SECTION 3.0
EXISTING SYSTEM EVALUATION

After updating the demand information in the model, PARE used the hydraulic model to evaluate system performance. PARE evaluated an average day demand (ADD) scenario, a maximum day demand (MDD) scenario, a peak hour (PH) demand scenario, and a fire flow analysis. PARE evaluated the available pressure throughout the system, as well as the available fire flow. PARE also evaluated the performance of the system pump stations and the rate at which the system storage tanks either filled or drained during each scenario.

AWWA Document M32 – *Distribution Network Analysis for Water Utilities* and *Recommended Standards for Water Works (Ten State Standards)* were used as guidelines in performing the hydraulic analysis. These documents dictate that the maximum day demands should be afforded through the system's source capacity, not distribution storage. Distribution storage shall provide the additional peak hour demands and fire flow. These documents also dictate that the fire flow at any given point in the system would be the rate of flow of water obtainable at a minimum residual pressure of 20 psi. Furthermore, these documents require that all points in the distribution system also maintain a minimum residual pressure of 20 psi during fire flow conditions.

PARE conducted two types of hydraulic analyses for the Town of Southborough, a steady-state analysis and an extended period analysis. A description of each analysis is provided below.

3.1 STEADY STATE ANALYSIS

The most common type of hydraulic model analysis is a steady state analysis. A steady state analysis provides a "snap shot" or an overview of system performance during an average day, maximum day, or peak hour demand scenario. A steady-state analysis is a useful tool because it provides a reasonable representation of system performance during each of the demand scenarios. PARE created a steady state demand scenario for the ADD, MDD, and PHD demand scenarios. The demand scenarios were established by dividing the total system demand for the ADD, MDD, and PHD over the entire model network.

There are 133 nodes in the High Service Area, six of which represent major users (note that nodes inside pump stations were not counted because they are not assigned a water demand). The ADD for the High Service Area is approximately 577,000 gpd, of which 73,000 gpd is attributed to major users. The remaining 504,000 gpd was distributed over 127 nodes in the High Service area (i.e., 2.76 gpm/per node). Each of the six major users has one node assigned to them, and their ADD was assigned to that node. For example, the Fay School, which is represented by node J-1022, averages approximately 10,900 gpd (7.57 gpm). Therefore, node J-1022 was assigned an ADD of 7.57 gpm.

There are 195 nodes in the Low Service Area, 11 of which represent major users (some major users share the same node). The ADD for the Low Service Area is approximately 512,000 gpd, of which 100,000 gpd is attributed to major users. The remaining 412,000 gpd was distributed over 184 nodes in the Low Service Area (i.e., 1.55 gpm/per node). Each of the 13 major users was assigned their individual ADD.

3.1.1 *Hydraulic Evaluation*

PARE used a steady state analysis to evaluate typical system pressures and the net change in system storage for the ADD and MDD scenarios. AWWA M32 recommends that a water system should have the capability of meeting system demands with system operations consisting of removing from service the largest active pump in each pump station. All remaining pumps within the pump stations may be active as required. This is consistent with Ten States, which recommends that system components be sized to provide the peak water demands with one pump in each station off-line. Therefore, PARE evaluated the system with the largest pump in each station off-line. In this case, the 650-gpm pump in the Hosmer Station was turned off. While Hosmer has an emergency backup motor for the 650-gpm pump, the pump itself is not redundant, and therefore the larger of the two pumps in the station was turned of. Both 550-gpm pumps in the Boland Station were left on because that station is equipped with a separate emergency backup pump with a capacity of 1,000-gpm, which technically is the largest pump in the station.

For the steady-state analysis, each of the three water system storage tanks were set to the bottom of their respective equalization levels, or 503 ft for Tara Road, and 482 ft for Oak Hill and Clear Hill.

The results of the steady-state analysis evaluation for existing conditions are summarized in the table below and the hydraulic model reports are attached as Appendix G.

TABLE 3-1: System Evaluation (Steady State Analysis)

	Available Pressure			Available Fire Flow
	Average Day Demand	Maximum Day Demand	Peak Hour Demand	
High Service Area	23 - 105 psi	23 - 110 psi	23 - 106 psi	650 - 4,000 gpm
Low Service Area	29 - 123 psi	29 - 123 psi	29 - 125 psi	830 - 4,900 gpm
Tank Filling Rate (HSA)	276 gpm	223 gpm	- 781 gpm	
Tank Filling Rate (LSA)	320 gpm	-235 gpm	-455 gpm	

Ten States recommends that systems operate within a pressure range of 35 to 90 psi, which is consistent with the MA DEP regulations. Relative to Ten States and MA DEP regulations, it appears as though most of the system is operating within an acceptable pressure range during an ADD, MDD, and PH demand scenarios. The pressure in the High Service Area ranges from 22 to 110 psi, with 7 nodes (out of 133 nodes) falling below 35 psi and 45 nodes above 90 psi on a regular basis. The pressure in the Low Service Area ranges from 29 to 125 psi, with 1 node (out of 195 nodes) falling below 35 psi and 62 nodes above 90 psi on a regular basis.

The area of Town in the Low Service Area with low pressure is along Oak Hill Road, which is in the vicinity of the Oak Hill Tank. The ground elevation in this portion of Town ranges from 400 to 434 ft MSL. The overflow of the Oak Hill Tank is 493 ft MSL and the bottom of the normal operating range is 482, therefore the highest elevation in the Low Service Area that will routinely experience a static pressure as low as 35-psi is approximately 401 feet. Portions of the Low Service Area that experiences high pressure are areas around the Sudbury Reservoir and some areas along the Hopkinton town-line. Portions of the Low Service Area below 285 ft MSL will routinely experience pressure above 90 psi.

The area of Town in the High Service Area with low pressure is along Tara Road, which is in the vicinity of the Tara Road Tank. The ground elevation in this portion of Town ranges from 440 to 450 ft MSL. The overflow of the Tara Road Tank is 515 ft MSL and the bottom of the normal operating range is 503 ft, therefore the highest elevation in the High Service Area that will routinely experience pressure as low as 35-psi is approximately 422 feet. There are several areas in the High Service Area that experience pressure above 90 psi, including Fisher Road and most of the area between Main Street and Rt. 9, with the exception of the area around the Tara Road tank. Portions of the High Service Area below 307 ft MSL will routinely experience pressure above 90 psi.

Appendix H provides a color-coded system map that indicates available system pressure on a maximum day.

3.1.2 *Supply Evaluation*

During an ADD scenario, the system pumps are able to keep up with system demand, as is evident by the net filling rate of the system storage tanks. On a MDD when the largest pump in each station is off-line, demand outpaces the pump stations' ability to supply water, as is evident by the net draining rate of the system storage tanks.

The Boland Station in the High Service Area has a capacity of approximately 1.58 MGD, or 1,100 gpm (with the largest pump off-line). The MDD for the High Service Area is approximately 1.46 MGD, or 92 percent of the station's capacity.

The Hosmer Station, in the Low Service Area, has a capacity of approximately 0.79 MGD, or 550 gpm (with the largest pump off-line). The maximum day demand for the Low Service Area is approximately 1.30 MG, or 165 percent of the station's capacity.

Based on these results, it appears as though the Boland Station has adequate, although marginal, capacity to supply the maximum day demand to the High Service Area with one-pump off-line. However, the Hosmer Station has a significant capacity deficit during a maximum day demand scenario with one pump off-line. With both pumps on-line, the station capacity of Hosmer is approximately 1.73 MGD, which is adequate for a maximum day, but provides no redundancy in the system. When the existing PRVs between the High Service Area and the Low Service Area allow water to be shared between the two service areas, the total pump station capacity in the system would be approximately 2.37 MGD, still 0.39 MGD short of the total system demand on a maximum day (i.e., 2.76 MGD). Therefore, even if the PRVs allowed water to be shared between the two services areas, the system would have a deficit in pump station capacity.

3.1.3 *Storage Tank Evaluation*

The distribution system currently has 2.04 MG of storage capacity in three tanks, the Tara Road tank in the High Service Area, and the Oak Hill and Clear Hill tanks in the Low Service Area. PARE evaluated the useable storage volume in both service areas. The useable volume is defined by AWWA as the volume above an elevation that would provide a minimum of 20 psi to the entire service area. To determine the useable storage, PARE took the elevation of the highest service connection and added 46 feet (i.e., 20 psi x 2.31) to establish the minimum useable water level in the system tanks. In the High Service Area, that elevation is 450 ft. In the Low Service Area, that elevation is 415 ft. Therefore, the total useable storage area in the High Service Area is 0.52 MG, and in the Low Service Area is 0.46 MG. System-wide, useable storage is 0.98 MG, significantly less than the total storage volume.

As stated in PARE's previous report on system storage, there is no set requirement for how much storage a system must have to operate, it is typically considered prudent to size storage for normal use, fire flow events, and emergency conditions. Each system, depending on its size and the adequacy of its supply pumps, will determine how much storage is necessary to satisfy these three requirements. In this case, PARE assumed that the volume of storage dedicated to normal use (also called equalization storage) should equal approximately one-half the maximum day's demand. The portion reserved for fire flow volume should be based on a fire flow rate and duration. Typically 3,500 gpm for three-hour duration is the maximum that would be required for a largely residential system such as Southborough. Finally, a system should have adequate emergency storage to prevent serious disruptions in service in the event of a water main break or other emergency situation. In this case, PARE assumed one-half the maximum day's demand would be adequate for emergency volume.

Therefore, in the High Service Area an appropriate amount of storage would be 2.1 MG (i.e., 0.73 MG + 0.63 MG + 0.73 MG = 2.1 MG). The current useable storage in the High Service Area is 0.52 MG, significantly less than 2.1 MG.

In the Low Service Area, an appropriate amount of storage would be 1.9 MG (i.e., 0.65 MG + 0.63 MG + 0.65 MG). The current useable storage in the Low Service Area is approximately 0.46 MG, significantly less than what would be considered adequate for this service area.

3.1.4 *Pipe Evaluation*

AWWA Document M32 was used as a guide in evaluating the adequacy of the piping in the distribution system. AWWA suggests that pipe segments are deficient, or limiting, if the have any of the following conditions:

- Velocities greater than 5 ft/sec;
- Head losses greater than 10 ft/1,000 ft; or
- Large-diameter pipes (i.e., 16-inch or greater) having head losses greater than 3 ft/1,000 ft.

Please note that pipes inside pump stations may routinely exceed the conditions described above, given that these pipes usually carry large volumes of water. However, given that these pipe sections are generally short, the overall impact on the system is generally small, and therefore pipes inside pump stations were not considered in this evaluation.

PARE used the hydraulic model to evaluate the system's piping network. The evaluation was conducted during a PHD scenario, when pipe velocities are anticipated to be at their highest. Based on the model results, there are no water mains in the system that have velocities in excess of 5 ft/ sec. The highest velocity in the system is in the 12-inch main along the service road to Hosmer, which has a velocity of 2.25 ft/sec.

PARE also reviewed the system for critical pipe segments, or segments that provide the sole sources of water to large areas of Town, or that provide a critical path for fire flow. While not currently causing significant adverse impact on the system, there are certain critical pipes that may be undersized or may not have significant redundancy.

Provided below is a list of system pipes that are critical to the system but appear to be either undersized or do not have substantial redundancy:

1. The 12-inch water main along the access road to the Hosmer Station (1,100 lf) – this main is the sole source of supply from the Hosmer Station to the Low Service Area;
2. The 12-inch and short section of 10-inch water main on Main Street between Northborough and Deerfoot Roads (4,200 lf) – while this main does have redundancy in the system, this main provides a significant critical path for fire flow to reach the north-central portion of Town;
3. The 12-inch water main on Sears Road (3,600 lf) – this water main has no system redundancy and is the sole source of supply to the north-central portion of Town;
4. The 12-inch water main on Rt. 9 between Crystal Pond and Deerfoot Roads (1,800 lf) – this water main has some redundancy in the system; however, a break in the main could cause a serious disruption in service to customers along Rt. 9;
5. The 12-inch water main that crosses under I-495 on Main Street (400 lf) – this water main has no redundancy in the system and is the sole source of supply to customers west of I-495;
6. The 6-inch water main on Rt. 9 between Brook Lane and Oak Hill Road (1,900 lf) – this water main has redundancy in the system, but given its small diameter, it appears to be a bottleneck for fire flow in that area of Town; and
7. The 8-inch water main that crosses under I-90 at Woodland Road (300 lf) – this water main appears to be a bottleneck as it is connected to two 8-inch mains on both sides of I-90.

As part of section 6 of this report, PARE evaluated potential capital improvements to either replace these system pipes or install redundant system pipes elsewhere in the system.

Please note that the 8-inch water main on Parkerville Road between Fairview and Middle Roads (600 lf) has no significant redundancy and is the sole source of supply to the southern portion of the High Service Area. However, the Town has recently installed a new 12-inch ductile iron water main along Parkerville Road to replace the existing 8-inch main. While this new main will also be a single connection with no significant redundancy, given its age and material the likelihood of this main breaking and leaving a large portion of the High Service Area without water is low. In addition, in an emergency the Town could backfeed this portion of the High Service Area through the Parkerville Road PRV. During that emergency situation, customers in this part of the High Service Area would experience pressures approximately 10 psi lower than what they currently experience, and fire flow would be significantly reduced. However, given that this would only occur during a short-term emergency condition, there may be no significant benefit to installing a parallel water main along Parkerville Road. Therefore, PARE is not proposing any capital improvements to address this apparent critical water main.

3.1.5 *Fire Flow Evaluation*

A fire flow demand that occurs during a MDD scenario is considered a limiting condition for service pumps and a piping system. Therefore, AWWA recommends that a fire flow analysis be conducted for a MDD scenario, in order to gauge a systems ability to meet critical water demands. PARE evaluated the available fire flow at each node in both service areas. As recommended by AWWA, the water level in each of the system storage tanks were set to the bottom of their equalization volumes, in order to represent a time of day when system storage tanks have been depleted by customer use. Furthermore, AWWA indicates that a water system should have the capability of meeting system demands with any one pump – preferably the largest pump – off line. Therefore, PARE evaluated the available fire flow with the emergency pump off-line in the Boland Station and with the 650-gpm pump off-line in the Hosmer Station.

The results indicated that the available fire flow in the High Service Area ranges from 625 gpm to 3,600 gpm and in the Low Service Area range from 840 gpm to 5,000 gpm. AWWA Document M31 – *Distribution System Requirements for Fire Protection*, indicates that 500 gpm is considered by some experts to be the minimum amount of water that can safely and effectively control any fire. It appears as though the system can provide at least 500 gpm to every node in the model. In addition, 290 of the total 328 system nodes have an available fire flow of 1,000 gpm or greater. Therefore, it appears as though fire flow is generally adequate in most areas of Town. Appendix I provides a color-coded system map that indicates available fire flow system-wide.

PARE conducted a separate fire flow for six specific locations that require significant fire flow volumes above 1,000 gpm. These locations, which are indicated in Table 3-2, were identified by the Insurance Services Office (ISO) as having insufficient fire flow. A copy of ISO's fire flow test reports are provided as Appendix J. Based on the model results, it appears as though the required fire flow is available at 3 of the 6 locations. Of the three locations that fire flow is not available, it appears as though existing piping in the vicinity of the locations may be undersized. In addition, it does not appear as though the PRVs are adequately contributing to the fire flow demand. Section 6 – Capital Improvements, will identify potential system improvements that could be made to provide adequate fire flow to these locations.

	TABLE 3-2: Summary of Fire Flow Analysis				
	Location	Needed Fire Flow based on ISO Requirements	Available Fire Flow		
			Based on ISO's Flow Tests	Based on PARE's 8-07 Flow Tests	Based on Model Results
1.	Marlborough Road @ St. Marks School	2,500 gpm	2,100 gpm**	**2,500 gpm**	**2,500 gpm**
2.	Trottier School	3,000 gpm	1,900 gpm***	**3,300 gpm**	2,500 gpm
3.	Mary E. Finn School	2,250 gpm	1,500 gpm**	1,800 gpm	1,550 gpm
4.	Highland Street @ Parkerville Road	1,500 gpm	1,200 gpm**	1,350 gpm	**1,550 gpm**
5.	Mt. Vickery Road @ Cordaville Road	3,500 gpm	1,600 gpm**	3,300 gpm	1,650 gpm
6.	Oregon Road @ Woodland Road	1,250 gpm	1,100 gpm***	**2,100 gpm**	**1,900 gpm**

* Results in bold text indicate that the required fire flow, as determined by ISO, is available at that location.
** ISO tests conducted in March 2002
*** ISO tests conducted in March 1990

In August of 2007, PARE conducted hydrant flow tests to verify the result of ISO's previous hydrant flow tests. PARE's hydrant flow test reports are provided as Appendix K. PARE's August 2007 hydrant flow tests consistently predicted a higher available fire flow than ISO's hydrant flow tests. The reason for this apparent discrepancy is due to the method used to conduct the hydrant flow tests. ISO uses a single hydrant methodology while PARE utilized a dual hydrant methodology. Both methods are common industry practices. A single hydrant method is generally more conservative because the test measures the drop in pressure at the flow hydrant, which includes 5 to 10 psi of pressure drop due to minor losses in the hydrant and hydrant branch. The dual hydrant method measures the drop in pressure at a residual hydrant upstream of the flow hydrant. This method does not account for losses in the hydrant or hydrant branch, and therefore usually results in a higher available fire flow. However, the dual hydrant test is a better predictor of the actual pressure in the water main, because it does not include losses in the hydrant. ISO's tests conclude that the needed fire flow is unavailable at all six locations. PARE's tests conclude that the needed fire flow is available at three locations.

The hydraulic model software utilizes a slightly different methodology to calculate available fire flow. ISO and PARE (prior to having the hydraulic model) utilized a methodology that only considers the hydrant in question and does not gauge how other areas of the system would respond to a fire flow event. The hydraulic model considers the system as a whole and estimates the available fire flow at a single hydrant while maintaining 20 psi everywhere in the system. As a result, other areas in the system might fall below 20 psi before the subject hydrant. For example, based on PARE's hydrant flow test, the available fire flow at Mount Vickery Road and Cordaville Road is estimated to be 3,300 gpm. However, the hydraulic model estimates that the available fire flow is 1,650 gpm. The difference is because pressure along Davis Road, approximately 0.25 miles east of Cordaville Road, falls to 20 psi when the hydrant on Cordaville Road flows at 1,650 gpm. Therefore, a more conservative estimate of available fire flow would be 1,650 gpm, even though the fire department could conceivably draw more water from the system at Cordaville Road while maintaining 20 psi at that location. However, customers on Davis Road would experience pressure below 20 psi, and may even experience negative pressure under extreme conditions.

Similar to PARE's hydrant flow tests, the model does not consider losses in the hydrant and hydrant branch, which can lead to a higher available fire flow than ISO's tests. However, the model predicts the pressure in the actual water main, which is more critical to protecting public health than the pressure at the hydrant outlet. Therefore, for the purposes of this evaluation, PARE is going to utilize the results of the hydraulic model to assess which locations fire flow is available and which locations fire flow is unavailable. PARE considers the available fire flow at St. Mark's School, Highland Street, and Oregon Road to be adequate, based on the results of the model evaluation. The available fire flow at Finn School, Trottier School, and Cordaville Road is considered inadequate.

To rectify the insufficient fire flow at these three locations, the Town may need to make certain improvements to the system. These improvements will likely include upgrading certain pipe sections to larger sizes and upgrading the existing PRVs. Such capital improvements are described in detail in section 6.

3.1.6 *PRV Evaluation*

PARE is currently conducting an evaluation of the system's existing four PRVs. It is our understanding that the PRVs rarely open during times of peak demand and therefore don't effectively move water from the High Service Area to the Low Service Area. Golden Anderson (GA), the manufacturer of all four PRVs, states that a minimum of 10-psi pressure reduction is required for satisfactory valve operation. The static head difference between the two service areas is 22 feet, or 9.5 psi, and is therefore less than recommended by GA. This may be one reason that the valves are not working properly. In addition, during peak water demand, the pressure difference at the inlet and outlet of the valve will vary. PARE utilized the hydraulic model, as well as pressure data collected in the field, to evaluate the upstream and downstream pressure at each valve location. Based on the data collected and the results of the hydraulic model, it appears as though typical pressure between the inlet and outlet pressure at all four PRVs ranges from 2 to 9 psi, even less than would be predicted by the static elevations of the system storage tanks.

GA also recommends that the velocity through the valve be 10-20 ft/sec, with a target velocity of 15-ft/sec. As such, PRVs are typically one to two sizes smaller than the actual line size, e.g. a 10-inch pipe might require an 8-inch or 6-inch PRV. Currently, all four PRVs are sized the same as the line size, which may be a contributing factor to their poor operation.

3.2 EXTENDED PERIOD ANALYSIS

While a steady state analysis is a valuable tool for evaluating system performance, it is important to understand its limitations. Because a steady state analysis provides only a "snap shot" of system performance, it cannot be used to evaluate tank fill/drain cycles, pump controls, water age, contaminant movement, etc. For these types of analyses an extended period simulation is utilized. An extended period simulation provides a dynamic evaluation of system performance over a fixed time period, usually anywhere from 24 to 72 hours. An extended period simulation can be used to determine how quickly the system tanks fill/drain, when system pumps turn on and off, the age of the water in any given section of the system, and fluctuations in pressure over the course of a given time period. In addition, an extended period simulation can be a valuable tool for predicting contaminant movement within a system, in the event that the Town experiences a contamination event. While an extended period analysis can do all these things, PARE utilized the extended period analysis primarily as a tool to measure water age in the system. However, in the event that the Town needs to conduct any of the other types of analyses described above, the model has the necessary extended period scenarios established for future evaluations.

PARE established an extended period analysis for the average day and maximum day demand scenarios. In addition, PARE created a minimum day demand scenario to evaluate water age. Typically, when system demand is lowest water age is highest, which can result in unpleasant water quality and possibly bacteriological growth at the ends of the system.

In order to perform an extended period analysis, PARE evaluated water demand over a typical

24-hour period. By reviewing pump records and tank charts for several different days between 2005 and 2007, PARE was able to evaluate the amount of water used by the Town for each hour of a typical day. The demands used during our steady state analysis were used as a base demand at each node in the model. For each hour of the day the base demand was adjusted by a peaking factor to represent the typical water demand during that time of day. For example, during the late night and early morning hours when water demand is low, the base demand on each node was multiplied by a factor less than 1 (i.e., 0.3, 0.6, 0.7, etc.). During high water demand times, such as between 7:00 am and 10:00 am and around dinnertime, the base water demand was multiplied by a factor greater than 1 (i.e., 1.25, 1.6, 1.7, etc). PARE established a unique multiplier for each hour of the day by reviewing water meter records and tank charts as described in section 2.1. Table 3-3 shows the hourly multiplier for each hour of a typical minimum, average, and maximum day scenario. Appendix L provides a graph of typical hourly peaking factors for the Town of Southborough over the course of a 24-hour period.

TABLE 3-3: Hourly Peaking Factors

Hour	Peaking Factor
0-1	0.46
1-2	0.63
2-3	0.81
3-4	1.50
4-5	1.93
5-6	2.05
6-7	1.62
7-8	1.20
8-9	1.02
9-10	0.95
10-11	0.88
11-12	0.76
12-13	0.68
13-14	0.84
14-15	0.94
15-16	0.84
16-17	1.07
17-18	1.02
18-19	1.09
19-20	0.81
20-21	0.80
21-22	0.72
22-23	0.77
23-24	0.62

3.2.1 *Water Age Evaluation*

An important indicator in the overall performance of a system is the age of the water in the pipes, also known as the hydraulic residence time. The US Environmental Protection Agency (EPA) conducted a study in 2002 in which they reported that based on a survey of 800 utilities in the US the average hydraulic residence time was 1.3 days, with a maximum time of 3 days. The report also suggests that water age increases as the size of the system decreases. The EPA study cites one example of a system with a population of 24,000 that has a water age of 12-24 days. While there is no set requirement for minimum or maximum water age, utilities should be cognizant of their system's water age because elevated water age can lead to taste and odor complaints, increases in temperature, increases in disinfection byproducts, decreases in disinfection residual, and other water quality issues. The appropriate water age for any particular system is a function of the age and material of the pipes, the type of disinfection utilized (i.e., chloramines, chlorine, etc.), and the amount of organic matter in the system.

PARE utilized the model to estimate the age of water throughout the Southborough system. During the minimum day scenario, which is generally representative of the winter months, the oldest water in the system is located between Rt. 9 and the Hopkinton town-line, as well as the southern half of the High Service Area. Water along the Hopkinton town-line, which is the oldest in the system, ranges in age from 8-13 days. Water in the southern half of the High Service Area ranges in age from 3-11 days. During an average day scenario, water age along the Hopkinton town-line ranges from 3-5 days, and during a maximum day demand scenario, ranges from 0.5 to 3 days. However, to determine more precisely that actual water age and the impact of water age on water quality, the Town would need to undertake a more comprehensive study of hydraulic residence time, which may include trace analysis for chlorine residual and disinfection byproducts, pH, temperature, and total organic carbon.

It appears as though the age of water in the system in the winter is significantly higher than during the other months of the year. As a result, the Town could experience water quality problems along the Hopkinton town-line and in the southern half of the High Service Area. The reason water age is elevated in the winter months is that there is essentially too much water in the system and not enough demand. To decrease water age, the Town can do two things – reduce the amount of water in the system or increase system demand. It's probably impractical for the Town to reduce the amount of water in the system. In order to reduce the amount of water in the system the Town would need to eliminate pipes, particularly large diameter pipes. However, this would have an adverse impact on fire protection Town-wide, and would eliminate service to some customers. Therefore, the Town must increase demand in order to reduce hydraulic residence time. The Town cannot mandate that customers increase their water consumption in order to reduce water age, but the Town can artificially increase demand by increasing the frequency of hydrant flushing or installing permanent blow-off valves on dead-end mains.

Therefore, PARE recommends that the Town perform an evaluation of their flushing program in order to identify the most effective means of circulating water in the southern half of Town by the Hopkinton town-line and along the western half of Rt. 9. The evaluation should consider what time of year pipes are flushed, the direction in which pipes are flushed, and the frequency of flushing.

The Town could also use this as an opportunity to create a unidirectional flushing (UDF) program, which would optimize the flushing program town-wide, not just in areas of elevated water age. The purpose of a UDF program is to optimize the Town's existing hydrant flushing program. It focuses on using the minimum amount of water to flush the system while attaining the maximum removal of sediment, bio-film, and stagnant water. The central premise behind a UDF is to move water in one direction, away from the source to the ends of the system by closing specific valves to direct the flow of water in the system. A well planned and executed UDF program can save a substantial amount of water and can significantly increase scouring velocities over a traditional flushing program. Another benefit of a UDF is that in the event of a contamination event, the UDF program can be utilized to effectively isolate and contain the contaminant outbreak and efficiently remove it from the system through flushing.