/L level because of the frequent and abrupt changes in source water quality. Average free ammonia level in the finished water and in the distribution system has been around 0.5 mg/L. With this free ammonia level, nitrification has been watched carefully and evaluated by monitoring free ammonia and ammonia oxidation products.

Several figures below are the evaluation of some of these monitoring data collected from March 2006 to February 2008 to find

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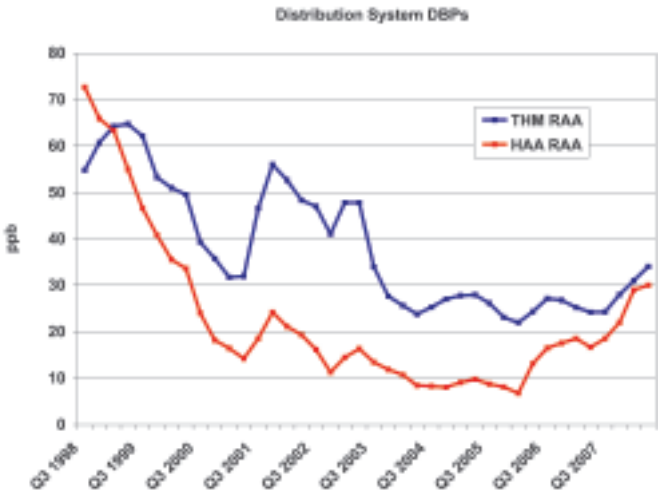

Figure 14: Compliance monitoring results (RAA) of THMs and HAAs.

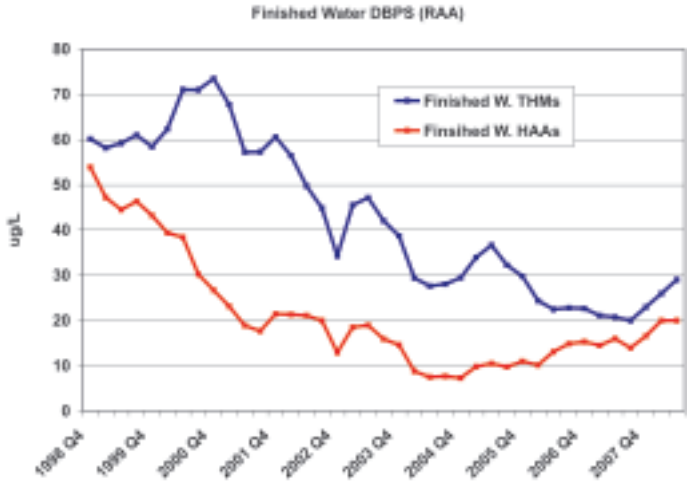

Figure 15: Running annual averages of the finished water THMs and HAAs

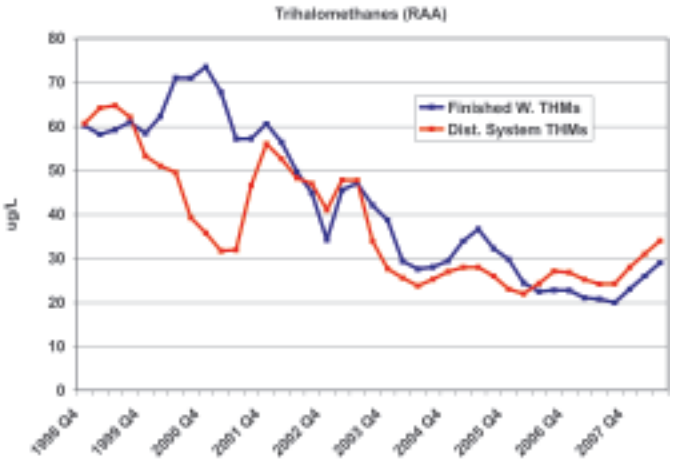

Figure 16: THMs of distribution system and finished water.

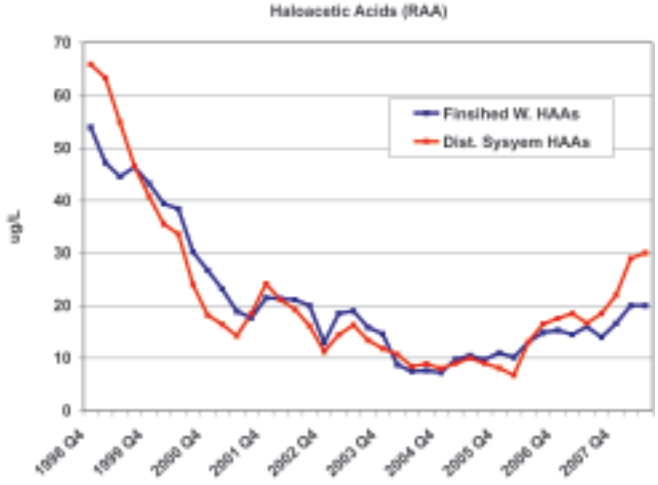

Figure 17: HAAs of distribution system and finished water

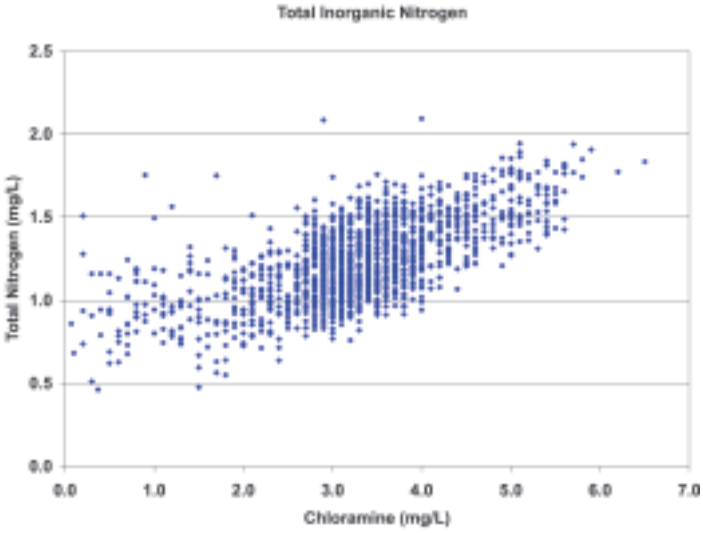

Figure 18: Total inorganic nitrogen and chloramine in the general distribution system.

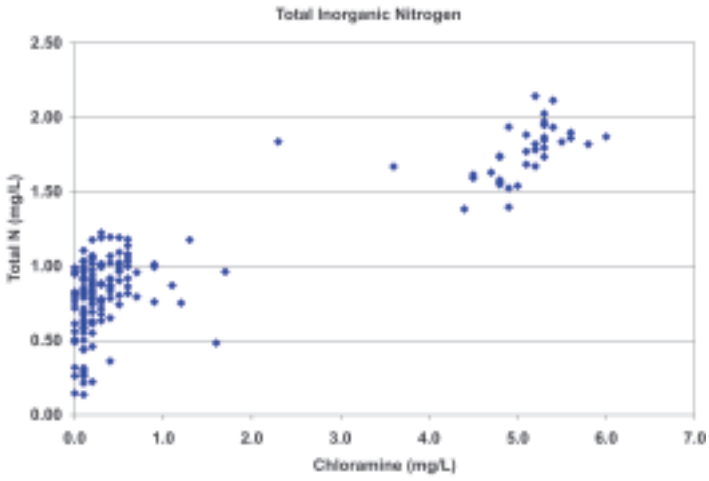

Figure 19: Total inorganic nitrogen and chloramine at finished water and the dead-end locations.

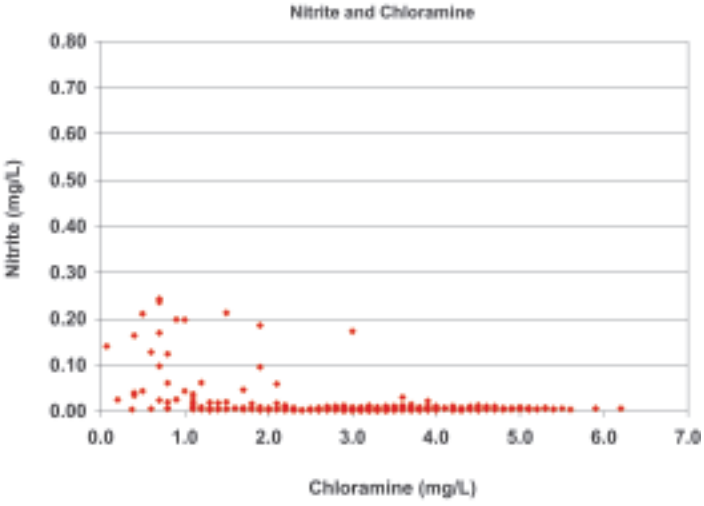

Figure 20: Nitrite and chloramine in the general distribution system.

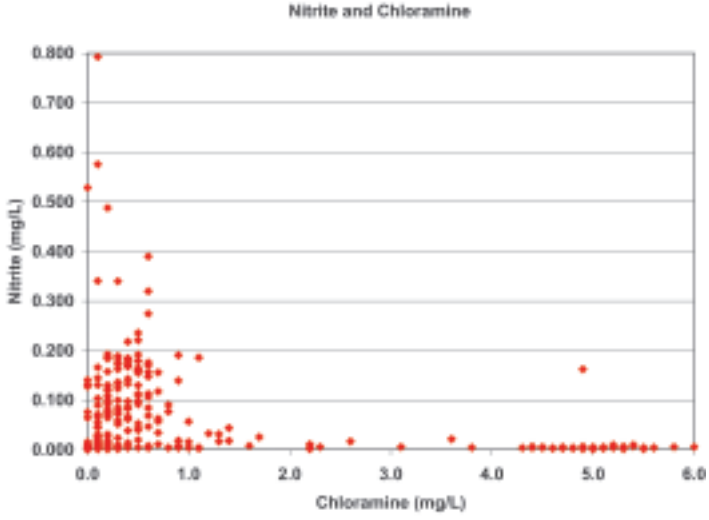

Figure 21: Nitrite and chloramine in the finished water and dead-end locations.

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patterns of ammonia oxidation into nitrite and nitrate as the water is distributed into our distribution system. Figures 18 and 19 show the pattern of "total inorganic nitrogen" and chloramine.

The "total inorganic nitrogen" here is defined as the sum of free ammonia, nitrate, and nitrite plus the ammonia combined with chlorine in the residual chloramine of the distributed water. The total inorganic nitrogen was calculated to assess the nitrogen mass balance in the water.

The added ammonia forms chloramine with chlorine; the remaining free ammonia and released ammonia from chloramine decay could be converted through the biological and chemical processes into nitrite and nitrate. Some of this inorganic nitrogen may be accu-

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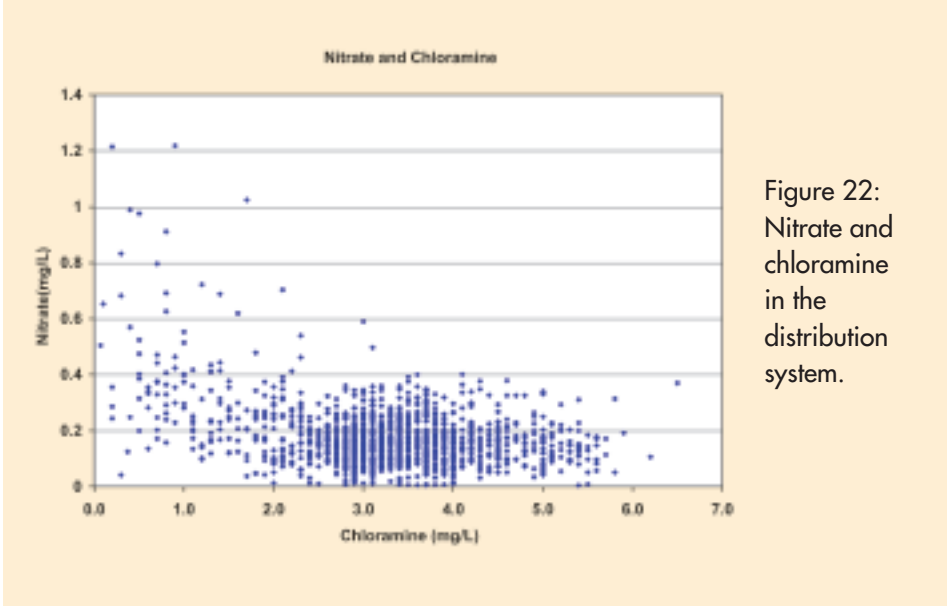

Figure 22: Nitrate and chloramine in the distribution system.

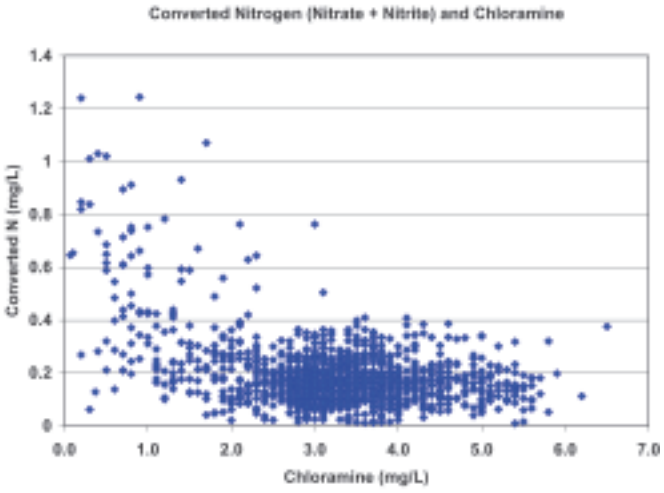

Figure 23: Converted nitrogen and chloramine in the distribution system.

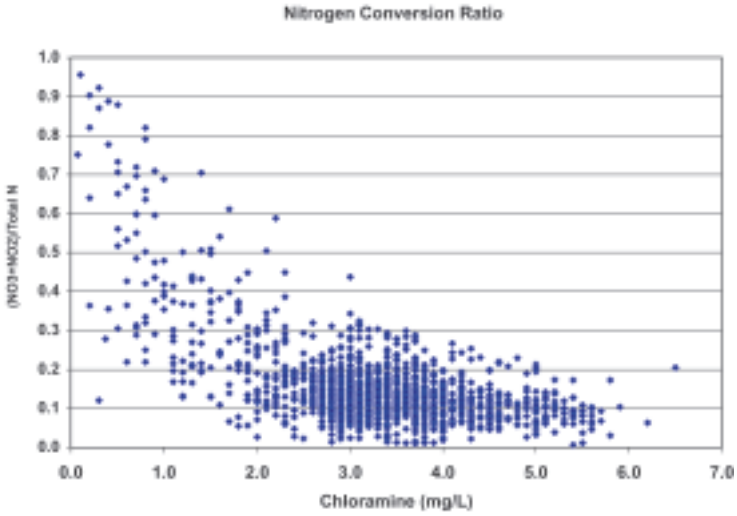

Figure 24: Nitrogen conversion ratio in the distribution system.

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mulated into the biological body as organic nitrogen. Some could be lost as gaseous nitrogen by denitrification.

Figures 18 and 19 strongly suggest these possibilities as they show the clear pattern of decrease in total inorganic nitrogen as the distributed water loses chloramine concentration as it ages in the distribution system.

The relationship between nitrite and chloramine concentrations is shown in Figures 20 and 21. As the distribution system chloramine level decreased below 2.0 mg/L, the increase in nitrite concentration became more obvious. This nitrite would become a major chloramine scavenger and get converted to nitrate.

Figure 22 shows the pattern of nitrate and chloramine levels. The average source water contribution of nitrate is 0.1 mg/L. The nitrate levels at all chloramine concentrations strongly indicate the formation of nitrate at higher chloramine conentrations.

The possible pathway could be the production of the nitrite by the ammonia oxidizing bacteria, even at higher chloramine levels, and the oxidation of nitrite into nitrate by the chloramine. The detection and isolation of ammonia oxidizing bacteria to verify this assumption is one of the objectives of the next study.

The relationship between the sum of the nitrite and nitrate, the converted nitrogen from ammonia, and the chloramine concentration is shown in Figure 23; the "nitrogen conversion ratio" is shown in Figure 24.

Figures 20 to 24 all reveal one of the unique characteristics of the city of Tampa's drinking water distribution system. Figures 20 and 21 show that with the current production condition of the finished water, the nitrite and nitrate formation in the distribution system will accelerate when the chloramine level drops below 2.0 mg/L. Figures 22, 23, and 24 show that the possible nitrification in our distribution system could be suppressed if the chloramine level is maintained above 2.5 mg/L.

The pattern of free ammonia and chloramine is shown in Figure 25.

Figure 25 also shows that the free ammonia reduction becomes noticeable below the 2.5-mg/L chloramine level. The information from the previous data helped us to focus on maintaining the distribution system chloramine level above 2.0 mg/L to avoid any possible nitrification incidents. As we proactively and vigorously maintained this empirical chloramine level above 2.0 mg/L in the distribution system, we were able to maintain our distribution system free of nitrification incidents and free of chlorine burning episodes.

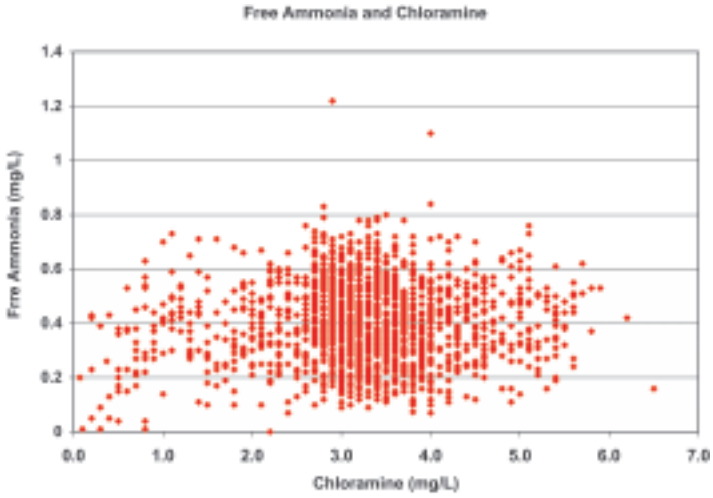

Figure 25: Free ammonia and chloramine in the distribution system.

Conclusion & Discussion

In spite of several initial shortcomings of the ozone/BAC filtration system that was added to the David L. Tippin Water Treatment Facility, the addition has improved the distribution system water quality with respect to the disinfectant residuals, disinfection byproducts, customer complaints, and taste and odor chemicals.

As the chloramine residuals in the distribution system improved over the years, they reduced the number of confirmed total coliform positives and suppressed the nitrification incidents. The suppression of nitrification could be achieved if the chloramine level in the distribution system can be maintained above 2.0 mg/L. Our practice has been to maintain

the level above 2.5 mg/L, and we have been successful in controlling the nitrification.

A careful review of the results clearly shows that the water quality could be further enhanced if the two areas of operation can be improved.

1) The ozonation system needs less interruption. This improvement could be achieved if the ozone contactor chambers could be isolated completely so that one chamber could be closed for maintenance while the other is in service.
2) The filtered water chloramine demand needs to be reduced. This improvement can be achieved by using BAC filters with a deeper filter depth or an additional blending chamber to increase chlorine contact time. The following facility improvements are under consideration to achieve these goals.

Ozone Contactor Improvement

The ozone contactor building consists of two parallel chambers. It was designed and built so that one chamber could be shut down for maintenance while the other chamber carried out the ozone treatment, but the partition wall was not completely leak proof and ozone gas leaked from the operating chamber into the drained chamber, so maintenance work could not be performed while the other chamber was in operation.

Completely sealing this wall is one of the capital improvement projects for the next two years. With this improvement, the ozone/BAC process will not be interrupted and the filtered water will have a much more stable, predictable chloramine demand to handle.

Blending Chamber Addition or Filter Media Depth Improvement

As mentioned previously, our extensive study showed that the elevated chloramine demand of the filtered water might be caused partly by the shallow depth of our filters. The existing remedy has been to add additional chlorine and lengthen the mixing time at the blending chamber before ammonia is added to produce chloraminated finished water.

Increasing filter depth in the existing filter structures is not feasible, and constructing all new filters would be cost prohibitive. One alternative way to reduce oxidant demand of the filtered water is to increase the contact time with chlorine before ammonia is added. This can be accomplished by building another blending chamber to increase chlorine contact time before the ammonia addition. The addition of a blending chamber is also one of the capital improvement projects for the next four years.

These improvements should reduce filtered water oxidant demand and would result in a reduced amount of ammonia addition, which can help control the free ammonia level in the water—hopefully below 0.3 mg/L—and may reduce the activity of ammonia oxidizing bacteria and incidents of nitrification at the outskirts and the dead-end locations of the distribution system.

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