Town of Paxton, Massachusetts Distribution System Evaluation and Improvements

Karen L. Gracey, P.E., Co-President and Steven H. Daunais, Project Engineer

Abstract

In 2012, the Town of Paxton, MA was experiencing significantly reduced chlorine residuals in the extremities of the system along with an aging water tank that required extensive rehabilitation. As a result, the Paxton Department of Public Works (DPW) determined the need to create an extended period simulation (EPS) hydraulic model to evaluate the water age and water quality in the distribution system. The study examined the residual chlorine concentrations and water age throughout the distribution system and presented various options to help mitigate these issues, including replacing the aging tank and adding a chlorine booster pump station at the existing site. Construction of the new tank and pump station was completed in the summer of 2016.

Distribution System

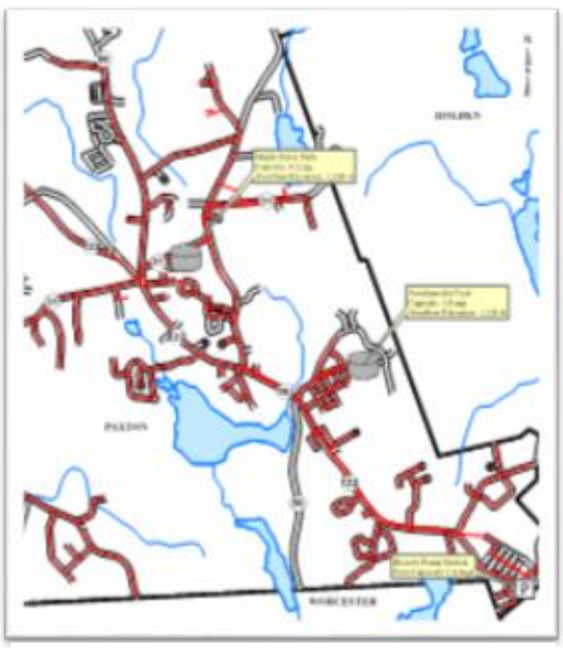

Figure 1 Map of Distribution System

The Paxton distribution system consists of approximately 33 miles of main ranging in size from two to twelve inches in diameter. The Town purchases water from the City of Worcester up to 450,000 gallons per day (gpd). A map of the distribution system can be found in Figure 1.

The Average Day Demand (ADD) for the system averaged approximately 290,000 gpd from 2008 through 2012 and the Maximum Day Demand (MDD) ranged from approximately 560,000 gpd to 710,000 gpd over the same time period.

There are two storage facilities in the system. The original Maple Street Tank (Figure 2) was a welded steel tank constructed in 1934 that was 25 feet in diameter, 100 feet in height, and had a reported capacity of 0.36 million gallons (mg). The overflow elevation was 1,320 feet USGS. The tank was connected to the distribution system by a 10-inch diameter unlined cast iron main and a 12-inch diameter ductile iron main. The existing tank was in need of rehabilitation at an estimated cost of approximately $500,000.

The Asnebumskit Tank was constructed in 1974. The prestressed concrete tank is 65 feet in diameter and 40 feet in height with a reported capacity of 1.0 mg and an overflow elevation of 1,320 feet USGS. A 12-inch diameter asbestos cement main connects the tank to the distribution system.

The system has one pump station, which is required to supply water from the Worcester system to the Paxton system. Two pumps are operated by the SCADA system with alternating on/off cycles based on the level in the Asnebumskit Tank.

Hydraulic Modeling

To examine the water quality issues affecting Paxton, the hydraulic model was updated to reflect recent modifications to the distribution system. Demands were allocated to the nearest junctions to represent actual metered demand in the system. Demand allocation was developed using billing data and SCADA data for August 1-5, 2012, December 1-5, 2012, and March 26-28, 2013. Demands were distributed to the junctions in the model using the "Demand Allocator" feature of the WaterGEMS software. The Demand Allocator assigns the water usage associated with each user to the nearest junction. These changes were then verified during an extended period simulation. As part of the study, chlorine residuals and water age were examined.

Figure 2 Original Maple Street Tank

Chlorine

On March 27, 2013, the DPW collected 14 samples from 12 locations throughout the distribution system to determine the residual chlorine levels for both free and total chlorine. Free chlorine measurements ranged from 1.1 mg/L at the booster pump station while only trace values were found at several locations at the extreme ends of the system. The sample results can be found in Figure 3.

Town of Paxton Cl2 Residuals

ALL SAMPLES WERE TAKEN ON 3/27/13

LOCATION	TIME	FREE CHLORINE RESIDUAL	TEMPERATURE F*
Asnebumskit Tank Draw	9:37 AM	0.53	38.6
Maple St. Tank Draw	10:05 AM	0.04	37.4
Asnebumskit Tank Fill	5:00 PM	1	39.6
Maple St. Tank Fill	4:00 PM	0.13	37.9
Booster Pump Station	11:11 AM	1.1	42.1
315 Pleasant St.	12:56 PM	0.92	45.7
Paxton Light Dept.	1:22 PM	0.44	41.3
79 Grove St.	1:33 AM	0.41	41.1
118 Holden Rd.	7:55 AM	0.06	47.9
Anna Marria Collage (Socqute House)	12:14 PM	0.02	48.9
Brooks Rd. (Hydrant in front of 18)	1:50 PM	0.03	41
West St. (last Hydrant)	2:11 PM	0.03	41.1
490 Marshall St. (Hydrant)	2:40 PM	0.07	41
1 Marshall St. (Hydrant)	3:07 AM	0.02	38.6

Figure 3 Chlorine Residuals

The field tests showed the amount of chlorine decay taking place in the storage tanks. The free chlorine just outside the Asnebumskit Tank during the fill cycle was approximately 1.0 mg/L and dropped to approximately 0.53 mg/L during the draw cycle. The chlorine residual just outside the Maple Street Tank was 0.13 mg/L during the fill cycle and 0.04 mg/L during the draw cycle. Figure 4 shows a chlorine profile of the system based on the March 27, 2013 samples.

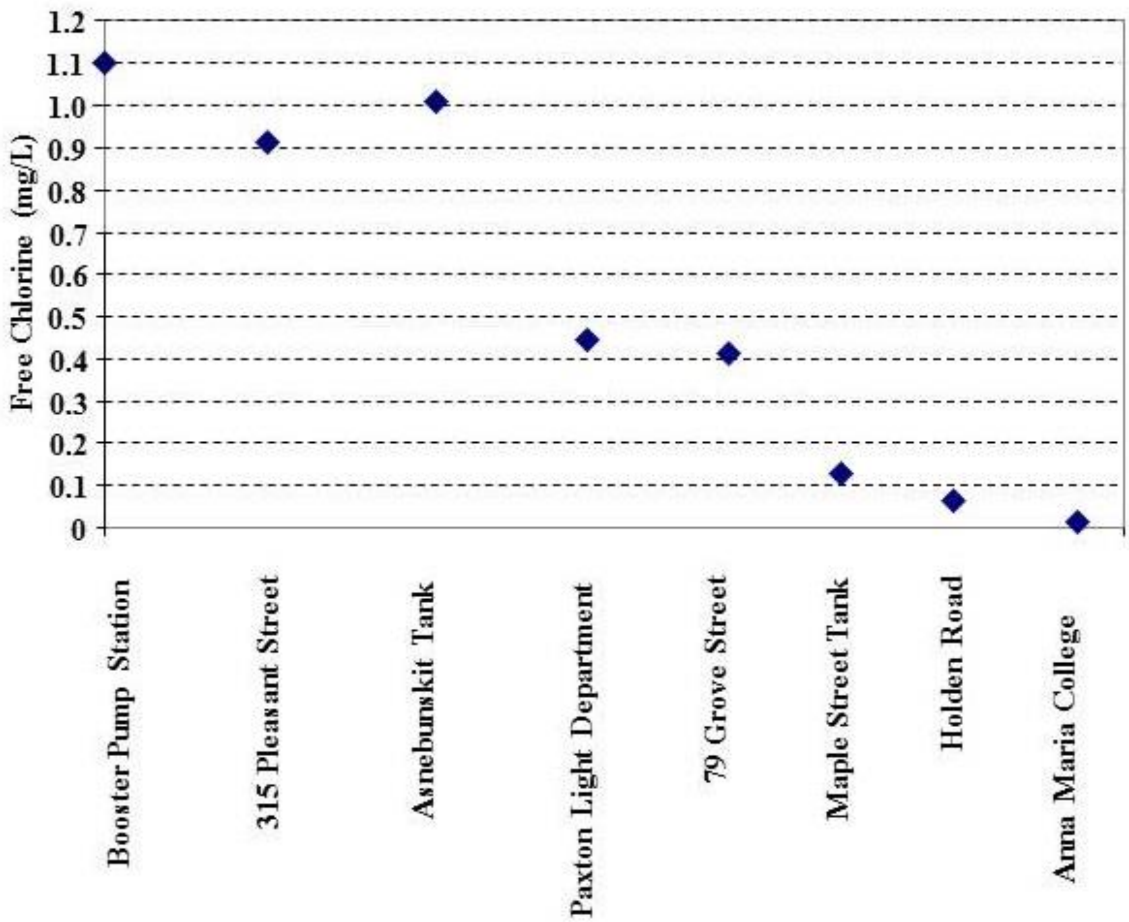

Figure 4 Chlorine Profile, March 27, 2013

The DPW conducted a chlorine decay bottle test on samples collected from the booster pump station on March 28, 2013 using the protocol documented by the American Water Works Association (AWWA) in *Computer Modeling of Distribution Systems – M32, Third Edition*, published in 2012. The results of the test are shown in Figure 5.

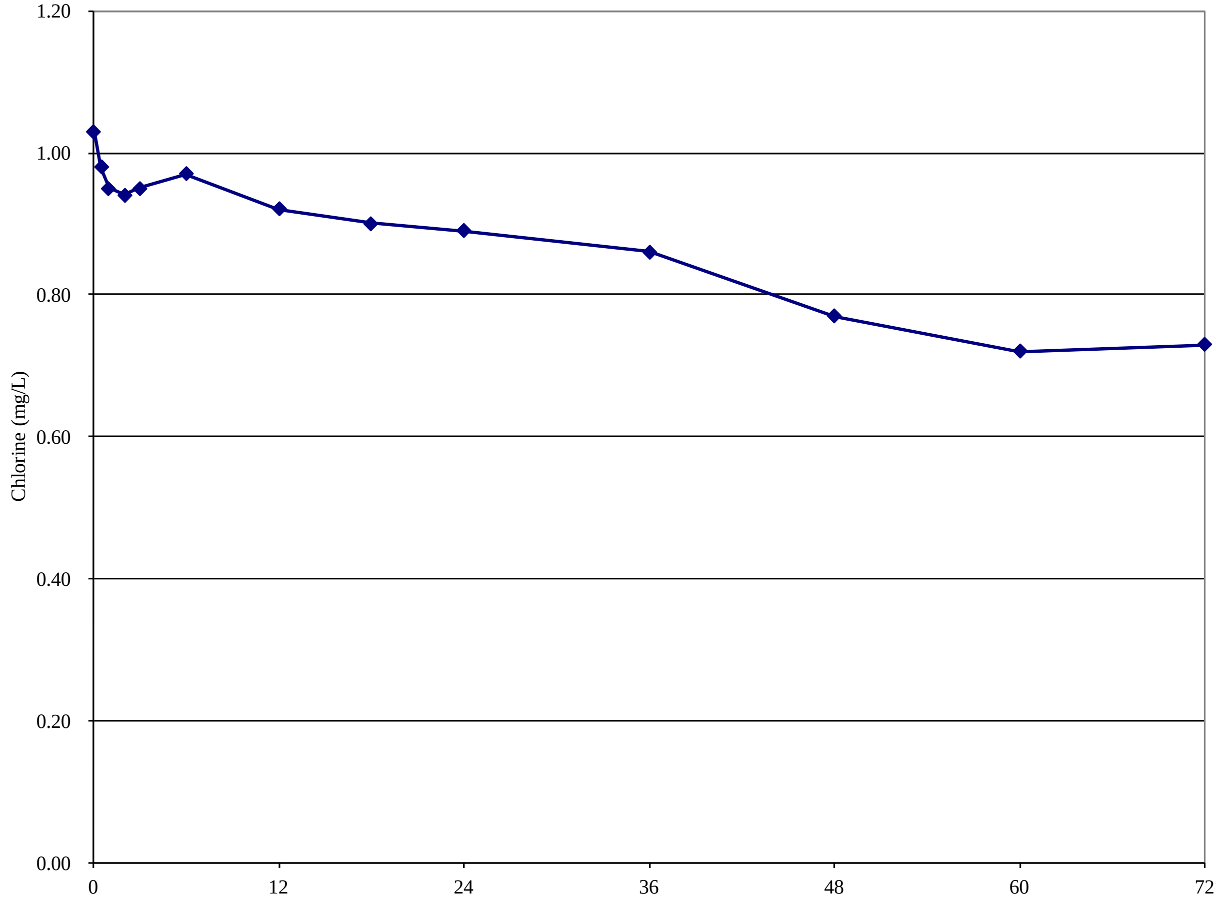

Figure 5 Booster Pump Station Free Chlorine Bottle Test Samples Collected March 28, 2013

The model was used to simulate the behavior of the chlorine throughout the distribution system. The results were compared to the field measurements taken on March 27, 2013 to calibrate and validate the model. Based on the decay bottle tests, a bulk coefficient rate of 0.144 per day was used. A wall decay rate of 0.20 feet/day was used on select 10-inch diameter unlined cast iron mains between the booster pump station and the Maple Street Tank to bring the model in line with the field measurements.

The DPW supplied the Chemical Treatment Reports for January through June 2012 and October through December 2012. A review of these reports showed the chlorine concentration measured at the booster pump station ranged from a low of 0.38 mg/L on May 25 to a high of 2.13 mg/L on December 15. The average concentration from the reports was 1.20 mg/L.

Water Age Impact on Water Quality

Water age is the time it takes for water to travel from a water treatment facility to a point within the distribution system. It is frequently used as an indicator for water quality based on the assumption that the older the water is, the greater the likelihood the water quality has deteriorated. Because the Town does not produce its own water and is instead supplied by the City of Worcester, the water has aged before it reaches the Paxton distribution system. It is estimated the water supplied from Worcester ranges in age from approximately 50 to 300 hours upon reaching the Paxton system. The age range depends on whether water serving the Paxton system comes directly from the source in Worcester or from Worcester's storage tank before entering the Paxton system. It should be noted that all water ages noted in this article do not reflect the time spent in the Worcester system before entering the Paxton system.

The water age shows a significant increase in age when it enters the Asnebumskit Tank, reducing the chlorine concentration by approximately half, and then shows a second increase in water age upon entering the Maple Street Tank, reducing chlorine concentrations to approximately 0.10 mg/L. Water age, by itself, does not necessarily indicate poor water quality. However, reducing water age may improve water quality by maintaining chlorine residual, which in turn will reduce the potential of a biofilm building up on the inside pipe walls in the extremities of the system.

Water Quality Evaluation

Water age in the Paxton distribution system was found to be high, potentially contributing to water quality issues, such as bacterial growth. As previously noted, chlorine residuals in parts of the distribution system were very low, due in part to the long residence time in the Maple Street Tank. By the time the water left the Maple Street Tank, only a trace amount of chlorine was left.

Modeling and analysis of the water quality data indicated high water ages throughout the service area at most times. The primary cause of the high water age was the residence time in the storage tanks. Water age in the Asnebumskit Tank typically exceeded 10 days (240 hours) during the summer and 12 days (288 hours) in the winter. At the Maple Street Tank, water age typically exceeded 24 days (576 hours) and 32 days (768 hours) in the summer and winter, respectively. The high water age was caused by low turnover in the storage tanks, especially the Maple Street Tank. During the summer, the Asnebumskit Tank fluctuated approximately six feet per day and the Maple Street Tank fluctuated approximately seven feet per day with one fill and one draw cycle at each tank. Both tanks have the same fill and draw cycles; however, because of varying demands in the system and headlosses in the pipes, the Maple Street Tank fluctuated slightly more than the Asnebumskit Tank. Because of the different heights of the storage tanks, the six-foot fluctuation at the Asnebumskit Tank was approximately 15 percent of the total tank volume, while at the Maple Street Tank, the seven-foot fluctuation was approximately seven percent of the total tank volume. This variance in tank volume turnover accounted for the large difference in water age at the two tanks. See Figure 6.

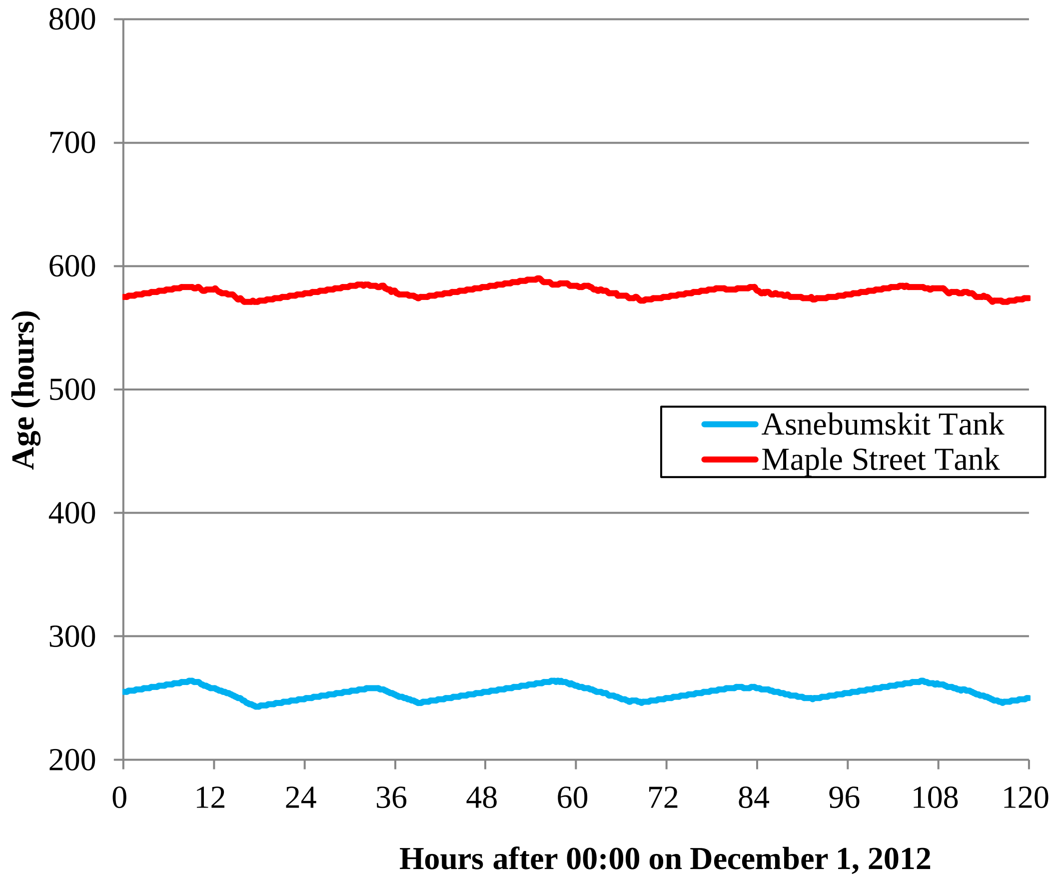

Figure 6 Estimated Water Age in Asnebumskit Tank and Maple Street Tank

During the winter, the Asnebumskit Tank fluctuated approximately five feet per day and the Maple Street Tank approximately six feet per day with one fill and draw cycle at each tank per day. The five-foot fluctuation at the Asnebumskit Tank was approximately twelve percent of the total volume and the six-foot fluctuation at the Maple Street Tank was approximately six percent of the total volume. The increase in water age during the winter was evidenced by the lower turnover of water in the storage tanks during this time period.

Water age in the distribution system can be grouped into three locations: the northeast part of the system between the Maple Street Tank and Anna Maria College, the southeast part of the system between the booster pump station and Asnebumskit Road, and the remainder of the distribution system. The southeast portion of the distribution system is primarily fed directly from the booster pump station resulting in a water age typically less than 50 hours old. The northeast part of the system had the oldest water age in the system. The water serving this area comes primarily from the Maple Street Tank with a smaller amount coming directly from the booster pump station. As a result, the water age in the northern part of the system varied from approximately 100 hours when being fed by the booster pump station to approximately 700 hours when being fed by the Maple Street Tank.

The remainder of the system was fed by a mixture of water from the booster pump station, the Asnebumskit Tank, and the Maple Street Tank, resulting in water age that ranged from approximately 40 to 350 hours while occasionally reaching an age over 500 hours when supplied primarily from the Maple Street Tank.

Alternatives to Reduce Water Age

Because the primary driver of high water age in the system was the residence time in the storage tanks, constructing a new elevated storage tank, modifying the pump operation, or a combination of the two were considered to reduce the water age. Another option was to add chlorine in the system to increase chlorine residuals at system extremities to mitigate the impact of extended water age.

The operating procedures provided by the DPW state that a pump at the booster pump station turns on when the water level at the Asnebumskit Tank drops to 27 feet and turns off when the water level reaches 36 feet. However, a review of the SCADA data shows the tank level only fluctuating five to six feet per day. Using the same pumping rate, the hydraulic model was used to estimate the water age in the storage tank if the pumps operate as stated in the operating procedures. Using the same demand conditions used to verify the model in the summer and winter, but altering the pump operation to allow for the nine feet of fluctuation stated in the operating procedures, lowered the estimated water age in the Asnebumskit Tank from approximately 250 hours in the summer to 175 hours and from approximately 290 hours in the winter to 180 hours. The estimated water age in the Maple Street Tank showed a similar decline, being reduced from approximately 570 hours in the summer to 500 hours and from approximately 770 hours in the winter to 630 hours. Additionally, reducing the water age by altering the pump schedule had the potential to save the DPW money by allowing them to pump during off peak electric periods. Further analysis found that each additional foot of fluctuation resulted in a reduction of water age approximately 24 hours during the summer. To address potential DPW concerns that the additional fluctuation would result in lower pressures at some locations, the tanks could be filled an additional three feet to a level of 39 feet and allowed to only drop to 30 feet. This range allows for nine feet of fluctuation and would result in a similar reduction in water age and still provide one foot of freeboard in the storage tanks.

An analysis was performed to determine the storage volume needed at the Maple Street Tank site. According to the Water Distribution System Study completed by Tata & Howard in 2006, the required storage for the Paxton system in 2025 is 0.34 mg. The Asnebumskit Tank has a total volume of 1.0 mg, which is more than the volume required even taking into consideration the additional storage requirements due to projected growth in the system by 2033. As part of the analysis, the basic fire flow of 1,500 gpm used in the Water Distribution System Study was simulated at various locations north of the Maple Street Tank. To meet this fire flow, a storage tank is required in the northern part of the distribution system. It was determined that approximately 80 percent, or 150,000 gallons, of the needed fire flow in the northern part of the distribution system was coming from the Maple Street Tank. Fluctuating the water level in the tanks nine feet per day equates to approximately 50,000 gallons of storage if the new elevated tank were to have the same 40-foot sidewall depth as the Asnebumskit Tank. In order to maintain 150,000 gallons for fire flow in the tank if the water level was nine feet down, a minimum of 200,000 gallons was required for the new tank.

The estimated dimensions of a new glass fused to steel elevated tank were a 64-foot tall pedestal, a diameter of 30.77 feet, and a sidewall height of 37.59 feet, giving the tank a nominal capacity of 209,100 gallons. Using these tank dimensions, the summer and winter demand conditions and an operating scenario of approximately six to seven foot fluctuation, the hydraulic model was used to estimate the water age in the two storage tanks. With the new tank, the estimated water age at the Asnebumskit Tank increased from approximately 250 hours in the summer to 270 hours and in the winter from approximately 290 hours to 320 hours. The estimated water age in the new Maple Street Tank in the summer decreased from approximately 570 hours to 310 hours and in the winter from approximately 770 hours to 425 hours. The increase in age at the Asnebumskit Tank is due to the increased gallons per foot of storage at the proposed new Maple Street Tank.

A combination of the previous two potential improvements was also examined. Using the same demand conditions as used above, but combining the increased fluctuation (nine foot fluctuation) with the new elevated storage tank dimensions provided, the estimated water age at both tanks decreased dramatically. During the summer, the estimated water age at the Asnebumskit Tank reduced to approximately 190 hours and during the winter to approximately 210 hours. At the Maple Street Tank, summer water age reduced to approximately 250 hours and winter water age to approximately 300 hours, as shown in Figure 7.

Estimated Summer Water Age with Improvements

Storage Tank	Water Age (hours)			
	Current Operations	Fluctuate Tanks Nine Feet	New Maple Street Tank	Additional Fluctuation and New Storage Tank
Asnebumskit Tank	250	170	270	190
Maple Street Tank	570	500	310	250

Estimated Winter Water Age with Improvements

Storage Tank	Water Age (hours)			
	Current Operations	Fluctuate Tanks Nine Feet	New Maple Street Tank	Additional Fluctuation and New Storage Tank
Asnebumskit Tank	290	180	320	210
Maple Street Tank	770	630	420	300

Figure 3 Estimated Summer and Winter Water Age with Improvements

Conclusions and Recommendations

The water quality issues, particularly the low chlorine residual in the outskirts of the distribution system, could be attributed primarily to the long residence time of the water in the Maple Street Tank, and to a lesser degree in the Asnebumskit Tank. The long residence time in the Maple Street Tank reduced the concentration of the remaining free chlorine to approximately 0.04 mg/L.

In addition, the water level in the Maple Street Tank did not fluctuate enough, which caused the water age to increase and the chlorine in the water to decay. Simply removing the tank was not an option because the tank is needed to provide fire protection in the northern part of the system as well as provide redundant storage in case the Asnebumskit Tank is offline.

The evaluation showed that replacing the Maple Street Tank with a 200,000-gallon elevated tank with sidewalls approximately 40-feet in height would reduce the residence time in the tank, which would reduce the amount of chlorine decay that occurred. Additionally, increasing the tank fluctuation to what is stated in the DPW's operating procedures would further decrease the water age by approximately 100 hours. These two improvements would greatly reduce the amount of time the chlorine in the water could decay.

Also, it was recommended that a chlorine booster pump station be installed. Flow patterns in the system indicated that the optimal location for the station was the Maple Street Tank due to its proximity to the outer extremities of the distribution system.

Conclusion and Construction

As a result of the study, a 210,000-gallon elevated glass-fused tank (Figure 8) was constructed at the existing Maple Street site in 2016. The new 35-foot tall tank has a 65-foot pedestal, utilizes a Tideflex mixing system with an external chlorine booster pump, and has the Town's communication antennas mounted on top of the tank. The 24-foot diameter pedestal houses the Town's communication equipment and also provides equipment storage.

Figure 4 New 210,000-Gallon Elevated Glass-Fused Tank Constructed in 2016

There were no major change orders during construction and the project was completed on time and on budget. The Town received 100% DWSRF funding for the project.

Chlorine residuals have improved with the new tank and chlorine booster pump. The amount of chlorine leaving the Maple Street tank, which was 0.04 mg/L prior to the improvement project, is now consistently maintained at 0.3-0.6 mg/L. The Town of Paxton continues to monitor the chlorine residuals at the extremities of the system, and has been very satisfied with the results of this key distribution improvement project.