Results of the Comprehensive Performance Evaluation for the City of Denmark Water System Denmark, South Carolina

March 25 - 29, 2019

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Date of Site Visit:

March 25 - 29, 2019

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OVERVIEW

A ground water/distribution Comprehensive Performance Evaluation (CPE) was conducted during the week of March 25, 2019 at the City of Denmark, South Carolina Water System by Process Applications, Inc. (PAI). This CPE was conducted at the request of the South Carolina Department of Health and Environmental Control (DHEC) because of a history of customer complaints indicating inadequate operation and management practices as well as periodic discolored water issues related to iron from their wells. The evaluation included a review of selected historical water quality data, Special Studies to assess current water quality in the distribution system, and interviews with City of Denmark personnel to collect information about the water system's policies, procedures, and roles and responsibilities with respect to the ground water and distribution system operation and water quality.

The CPE is the evaluation component of a larger optimization program (the Composite Correction Program), which focuses on improving and maintaining excellent water quality in the water treatment plant and distribution system. This is achieved by working with existing facilities and water system personnel, to optimize water system operations (e.g., process monitoring and control), rather than making design changes in a system. The Composite Correction Program (CCP)[1], developed by PAI and the USEPA Technical Support Center, has been used nationwide since 1988 to optimize surface water treatment plant performance with respect to protection from microbial pathogens. The USEPA Region 6 Office initiated a development and demonstration project in 1999 to apply the CCP concepts to ground water systems. Between 2007 and 2014, development work was also conducted by the USEPA Technical Support Center and PAI on incorporating distribution system optimization concepts into the CPE. The following report presents the findings from this CPE and is intended to provide the City of Denmark with information that can be used to enhance and maintain their drinking water quality.

<u>It is important to understand that the information in this report is presented in the context of optimization.</u> The term *optimization* in this report refers to <u>voluntarily</u> improving drinking water quality to the highest levels possible, which are normally above those required by USEPA and the State of South Carolina Primary Drinking Water Regulations. Water systems that choose to voluntarily

[1] Hegg, B.A., L.D. DeMers, J.H. Bender, E.M. Bissonette, and R.J. Lieberman, Handbook - Optimizing Water Treatment Plant Performance Using the Composite Correction Program, EPA 625/6-91/027, USEPA, Washington, D.C. (August 1998).

pursue optimization, versus simply meeting the regulatory requirements, believe that optimization will allow them to provide the highest levels of public health protection and water quality to their customers.

PERORMANCE GOALS

To pursue optimization at a water system, goals must be established and the system performance must be measured against those goals. There are three barriers to contamination present at conventional ground water systems: 1) the well site where proper siting, construction, natural filtration, and source protection act as a barrier to microorganisms; 2) the point of disinfection where microorganisms are inactivated or killed; and 3) the distribution system where an environment for regrowth or recontamination is avoided. The three barriers are graphically depicted in Figure 1.

For each barrier, a set of goals has been established. These goals are not regulatory requirements but have been found to be helpful tools for optimizing performance. The goals, along with the barriers they represent, are presented in Table 1.

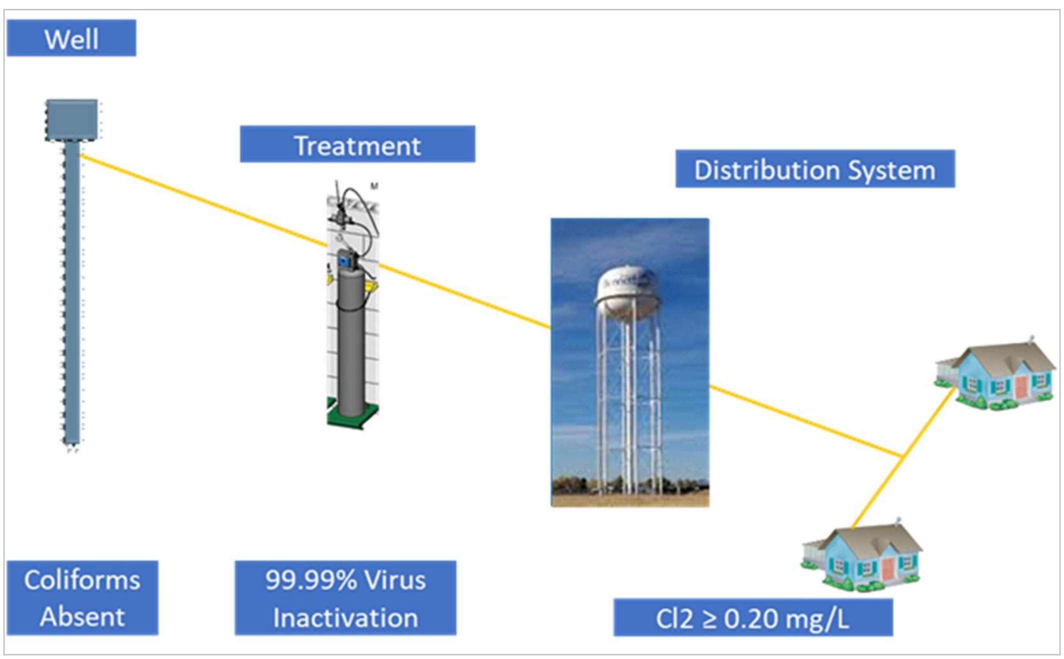


FIGURE 1. Ground water system multiple barriers and related optimization goals.

TABLE 1. Performance goals description.

Criteria	Barrier Measured
Less than 5% of total coliform analysis results for samples taken at all wells test positive for coliforms in raw water.	Well Siting
At least 99.99% virus inactivation achieved at the first customer. Disinfectant concentrations below the Maximum Residual Disinfectant Level (MRDL) (i.e., highest level of disinfectant allowed in drinking water is 4.0 mg/L for chlorine).	Point of Treatment (Disinfection)
Not more than 5% total coliform positive samples based on the last 12 months of compliance monitoring. Not more than 5% disinfectant residual results below 0.20 mg/L in distribution system monitoring.	Distribution

UTILITY INFORMATION AND DESCRIPTION

The City of Denmark supplies water to approximately 1,500 connections, including service to two local colleges (Voorhees College and Denmark Technical College). The population served is approximately 3,500. The system, including sources, treatment, and distribution, is owned and operated by the city. The water utility is managed by the Public Works Director who oversees two certified operators (Class D) and additional utility workers. The weekday routine includes a morning meeting at the city shop to coordinate daily activities, including daily visits to the wells and storage tanks. On a weekly basis, city personnel implement a hydrant flushing program that includes locations that coincide with their monthly coliform sampling.

The Denmark Water System (Figure 2) uses ground water from three well locations – East Voorhees Road, West Voorhees Road, and Acacia. One well is located at each site, and capacities are 330 gallons per minute (gpm) (E. Voorhees), 300 gpm (W. Voorhees), and 400 gpm (Acacia). A fourth well, Cox Mill, has not been used since last August due to iron bacteria plugging the well screen and issues related to a non-FIFRA registered chemical being fed to the well; FIFRA is the Federal Insecticide, Fungicide, and Rodenticide Act that was passed to regulate pesticide distribution, sale, and use. Water from the wells is disinfected with chlorine gas at each well site. Water is supplied to customers by a distribution system consisting of a variety of pipe materials, including cast iron, ductile iron, and polyvinyl chloride (PVC). Pipe sizes vary from 1/2-inch to

12-inch diameter, and the city has been implementing replacement programs to replace the smaller line sizes with 6-inch piping. Three elevated water storage tanks are located in the system. Two of the tanks are owned by the city (i.e., the East Voorhees tank (125,000 gallon capacity) and the South Locust tank (250,000 gallon capacity). A third tank is tied into the Denmark potable water distribution system but owned by the county; the city is currently the only user of the tank.

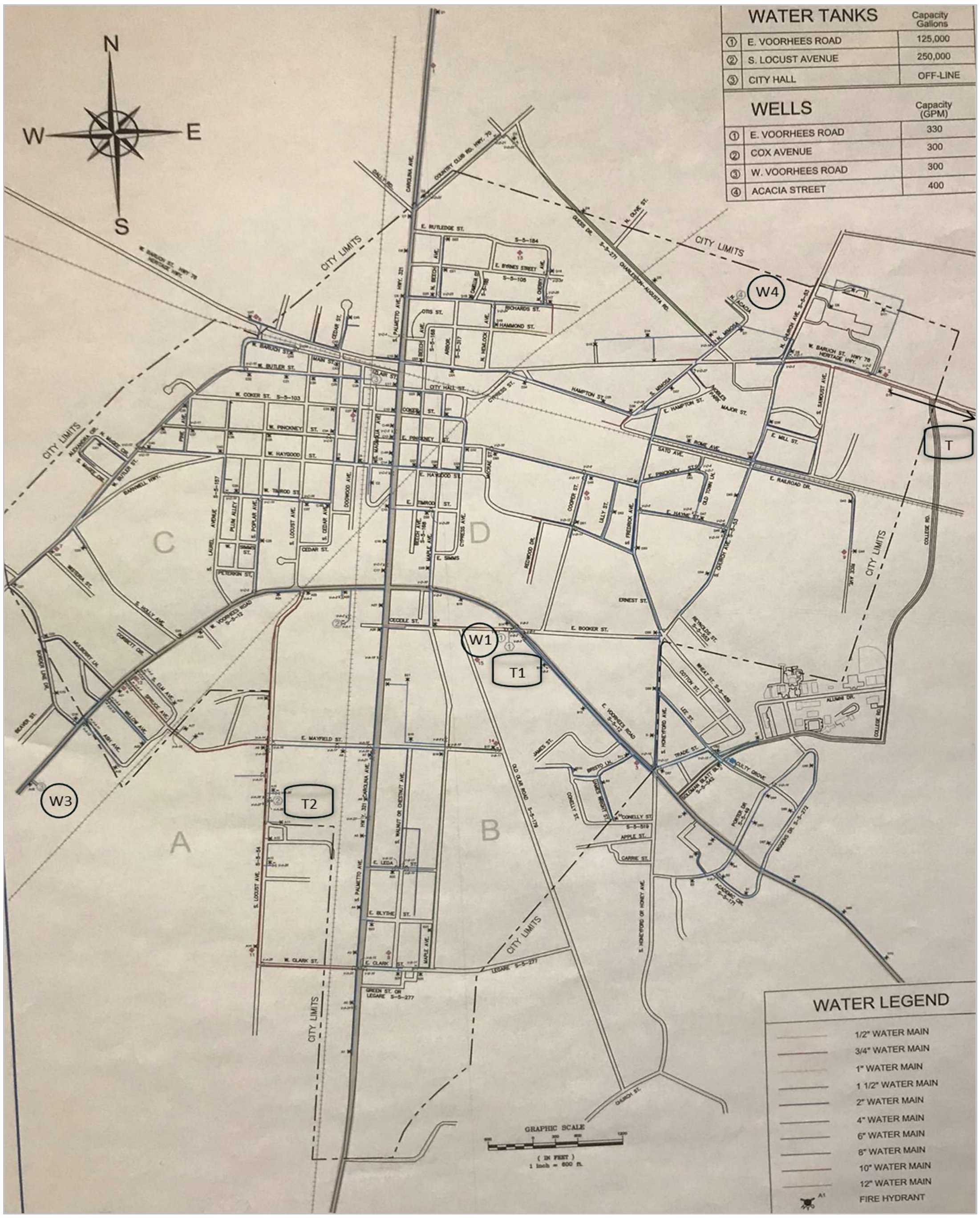


FIGURE 2. Denmark water system schematic.

PERFORMANCE ASSESSMENT

To determine if the Denmark Water System meets the optimization goals, an assessment of the past and present performance of the water system must be conducted. This performance assessment is intended to identify whether the source, disinfection treatment, and distribution systems are providing multiple barrier protection through optimal performance and if each barrier is capable of complying with current regulations. The performance assessment uses the performance criteria listed in Table 1 and is based on data collected from plant records and data collected during Special Studies and interviews performed during the CPE.

Well Assessment – Barrier 1

As shown in Table 1, wells should be evaluated against the total coliform performance goal. During the well assessment, it was necessary to collect several raw water samples for analysis. This sampling was performed at the Denmark Water System on March 26, 2019. Samples were collected from the three active wells and analyzed for total coliform and *E. coli* bacteria. The results of the raw water analyses are displayed below in Table 2.

TABLE 2. Summary of Barrier 1 performance.

Analysis	East Voorhees Well	West Voorhees Well	Acacia Well
Total Coliform	Absent	Absent	Absent
E. coli	Absent	Absent	Absent

The results in Table 2 indicate that performance goals for raw water were met on the day the samples were collected. The sample results, however, represent the water quality on a single day and may not be indicative of long-term trends. A limited history of raw water monitoring for coliforms exists for the Denmark wells, so a long-term trend cannot be established. However, the investigative monitoring performed during the CPE site visit can be used to begin to establish a long-term record. In addition to the investigative monitoring performed at the wells by the CPE team, inspections of the well heads were also performed to determine if sanitary defects could potentially affect the ability of the wells to meet the coliform goals in the future. The results of the sanitary inspections for each well are presented below.

West Voorhees Well

A lumberyard is located a few hundred feet from the well head, but there did not appear to be any activity on the day of the inspection that would increase the risk of contamination to the West Voorhees Well. The well appears to be vented through an old sounding tube that terminates at the well head (see Figure 3 below). The vent is not turned downward to prevent rain from entering the well and is screened with a mesh that is too large to prevent small insects from entering the well vent (#24 mesh screens are considered best for preventing insects from entering the well). Although the wells met the performance goal of no total coliform organisms present during the week of the CPE site visit, these sanitary defects could allow contamination of the well in the future.

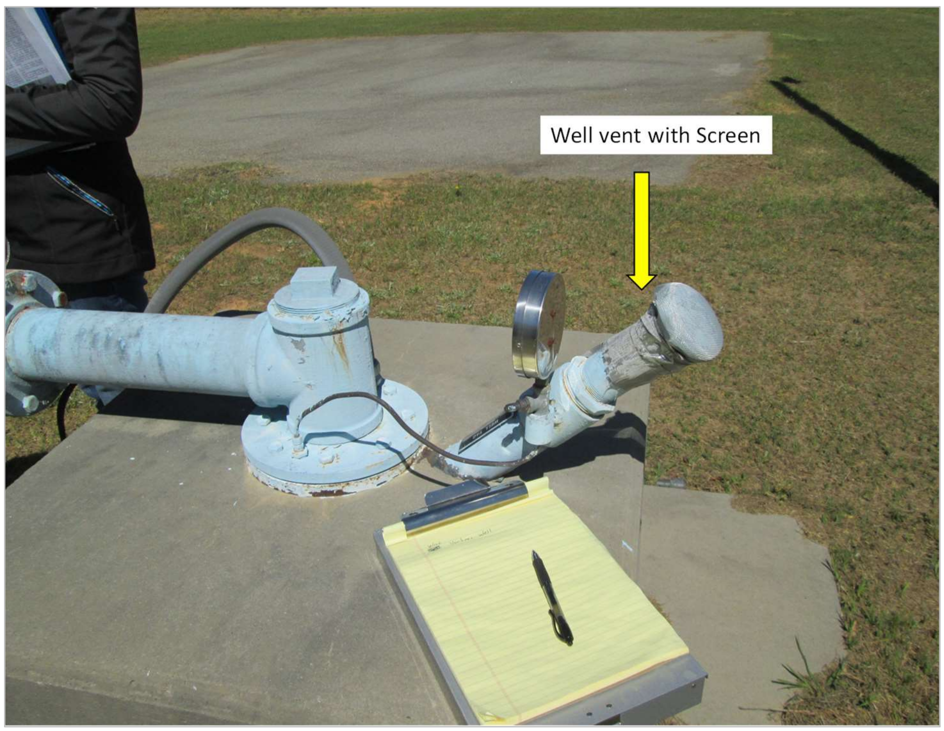


FIGURE 3. West Voorhees well head showing vent.

East Voorhees Well

The East Voorhees well head and well seal sit virtually on top of the well pad (see Figure 4). Well casings should extend at least 12 inches above the top of the well pad to prevent runoff from entering the well and to prevent dust that collects on the well pad from entering the well. There appear to be vents on the well head on three of the four sides, the largest of which was screened but not with a fine enough screen (larger than #24 mesh), and the others were not screened (see Figure 5 for a photo of the vent that was screened showing greater than #24 mesh). Also, at the East Voorhees well, there is a gap at one corner of the well head between the well head and the well pad (see Figure 6). The gap could allow runoff to seep into the well head area and potentially enter the well through the well head. The well head has two air relief valves just downstream of the well, each with an air vent that is not turned downward and not screened. Air relief valves open when air is blown off. They should be turned downward to prevent rain from entering and should be screened to prevent insects from entering. The air relief valves can be seen in Figure 4.

FIGURE 4. East Voorhees well head and pad (casing does not extend 12 inches above pad and air relief valve discharge is not downturned and screened).

FIGURE 5. East Voorhees well vent (well vent with screen mesh larger than #24).

FIGURE 6. East Voorhees well mounting (crack shown between well head and pad).

Acacia Well

The Acacia well has a vent that is properly turned downward, but it is screened with a coarse mesh screen (larger than #24 mesh). A vent screen that is not as fine as #24 mesh can allow small insects to enter the well. There is an electrical conduit line that penetrates the well pad about 10 inches from the well, allowing a route of contamination to the well (see Figure 7).

FIGURE 7. Acacia well site (electrical conduit shown penetrating well pad).

<u>Point of Treatment (disinfection) – Barrier 2</u>

The optimization goal encourages ground water systems with disinfection to be capable of inactivating 99.99% of the viruses present in the raw water by the time the water reaches the first customer. The percent inactivation of viruses is determined by using the peak instantaneous flow and the range of disinfectant residuals expected. The product of the disinfectant contact time at peak instantaneous flow and the disinfectant residual is used to determine the expected inactivation based on tables published by USEPA. As shown in Table 1, disinfection treatment should be evaluated against the four log (99.99%) virus inactivation goal.

Disinfection is evaluated using a parameter known as CT; CT is calculated by multiplying the concentration of the disinfectant (C) by the amount of time the disinfectant is in contact with the water (T). Based on the CT tables published by USEPA, the pH and temperature of the water was used to determine the necessary CT for each chlorination facility. During the CPE, the concentration of chlorine, the temperature, and the pH were measured at each of the three active wells. The distance to each well's first customer after chlorination was estimated, and calculations were performed to determine the contact time for disinfection and whether the current chlorination practices resulted in sufficient virus inactivation by the time the water reached the first customer to meet the optimization goal. Figures 8, 9, and 10 show the piping arrangements and flows for each well.

Figure 8 shows the piping arrangement and flow for the West Voorhees well. For the analysis of the West Voorhees well, it was assumed the well was pumping at full capacity (250 gpm). Chlorine is injected directly downstream of the well. The average daily chlorine residual recorded by the operator on the log in the well house was considered the current chlorine residual for the purpose of calculating disinfection capacity.

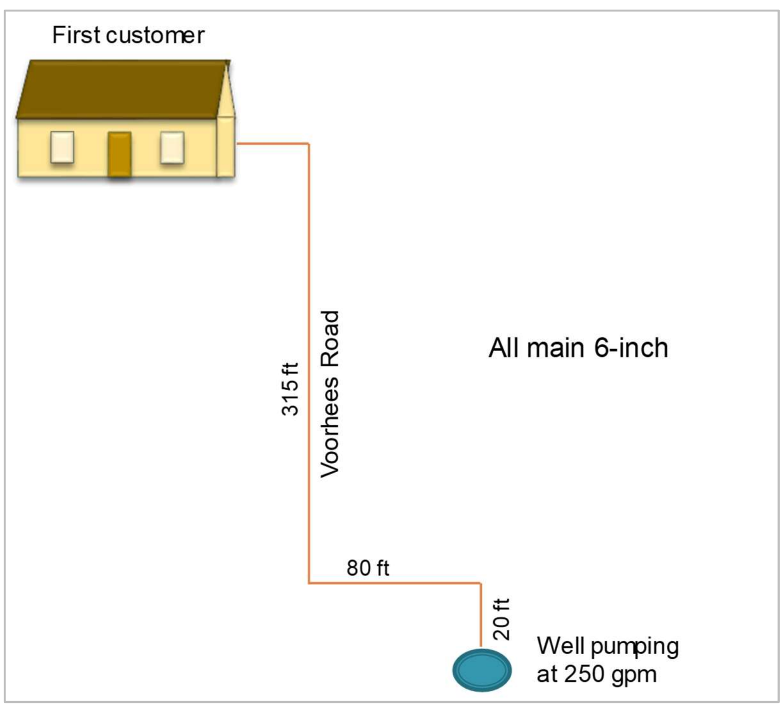


FIGURE 8. West Voorhees piping arrangement and flow.

Figure 9 shows the piping arrangement and flow for the East Voorhees well. For the analysis of the East Voorhees well, the well pumping capacity that was recorded by the flow meter during the CPE (445 gpm) was used. Chlorine is injected directly downstream of the well. The average daily chlorine residual recorded by the operator on the log in the well house was considered the current chlorine residual for the purpose of calculating disinfection capacity. It was assumed that 50% of the flow would be directed to the elevated tank and 50% of the flow would go to the distribution system when the well was pumping; as a result, 222.5 gpm was used to calculate the contact time for the segments prior to and along Ceceile Street. The elevated tank was not included in the analysis due to the fact that all flow is not necessarily routed through the tank prior to entering the distribution system. When the flow reached East Voorhees Road, it was assumed that 50% of the flow was directed to the northwest and 50% of the flow was directed to the southwest along East Voorhees. As a result, a flow of 112 gpm was used to calculate contact time for the segment between Ceceile Street and the first customer to the northwest on East Voorhees Road.

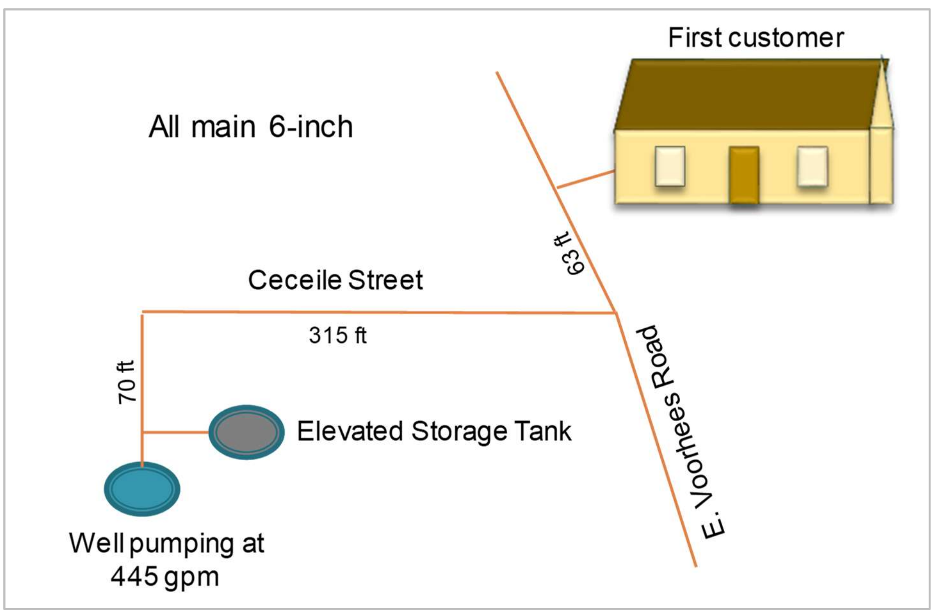


FIGURE 9. East Voorhees piping arrangement and flow.

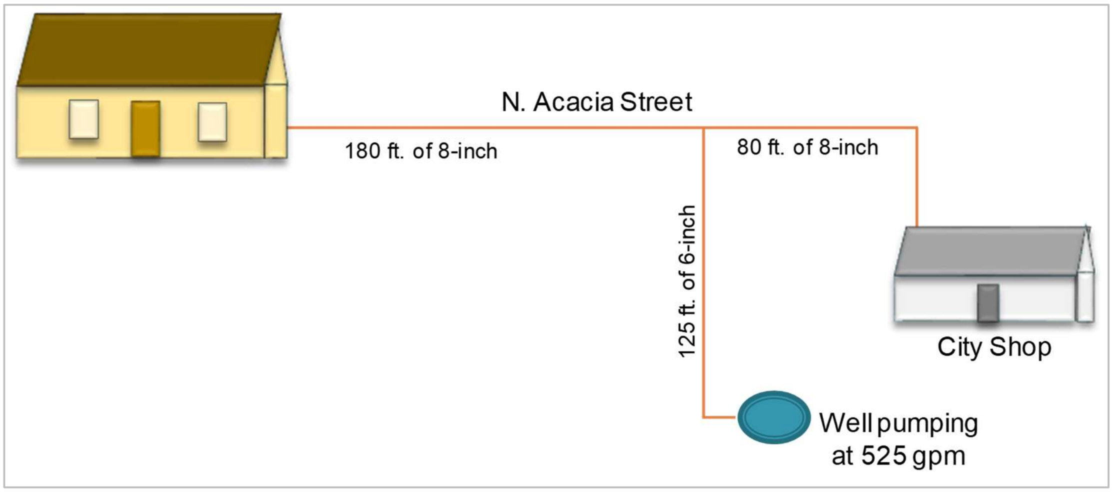


FIGURE 10. Acacia piping arrangement and flow.

Figure 10 shows the arrangement of piping and flow for the Acacia well. For the analysis of the Acacia well, it was assumed that the well was pumping at full capacity (525 gpm). Chlorine is injected directly downstream of the well. The average daily chlorine residual recorded by the operator on the log in the well house was considered the current chlorine residual for the purpose of calculating disinfection capacity. It was assumed that 525 gpm was flowing through the segment between the well and North Acacia Street; 525 gpm was used to calculate the contact time for this segment. When the water reached North Acacia Street, it was assumed that 20 gpm was diverted to the northwest to serve the city shop building. As a result, the remaining flow of 505 gpm was assumed to flow to the southeast along North Acacia Street and was used to calculate contact time for the segment between the well yard piping and the first customer to the southeast at the intersection of N. Acacia and N. Mimosa.

Based on the estimated contact time for water at the first customer when each of the wells was running, the current disinfection dosages were not adequate to meet the disinfection optimization goals at any of the three chlorination facilities during the CPE site visit, as shown in Table 3.

TABLE 3. Summary of Barrier 2 (disinfection) performance.

	Free Chlorine Residual Required to Meet the Disinfection Goal (mg/L)[1]	Free Chlorine Residual Measured on March 28, 2019 (mg/L)
West Voorhees Chlorination	1.56	0.70
East Voorhees Chlorination	1.06	0.70
Acacia Chlorination	3.02	0.70

[1] Milligrams per liter = mg/L

Figures 11, 12, and 13 show the results of Table 3 for each well in a graphical format. The portion of the bar graph shown in blue shows the free chlorine residual used for the evaluation. The portion of the bar graph shown in orange indicates the additional free chlorine residual that would be required to meet the disinfection goal of 4-log virus inactivation. The number shown to the right of the orange bar is the total free chlorine residual required to meet the required virus inactivation. The smallest increase in free chlorine residual necessary to achieve the disinfection optimization goal would be required at the East Voorhees well. Free chlorine residual would need to increase by more than 120% at the West Voorhees well, and by more than 430% at the Acacia well to meet the optimization goal for disinfection.

This analysis shows that, if the City of Denmark intended to adopt the optimization goal for disinfection, free chlorine residual would need to increase at each well, the contact time would need to be increased, or a combination of these options would be required.

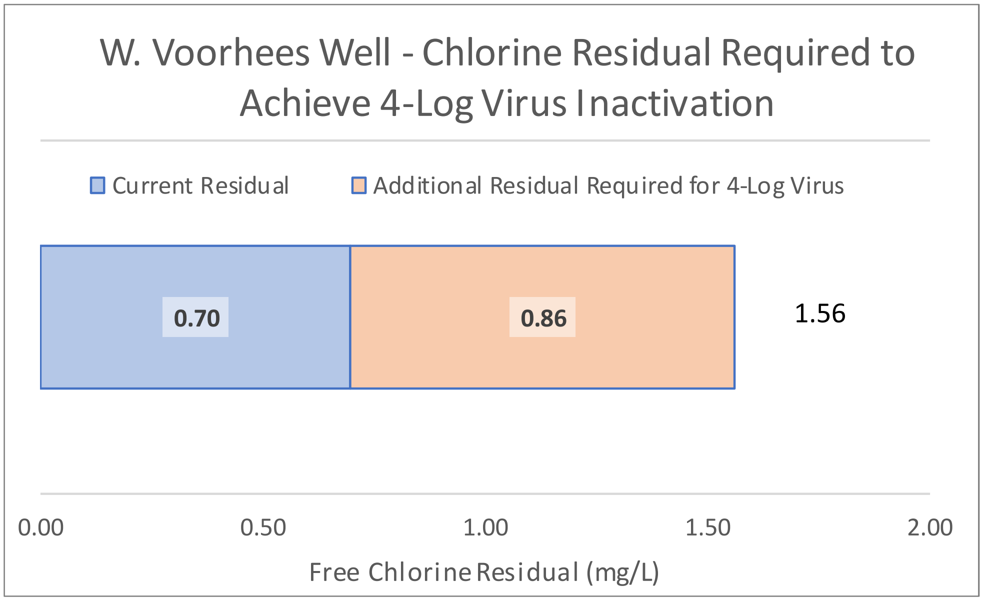


FIGURE 11. West Voorhees well disinfection performance potential.

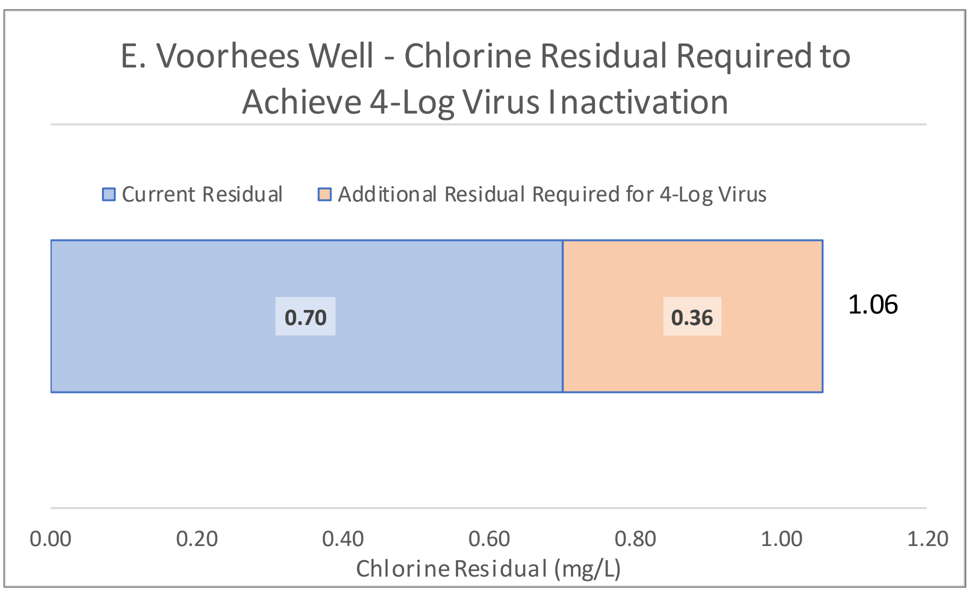


FIGURE 12. East Voorhees well disinfection performance potential.

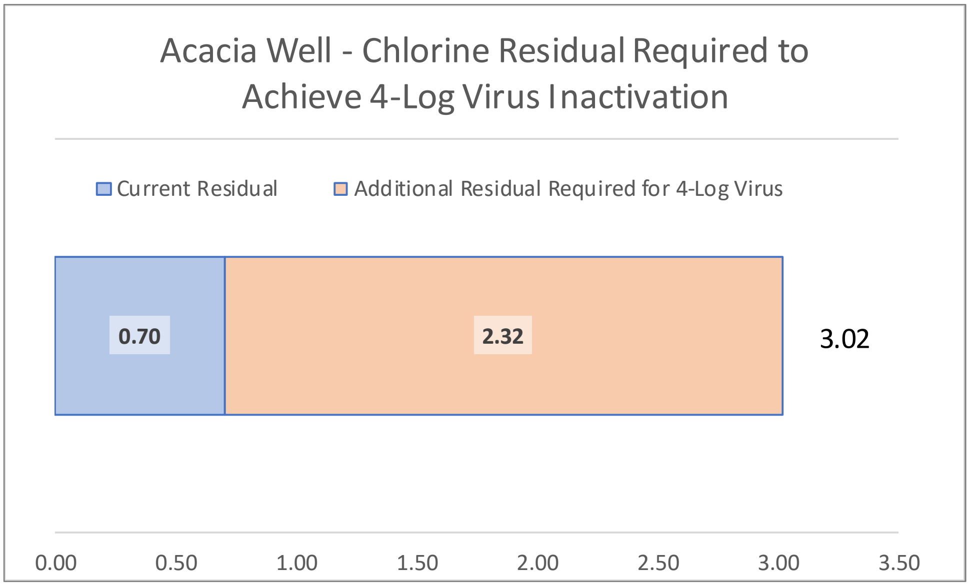


FIGURE 13. Acacia well disinfection performance potential.

Distribution System Assessment – Barrier 3

Historical Chlorine Residual Data Review

As described in Table 1, the distribution system was evaluated against the following criteria:

- Not more than 5% of the total coliform results based on the last 12 months of compliance monitoring should be positive.
- Not more than 5% of total coliform results collected during distribution system investigative sampling should be positive.
- A disinfectant residual equal to or greater than 0.20 mg/L should be present in at least 95% of samples collected during distribution system investigative sampling.

A review of 12 months of historical data indicated that one total coliform sample was positive at the Old Olar Road site during the September 18, 2018 sampling event. The follow-up sampling showed total coliform was absent at the site as well as at upstream and downstream sample sites. Based on this one positive sample, 1 out of 64 (1.5%) sample results were positive for total coliform in the distribution system during the previous 12 months; consequently, the first optimization criterion for the distribution assessment was met. Excluding the required repeat sampling after the positive sample result last September, no additional investigative sampling for coliform was completed by city staff over the last year.

To assess the last criterion listed above related to maintaining a minimum free chlorine residual of 0.20 mg/L throughout the system, the chlorine residual results from the routine coliform monitoring were evaluated for the previous 12 months. Those results showed that the goal was achieved in 94% of the sampling results, coming very close to achieving the goal of 95%. These results are qualified, though, due to the practice by city staff of flushing adjacent to the sampling sites one to two weeks prior to the sampling event. This practice and its impact on assessing distribution system minimum chlorine residual levels is discussed later in this section.

Further analysis of the chorine residual results from the 2018 coliform monitoring is shown in Figure 14. This chart shows the lowest chlorine residual recorded at each sample site. Three sample sites (Cooper Street, Dogwood Ave., and Chestnut Ave.) had chlorine residual levels below the optimization goal.

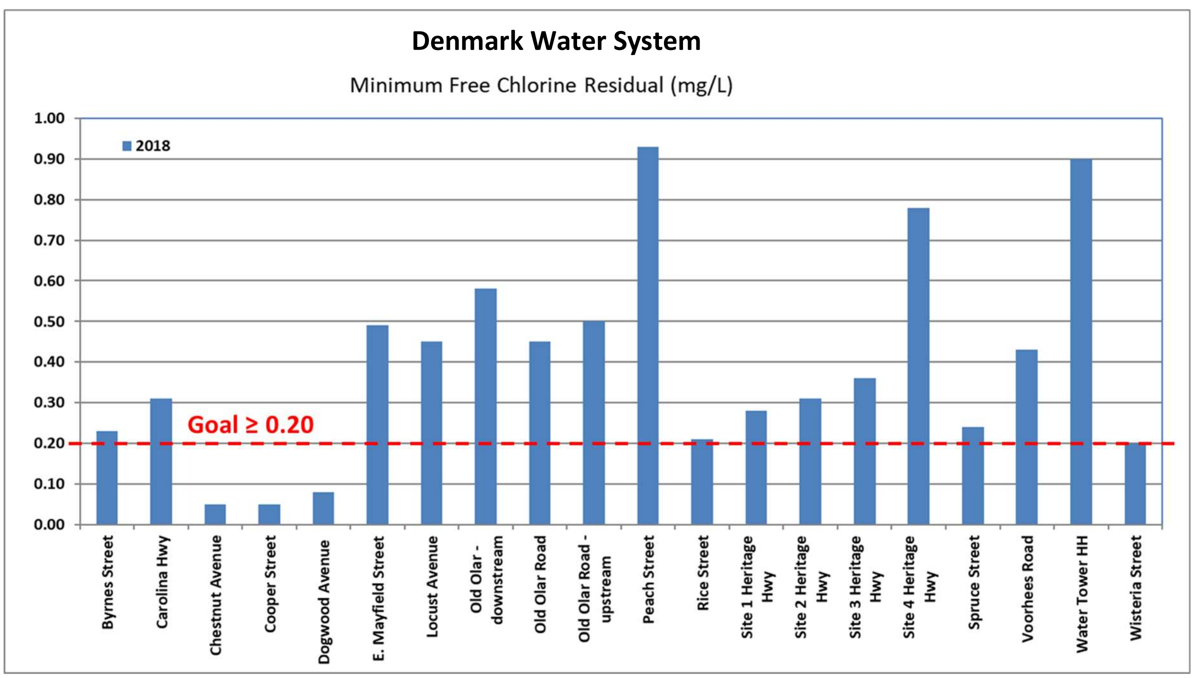


FIGURE 14. Lowest free chlorine residual at monitoring sites in 2018.

Figure 15 shows the months when these results occurred; three of the four events occurred during warm weather months of July and August. Water systems using ground water typically have relatively stable water temperature, but summer water temperature in the distribution system can be influenced by the water age in the piping and the elevated storage tanks. As water temperature increases, the chlorine residual decays more rapidly, resulting in low residuals like those experienced during the July and August sampling events. One low residual reading at the Dogwood Avenue site occurred in January, a colder weather month. This is somewhat unusual and may be related to other factors at the site that could impact chlorine residual (e.g., corrosion in older water mains).

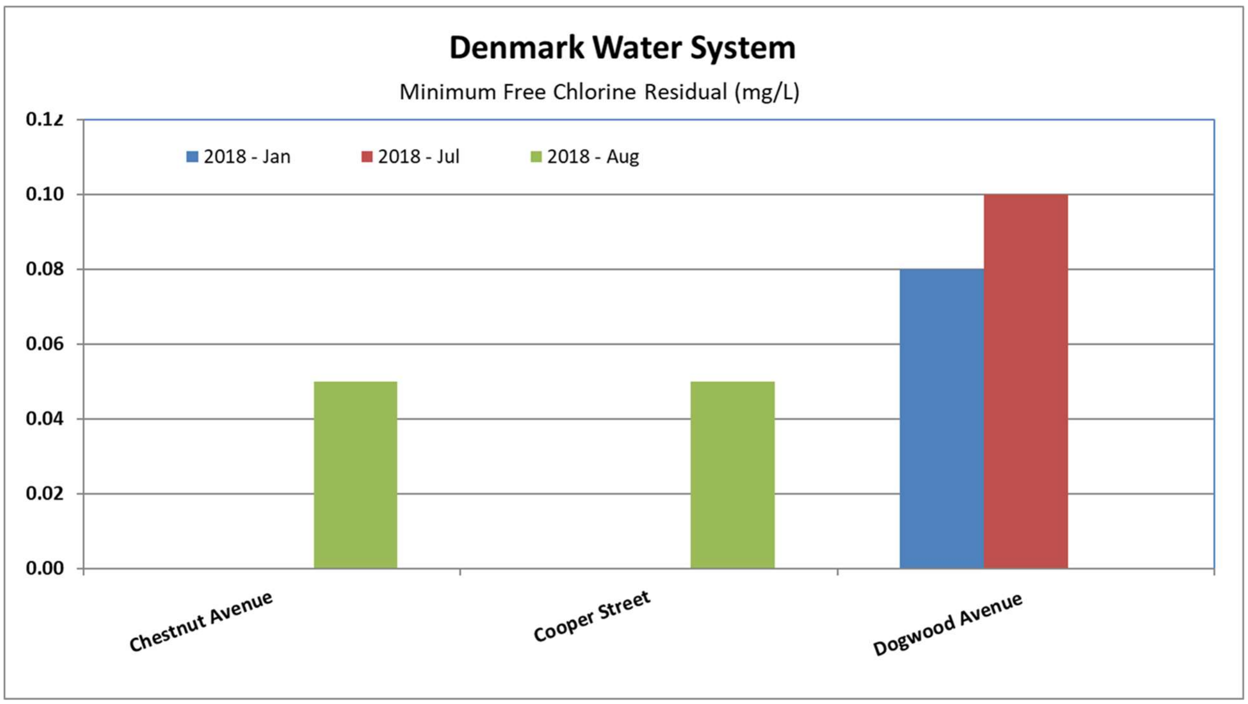


FIGURE 15. Sampling events when free chlorine residual was < 0.20 mg/L at monitoring sites in 2018.

Water utility staff measure chlorine residual before and after their weekly flushing at targeted locations in the system. The flushing program was established by a consultant in 2012 and involves flushing five hydrants each week. The selection of the hydrants to be flushed is determined by the monthly coliform sampling locations (i.e., a hydrant close to each sampling location is flushed one or more times prior to the sampling event to ensure that *"fresh"* water is present at the sampling time). As an example, during 2018 the following sample locations were sampled for coliforms on July 25: Site 2 Heritage Hwy, Site 1 Heritage Highway, Voorhees Road, Dogwood Avenue, and Carolina Highway. Results of the chlorine residual testing at the flushing hydrant sites in July 2018 are shown in Figure 16. The area near these five sample sites was flushed twice during the month (i.e., two weeks before the total coliform sampling event and again on the day of the sampling event). The chlorine residual values following hydrant flushing varied from 0.5 to 0.85 mg/L. The operator reported that chlorine residual is measured before flushing the hydrants, but the results are not recorded. Recording these chlorine residuals prior to extensive hydrant flushing would provide a better indication of the minimum residuals in the system. Sufficient flushing of the hydrant is required to displace water in the hydrant barrel and service line to assure that a representative sample is collected from the distribution system. Excessive flushing before a residual sample is collected is discouraged, however, because the sample may not be representative of water near the hydrant. Additional information on representative sampling is provided in the next section.

The impact of hydrant flushing on the coliform sampling sites that had low chlorine residuals in July and August (see Figure 15) can be further assessed. While the area near the coliform sampling sites was flushed twice in July, this was not enough to raise the chlorine residual to 0.2 mg/L at the Dogwood site on the day of sampling. The August sites (Cooper St., Chestnut Ave.) were sampled on August 8th. These sites were flushed on July 19th, but it appears that the August coliform sampling was performed earlier than usual, and this did not allow for the customary flushing of the area prior to sampling as would have been expected. The low chlorine residuals recorded at the Cooper Street and Chestnut Avenue sites during the August sampling indicate that the system was unable to maintain a chlorine residual of 0.2 mg/L without recent and targeted flushing. This indicates that the flushing program is impacting the results of the coliform sampling and that a sufficient chlorine residual is not being maintained above the optimization goal at all times.

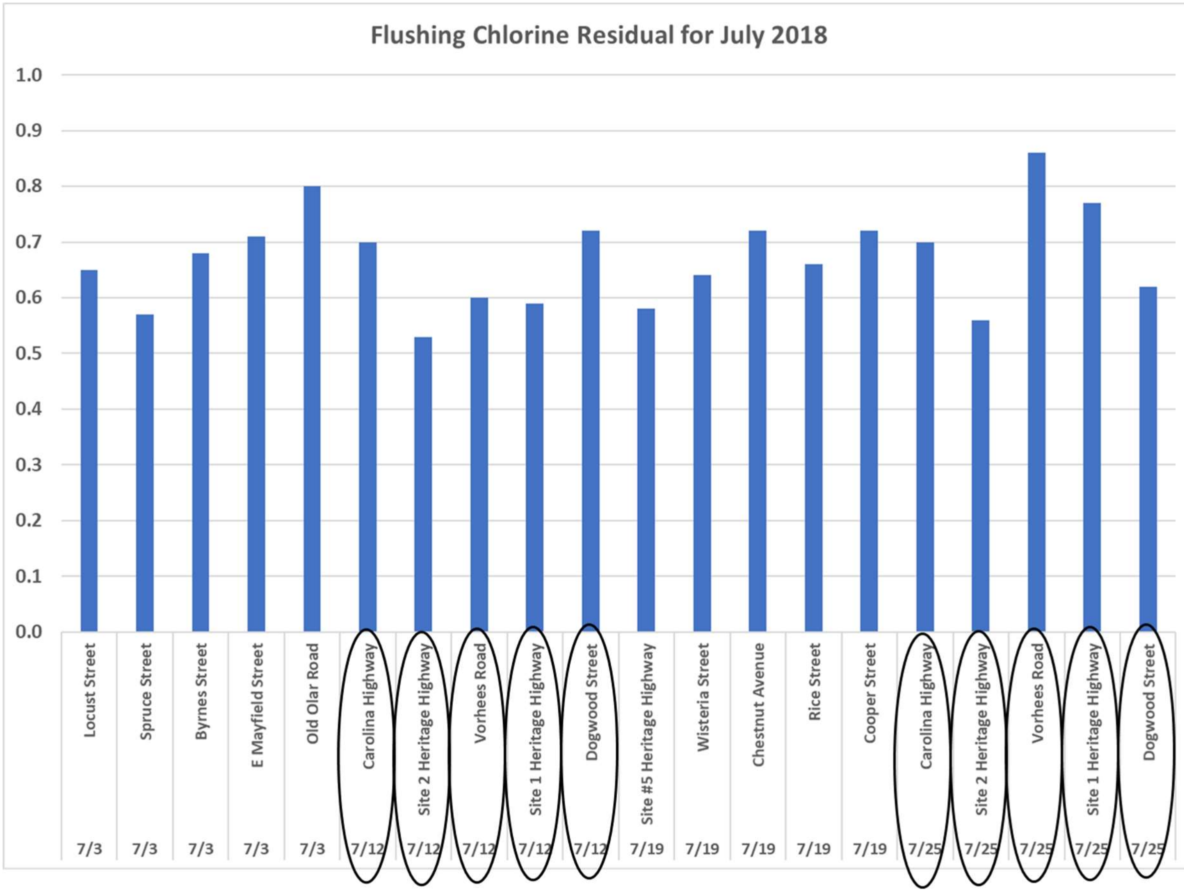


FIGURE 16. Free chlorine residual at flushing sites (post flushing) during July 2018.

Investigative Sampling Results

The main objective of this Special Study was to assess water quality throughout the system and identify any areas of suspected high-water age, as indicated by low chlorine residual.

The first step of the Special Study involved reviewing a distribution system map and soliciting feedback from Denmark personnel regarding areas of their distribution system with suspected water quality degradation. The goal of this review was to identify critical areas of the system. The following criteria were used by the team to assess potential sampling locations:

- Distribution system entry points (i.e., wells) to provide a reference to compare all other distribution system water quality data

- Areas with frequent customer complaints (e.g., taste and odor, low pressure, color)

- Regulatory sample locations (Total Coliform Rule)

- Areas with aging pipes (e.g., old cast iron lines)

- Areas with reactive pipe materials (e.g., unlined cast iron, asbestos cement)

- Storage tanks (while draining):
  - Samples may be collected from within the tank (if taps are installed), from the inlet/outlet, or in the proximity of the tank in the distribution system
  - Poor mixing and/or turnover
  - Operating in series
  - Standpipes (height > diameter; prone to poor mixing)

- Areas where high water age is anticipated:
  - Extremities of the distribution system and/or maximum residence time locations
  - Areas with physical and/or hydraulic dead-ends (i.e., valves or pressure boundaries impede flow)
  - Areas with vacant industrial, commercial, or residential developments

The CPE team was not able to completely assess the impact of the Denmark elevated storage tanks on water quality because of the lack of real-time tank water elevation data (i.e., no tank Supervisory Control and Data Acquisition [SCADA] data available). The city tanks have visual water level indicators located on the exterior of the tanks, but the indicator at the East Voorhees Road tank was not operational during the CPE.

The CPE evaluation team, with the help of Denmark personnel, collected water samples at twelve locations over two days. The sites were located in all four quadrants of the system and included the well and storage tank sites. All locations were monitored for free chlorine, total chlorine, temperature, pH, and iron.

Except for the well sites and the storage tanks, all other samples were collected from fire hydrants. A hydrant sampling procedure and sampling device described in Appendix A were used to sample from the hydrants. At each hydrant site, the sampling device was attached to the hydrant and the hydrant was completely opened. A flow restrictor in the sampling device maintained a constant flow rate of 20 gpm. By estimating the length and diameter of the service line to the hydrant, the volume of water required to flush the service line can be estimated, and knowing the flow rate, an estimated flush time can be determined. To be conservative, the estimated flush time is doubled.

Free and total chlorine were measured throughout the system because the relative difference between free and total residual may indicate combined chlorine residual. Temperature and pH were measured as well. In field studies at other water systems, areas of elevated pH and temperature have been associated with high water age. Iron was measured during this study because of the history of iron-related customer complaints with the system.

The sample locations and all water quality data are included in a table in Appendix B. The sample locations and free chlorine residual results are shown in Figure 17.

Chlorine residual concentrations from the twelve sample sites varied from a low of 0.22 mg/L at the County storage tank to a high of 0.90 mg/L at the Barnwell and Wisteria sites. Consequently, all of the sites met the optimization goal of having a free chlorine residual of at least 0.20 mg/L. The lowest residuals were generally at sample sites in the northeast quadrant of the system (the area influenced by the County storage tank). This tank is currently only being used by the city, and, given its location (approximately two miles east of town) and the relatively low demand on this tank, high water age may be the cause of the lower residuals in the area.

Both the pH and water temperature measurements were stable at all the sample sites. The pH was typically in the 7.8 to 8.1 units range, and temperature varied between 16 – 19°C. Total chlorine was also measured at each site, and the results were typically within about 0.1 mg/L of the free chlorine residual measurement, indicating that almost all of the chlorine in the system was free and not tied up with other chlorine-reacting compounds in the water.

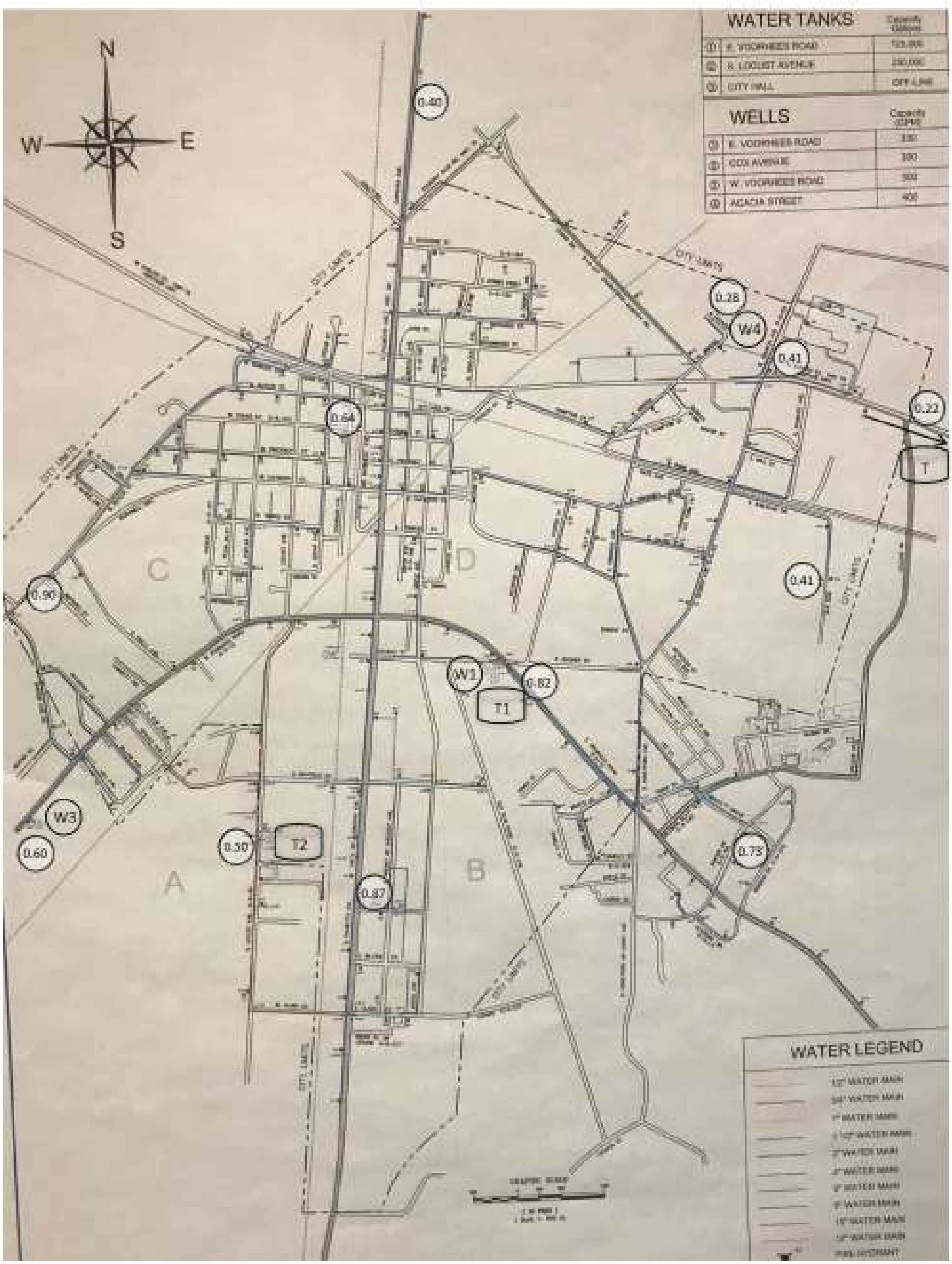


FIGURE 17. CPE investigative sampling locations and free chlorine residual.

Special Study on Iron in the System

Iron was measured at each of the sample sites. Relatively high iron concentrations (up to 3 mg/L) were measured throughout the system, but the use of the hydrant sampler to flush the service line to the main was questioned by city personnel. Although the hydrant sampling procedure was based on flushing at least two times the service line volume, the thought was that the flushing velocity was not sufficient to remove the iron deposits from the service line. And, even though the water was replaced in the service line, iron might continue to leach into the sample. Further study would be needed to fully assess the use of the hydrant sampling device for this purpose. Due to the uncertainties of the sampling method, the iron testing results from the hydrant sampling sites were not included in this evaluation. The iron sampling results obtained from the well and tank sites were considered valid, and these results are summarized in Table 4.

TABLE 4. Iron sampling results from wells and storage tank (mg/L).

	W. Voorhees Well	E. Voorhees Well	Acacia Well	S. Locust Tank
March 26	Not sampled	0.35	0.23	Not sampled
March 27	0.15*	0.07*	0.22	0.63

*Sample collected shortly after well manually turned on.

On March 26th, water was sampled prior to chlorine addition at two well sites, and the raw water iron concentrations varied from 0.23 to 0.35 mg/L. Although iron is not regulated in drinking water as a primary health-related contaminant, the USEPA has set a secondary maximum contaminant level of 0.3 mg/L based on aesthetic (rust and iron staining) considerations. All three wells and the South Locust Tank were sampled on the next day. A lower concentration of 0.07 mg/L was obtained from the East Voorhees well; however, this well was turned on just prior to sampling, and it may not have been running long enough to achieve a stable iron concentration. This was also the situation with the West Voorhees well. The Acacia well had been running prior to sampling, and the result was similar to the result from the previous day. The highest iron concentration of 0.63 mg/L was obtained from the South Locust tank.

The presence of iron deposits in the water is not a primary public health concern, so characterization of iron was not considered a key objective of this evaluation. However, more attention by the city to possible aesthetic concerns by customers could support improving overall confidence in the water system. The addition of chlorine at the wells in the presence of dissolved iron will result in iron precipitate forming and being deposited in the system. The city's approach to address this situation has been to implement a routine hydrant flushing program to help remove the deposits. However, the city's current flushing program was developed primarily to assure that fresh water was in the system near the coliform sampling locations on the day of sampling.

Recent developments in distribution system flushing methods, commonly referred to as unidirectional flushing, have been shown to be effective for removing accumulated deposits in systems. Unidirectional flushing can be more labor intensive than conventional flushing practices, so water utilities that practice the unidirectional approach will implement it once or twice a year (e.g., spring, fall). Additional measures could be pursued that would involve the addition of a sequestering agent to the water that would reduce the formation of iron precipitates in the system. Prior to pursuing these options, the city would benefit from implementing routine monitoring of iron in the raw water and system to establish a baseline for this water quality parameter. The testing method is relatively simple, similar to chlorine testing, and could be conducted by city personnel.

Special Study on Potential Contamination From Storage Tanks to the Distribution System

A recent sanitary survey conducted by the South Carolina DHEC identified sanitary defects in storage tanks as significant deficiencies at the Denmark Water System. As follow-up, the Denmark utility personnel addressed some of the concerns raised in the inspection report but were required to develop a plan to address the remaining items. Sanitary defects at storage tanks can impact the ability of the distribution barrier to prevent the introduction of contamination into the distributed water. As part of the CPE site visit, inspections were not conducted due to inaccessibility (the tanks are all elevated tanks and could not be safely climbed during the CPE). At the East Voorhees tank, however, the CPE team did find evidence of heavy bird activity (droppings and feathers were present on the grounds surrounding the tank and bird droppings were evident at the top of the elevated tank, when viewing it from the ground level). In addition, observations of the overflow pipe at the East Voorhees tank showed feathers trapped against the screen inside the overflow line, indicating feathers came down the overflow. Contamination of tanks by birds has been the cause of waterborne disease outbreaks in water systems in other locations around the country in the past and indicates a potential pathway for contamination in the Denmark system. The bird feathers in the overflow line are shown in Figure 18.

FIGURE 18. East Voorhees storage tank overflow showing trapped bird feathers.

PERFORMANCE-LIMITING FACTORS

The areas of design, operation, maintenance, and administration were evaluated in order to identify any factors that may limit performance of the water system. These evaluations were based on information obtained from the plant tour, interviews, performance and design assessments, Special Studies, and the judgment of the evaluation team. Each of the factors was classified as A, B, or C according to the following guidelines:

A – Major effect on a long term, repetitive basis

B – Moderate effect on a routine basis or major effect on a periodic basis

C – Minor effect

The performance-limiting factors were prioritized as to their relative impact on performance and are summarized below. In developing this list of factors limiting performance, over 50 potential factors were reviewed and their potential impact on the performance on Denmark Water System's water quality was assessed. A summary of the factors identified during the CPE is shown in Table 5. Each factor and site-specific examples of why the factors were identified are summarized below.

TABLE 5. Ranking of performance-limiting factors for the City of Denmark Water System.

Rank	Rating	Factors
1	A	Administration – Response to Tank Inspection and Sanitary Survey Reports
2	A	Administration – Policies
3	A	Operation – Treatment Barrier – Disinfection
4	B	Operation – Testing – Representative Testing
5	B	Administration – Planning
6	C	Operations – Flushing Program
7	C	Design – Iron Treatment
8	C	Design – Alarm Systems

Response to Tank Inspection and Sanitary Survey Reports (Administration) – A

- A tank inspection revealed that two storage tanks had unscreened or inadequately screened vents and a separation in the overflow line in April 2018, resulting in an opportunity for contamination (e.g., birds/insects) to enter the tank. The city had not addressed these issues at the time of this evaluation.

- The storage tank deficiencies were mentioned in a recent sanitary survey, with a request for a response by March 4, 2019. At the time of this evaluation, the city had not yet developed a response.

Polices (Administration) – A

- The City of Denmark has not adopted optimization goals for water quality or monitoring at the source or the disinfection barriers to evaluate source protection and disinfection barrier performance.

- Total coliform monitoring is being performed at one of the three wells to evaluate the source barrier. A policy of monitoring beyond regulatory requirements to evaluate the wells has not been adopted.
- The county tank needs repair, and an arrangement with the County has not been negotiated.
- There is no policy to share water quality data with all levels of operations, including operators doing the flushing.

Treatment Barrier – Disinfection (Design) – A

- The current chlorine dosages are not sufficient to meet 4-log virus inactivation.

Testing – Representative Sampling (Operations) – B

- Operators are not measuring and recording chlorine before flushes. The recorded residuals after the flush represent a *"best case"* water quality scenario after flushing.
- Prior to collection of coliform samples, it appears that multiple flushing events sometimes take place to target the specific sample locations. The historical coliform and chlorine residual record, therefore, represents a *"best case"* water quality scenario after flushing.
- *"Worst case"* chlorine residual levels are not being evaluated to assure that performance goals are maintained at all times.

Planning (Administration) – B

- The system is dependent on grants for future infrastructure needs. The existing funding set aside for facility replacement may be insufficient.
- A high *"unaccounted for water"* rate indicates there may be metering or other maintenance issues, resulting in lost revenue and possibly affecting system finances.
- The operating ratio is less than 1.0 (operating costs exceed water revenues). A review of the 2017 and 2018 financial audits, however, do show that the operating ratio has improved.

<u>Flushing Program (Operations) – C</u>

- The current extensive flushing program may not be effectively removing sediment from the distribution system, as documented by the increased customer complaints after flushing.

<u>Alarm Systems (Design) – C</u>

- There is no alarm to alert operators of a failure to feed or maintain chlorine residual that would indicate a compromise in the disinfection barrier.

<u>Iron Treatment (Design) – C</u>

- There is currently no iron treatment, which has resulted in iron sediment throughout the distribution system and periodic customer complaints.

CONCLUSIONS AND FOLLOW-UP

Overall, City of Denmark has dedicated staff and managers, as well as the capability to implement aspects of ground water and distribution system optimization approaches that will likely lead to improved water quality in the system. If the city chooses to implement this optimization approach, it could be achieved through addressing the performance-limiting factors that were identified during the CPE. This process typically requires several years to implement, but, based on assessment of implementation practices at other utilities, the personnel and managers at the City of Denmark have the potential to more assertively address water quality concerns in their water system.

The South Carolina DHEC staff is available to assist the city if it is interested in pursuing ground water and distribution system optimization. Please contact Mr. Richard Welch, PE for additional information at 808-898-3546.

Appendix A
Hydrant Sampling Device

Hydrant Flush Time Approaches for Sampling (assumes flow rate of 20 gpm, regulated by hydrant sampler)

- ***Objective:*** assess water quality in the proximity of the sample location; under flushing may result in sampling from the service line; over flushing may pull water from another part of the system!
- ***Rule of Thumb*** approach is easiest (ok for one-time sampling): **3 minute total flush time before sampling** (assumes pipe diameter is 6 inches or less, and the pipe length is less than 20 feet)
- ***CFT*** approach should be determined if time allows: **Flush for two times the CFT before sampling;** the CFT is determined using the following steps:

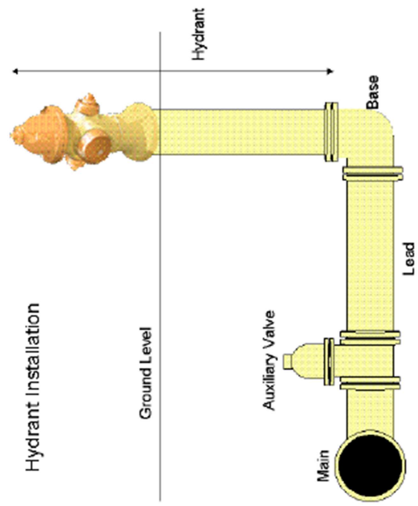
1. Estimate the (total) length and diameter of hydrant piping (see figure, below); Utilize operator's knowledge of system, a system/site map, and/or design standards as needed

Vertical length/diameter:

- Assume hydrant diameter is 6 inches (unless indicated differently)
- Assume hydrant length is 6 feet (based on design standards)

Horizontal length/diameter:

- Assume hydrant lead diameter is 6 inches
- Measure/estimate the length of pipe between main and hydrant base; if location of main is not known, measure the horizontal distance between the auxiliary valve to the hydrant and add one foot to account for distance from the main to the auxiliary valve



2. Determine the necessary flush time (from matrix, on right) based on vertical and horizontal pipe lengths and diameters; assume 20 gpm flow rate due to the flow control valve on hydrant sampler.

Number of Minutes needed to Flush Hydrant at 20 gpm						
Length of Pipe	Inside (Nominal) Diameter of Hydrant/ Pipe (inches)					
	2	4	6	8	12	16
1	0.0	0.0	0.1	0.1	0.3	0.5
5	0.0	0.2	0.4	0.7	1.5	2.6
10	0.1	0.3	0.7	1.3	2.9	5.2
15	0.1	0.5	1.1	2.0	4.4	7.8
20	0.2	0.7	1.5	2.6	5.9	10.4
25	0.2	0.8	1.8	3.3	7.3	13.1
30	0.2	1.0	2.2	3.9	8.8	15.7
35	0.3	1.1	2.6	4.6	10.3	18.3
40	0.3	1.3	2.9	5.2	11.8	20.9
45	0.4	1.5	3.3	5.9	13.2	23.5
50	0.4	1.6	3.7	6.5	14.7	26.1
55	0.4	1.8	4.0	7.2	16.2	28.7
60	0.5	2.0	4.4	7.8	17.6	31.3
65	0.5	2.1	4.8	8.5	19.1	33.9
70	0.6	2.3	5.1	9.1	20.6	36.6
75	0.6	2.4	5.5	9.8	22.0	39.2
80	0.7	2.6	5.9	10.4	23.5	41.8
85	0.7	2.8	6.2	11.1	25.0	44.4
90	0.7	2.9	6.6	11.8	26.4	47.0
95	0.8	3.1	7.0	12.4	27.9	49.6
100	0.8	3.3	7.3	13.1	29.4	52.2

1. Depending on the type of pipe material and degree of corrosion inside the pipe, the inner diameter will vary. These diameters are meant to be approximations.

Instructions on constructing a hydrant sampling device like the one used during the CPE can be found at the following website:
https://www.asdwa.org/2018/09/17/streamlined-hydrant-sampler-redesign-smaller-lighter-and-less-expensive/

Appendix B
Investigative Sampling Data Table

Description	Date of Collection	Time	Sample Collector Initials	Free Chlorine (mg/L)[1]	Total Chlorine (mg/L)[1]	Pressure (psi)[2]	pH units	Temp (°C)[3]	Coliform Analysis (Y/N)	Iron (mg/L)[1]
West Vorhees Well	3/26/19	11:42	LD	0.6	0.61		7.09*	17.3	Y	
East Vorhees Well	3/26/19	12:23	JB	0.82	0.83		7.49*	19.1	Y	0.35
Acacia Well	3/26/19	12:49	JB	0.19, 0.28	0.4		7.83	18.8	Y	0.23
Hwy. 78 County Tank	3/26/19	14:45	JB	0.22, 0.24	0.23	60	7.93	16	N	
Church & Hwy. 78 (Heritage)	3/26/19	15:22	JB	0.41	0.38	55	7.91	19.7	N	
Carolina Highway	3/26/19	15:48	JB	0.59, 0.40	0.46	60	7.95	17.3	N	
Dogwood	3/27/19	10:30	JB	2.20, 1.05, 0.64,	0.69		7.92	18.1	N	
Barnwell & Wisteria	3/27/19	10:54	JB	0.70, 0.90	0.90		7.81	17.1	N	
Chestnut & Leda St.	3/27/19	11:14	LD	0.87	0.91	60	8.02	16.3	N	
Vorhees College	3/27/19	11:37	LD	0.73	0.79	60	7.96	17.0	N	
S. Rice Ave.	3/27/19	11:59	LD	0.41	0.52		8.0	14.4	N	
S. Locust Tank	3/27/19	12:36	LD	0.50	0.50		8.07	14.4	N	0.63
West Vorhees Well	3/27/19	14:32	LD				7.95	19.0	N	0.15
East Vorhees Well	3/27/19	15:17	LD						N	0.07, 0.05
Acacia Well	3/27/19	16:00	LD						N	0.22

[1] Milligrams per liter = mg/L
[2] Pounds per square inch = psi
[3] Degrees Celsius = °C

* Suspect reading was low due to new pH probe acclimation.