CITY OF RALEIGH

PUBLIC UTILITIES DEPARTMENT

REUSE WATER SYSTEM MASTER PLAN UPDATE

PHASE 2 FINAL REPORT

December 2017

CDM Smith

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December 6, 2017

Ms. Eileen Navarrete, P.E., PMP
Construction Projects Administrator
City of Raleigh Public Utilities Department
One Exchange Plaza, Suite 620
Raleigh, NC 27601

Subject: Reuse Water System Master Plan Update – Phase 2
Final Report

Dear Ms. Navarrete:

Enclosed please find five copies of the Reuse Water System Master Plan Update Phase 2 final report. Also enclosed is a USB drive with the document in PDF format. This report summarizes results of the work performed for the second phase of the Master Plan Update and additional reuse-related tasks.

If you have any questions, please feel free to contact me at your convenience. Thank you for the opportunity to work with you on this project.

Sincerely,

Sheryl D. Smith

Sheryl D. Smith, P.E.
CDM Smith Inc.

Enclosures: 5 copies of report
One USB drive with PDF files

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Section 1

Introduction

1.1 Project Background and Objectives

The City of Raleigh Public Utilities (CORPUD) manages a water reuse program that includes two reuse water distribution systems, bulk reuse water stations throughout the service area, and on-site uses of reclaimed water at the treatment facilities. The goals of the water reuse program include:

- The reduction in peak potable water demand to reduce capital and operating costs of the potable water supply, treatment, transmission, and distribution system and to defer or eliminate new capital investments in the potable system and the development of new potable water supply sources;
- The reduction of nutrients discharged into the Neuse River to cost-effectively comply with the Neuse River Nutrient Sensitive Waters Management Strategy;
- Providing a more cost-effective and reliable source of water for non-potable uses such as irrigation, cooling and process water, and sanitary needs.
- The consideration of reclaimed water for potential potable uses in the future as a means of meeting future water resource needs.

Phase 1 of this Master Plan Update was completed in 2013. This phase examined big-picture issues related to the role of reuse in meeting CORPUD's water resources objectives, the location and magnitude of potential concentrated non-potable demand in the service area, and various strategies for expanding the reuse program to meet additional non-potable customers.

Phase 2 objectives are to evaluate the current reuse system and further define the conceptual alternatives for expanding the reuse system. This phase assesses the required infrastructure and cost for implementing specific water reuse projects. It also provides a comparison of the costs and benefits of selected alternatives for expanding the reuse system to serve either non-potable or potable uses.

1.2 Terminology

Throughout this report, the term reuse refers specifically to water reuse. The terms reclaimed water and reuse water are also used interchangeably to describe wastewater that has been treated to meet specific water quality criteria with the intent of being used for a range of purposes.

1.3 Existing Water Reuse Program

The existing water reuse system includes bulk reclaimed water distributed from CORPUD's treatment plants located throughout the service area, and two piped distribution systems that supply reclaimed water to industrial, commercial, and municipal facilities. **Figure 1-1** shows the location of CORPUD's existing water and wastewater service area, water and wastewater treatment facilities, and reuse facilities. The water reuse program is designed to meet the North Carolina Department of Environmental Quality (NCDEQ) mandatory treatment standards. CORPUD's water reuse system permits specify the water quality standards listed in **Table 1-1**, which corresponds to Type I reclaimed water.

Table 1-1. Minimum Reclaimed Water Quality Standards

Parameter	Daily Maximum	Maximum Monthly Average
Turbidity (ntu)	10	--
BOD_5 (mg/L)	15	10
TSS (mg/L)	10	5
NH_3 (mg/L)	6	4
Fecal Coliform (#/100 mL)	25	14

1.3.1 Bulk Reclaimed Water

CORPUD operates bulk reclaimed water loading stations at the E. M. Johnson Water Treatment Plant (WTP), Neuse River Resource Recovery Facility (NRRRF), and Little Creek Wastewater Treatment Plant (WWTP). The bulk reuse facility at the Smith Creek WWTP closed indefinitely in June 2016. Bulk reclaimed water is provided at no charge to approved citizens and contractors who complete a certification training course. The NCDEQ restricts allowable uses of bulk reclaimed water. Allowable uses are listed in the reclaimed water system permits and include the following:

- Landscape irrigation of residential lawns, golf courses, parks, landscaped areas, and other public, industrial, or commercial grounds
- Dust control for street sweeping
- Roadway pretreatment
- Vehicle washing
- Pesticide application
- Pressure washing
- Sewer line flushing
- Decorative ponds & fountains that do not drain to surface waters, storm drains, or catch basins
- General construction purposes such as soil compaction, dust control, and asphalt reclamation

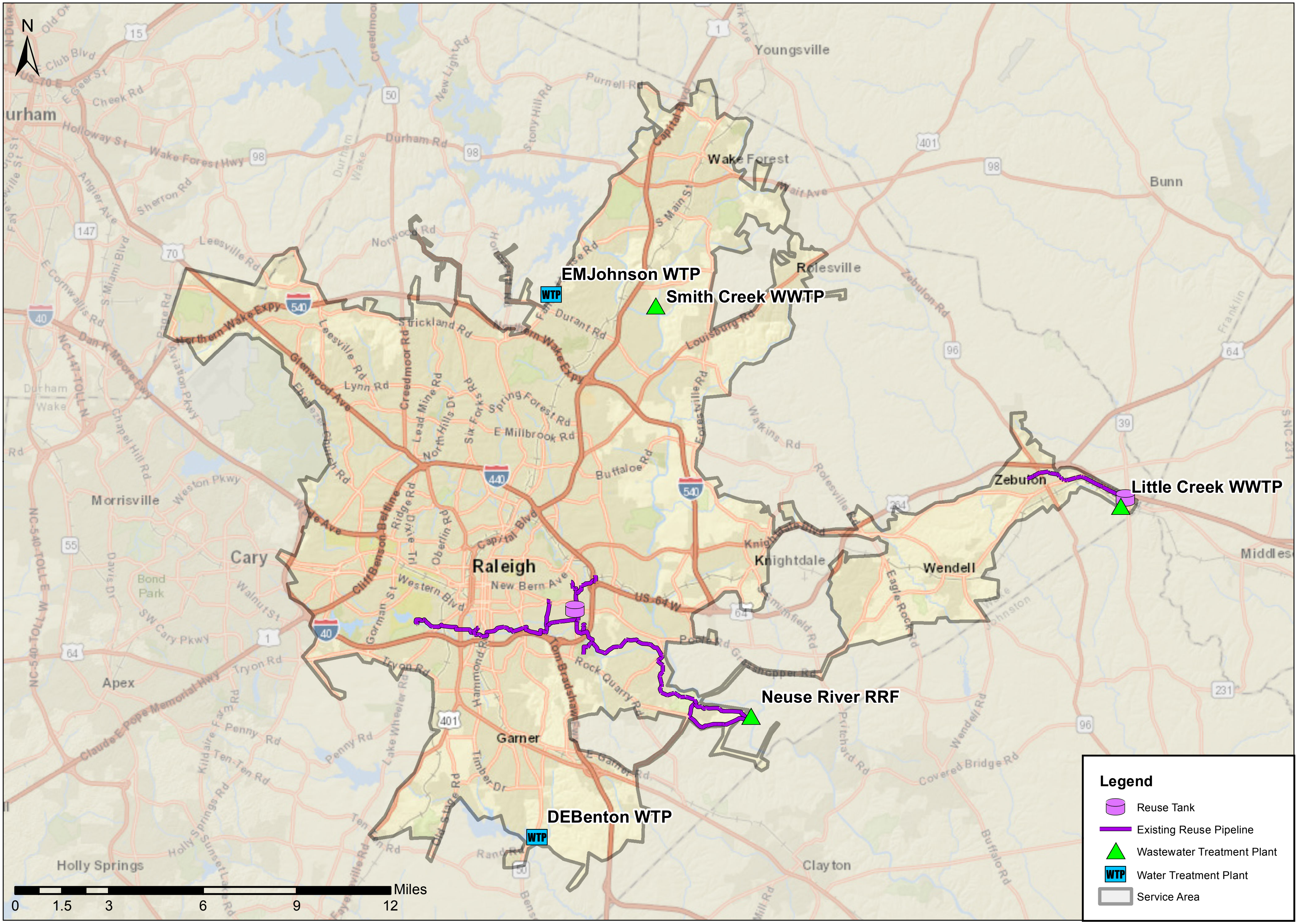

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Figure 1-1
Existing Treatment Plants and Reuse System

In general, bulk reclaimed water accounts for a very small portion (less than 1 percent) of the overall reuse demands.

1.3.2 Raleigh Reuse Water Distribution System

The Raleigh reuse distribution system originates at the NRRRF. The NRRRF is located approximately 12 miles southeast of Raleigh in Wake County. It is CORPUD's largest wastewater treatment facility, with a treatment capacity of 60 million gallons per day (mgd). CORPUD is undertaking a project to expand the capacity to 75 mgd. The wastewater treatment process stream includes preliminary treatment, primary treatment, activated sludge secondary treatment with biological nutrient removal, tertiary filters, and ultraviolet (UV) disinfection.

The reuse system began operations in 1996 by providing irrigation water to the agricultural fields near the NRRRF and for non-potable use at the NRRRF. The distribution system has since been expanded to serve off-site public utility facilities, parks and recreational fields, golf courses, and commercial/ industrial/ institutional uses along the pipeline corridor in southeast Raleigh.

The reuse facilities at the NRRRF pump reclaimed water through three separate systems:

- On-site reuse system for uses at the headworks/pretreatment facility, secondary clarifiers, centrifuge building, dewatering building, sludge thickening building, and miscellaneous washdown areas,
- High pressure irritation system for irrigation of the agricultural fields near the NRRRF and water cannons at the flow equalization basin, and
- Off-site distribution system.

The existing Raleigh off-site reuse distribution system infrastructure and facilities include:

- Sodium hypochlorite feed system at the NRRRF to maintain a disinfection residual in the water reuse system. A detailed description of the sodium hypochlorite feed system is included in the *Reuse System Water Quality Technical Memorandum* included in **Appendix A**.
- 3.7-mgd off-site reuse pumping station at the NRRRF, equipped with three 1,040-gallon-per-minute (gpm) vertical turbine pumps.
- Approximately 119,300 linear feet of 6-inch diameter through 24-inch diameter pipeline, terminating at the Lonnie Poole golf course on the North Carolina State University (NCSU) Centennial Campus.
- 750,000-gallon composite elevated storage tank along Sunnybrook Road.

The City's total investment in the Raleigh off-site reuse distribution system is approximately $21 million. Additional details for the on-site and high pressure irrigation system can be found in the *Evaluation of Reuse Water for Bioenergy Recovery at the Neuse River Resource Recovery Facility Technical Memorandum* included in **Appendix B**.

1.3.3 Zebulon Reuse Water Distribution System

In 2002, the Town of Zebulon began operations of a reuse distribution pipeline from the Little Creek WWTP to provide reclaimed water to public facilities and an industrial user for irrigation and cooling water makeup. The reuse pipeline has since been extended to additional irrigation and industrial users, including GlaxoSmithKline (GSK), the town's largest industrial water user. As part of the 2006 utility system merger, the operations of the Little Creek WWTP and Town of Zebulon reuse distribution system were transferred to CORPUD.

The Little Creek WWTP has a treatment capacity of 1.85 mgd and currently treats an annual average of approximately 0.8 mgd. The wastewater treatment process stream includes preliminary treatment, activated sludge secondary treatment with biological nutrient removal, tertiary filters, and UV disinfection. The facility discharges treated effluent to Little Creek.

The Zebulon reuse infrastructure and facilities include:

- 1.0-mgd reuse pumping station at the Little Creek WWTP, equipped with two 500-gpm vertical turbine pumps.
- Approximately 19,800 linear feet of 12-inch diameter pipeline
- 250,000-gallon elevated storage tank at Five County Stadium

The Zebulon reuse distribution system is supplemented with water from the potable water system. Since Zebulon is at the extreme end of CORPUD's potable water service area, flushing is employed to maintain water quality. Water flushed from the potable system is used to fill a portion of the reuse system storage tank.

The first phase of the Zebulon reuse system was constructed and plans for the second phase of the Zebulon reuse pipeline were initiated prior to the utility merger; therefore, the Zebulon reuse system is considered to be an 'existing' facility transferred to CORPUD through the utility merger.

1.3.4 Rates and Policies

Water Reuse Rates

Reclaimed water usage is metered by CORPUD. Rates are currently set to promote the beneficial use of reclaimed water, as opposed to providing full cost recovery. For customers within the Raleigh city limits, reclaimed water consumptive billing rates are currently set at half of the non-residential potable rate and approximately one third of the irrigation rate. For customers in the Town of Zebulon, the reclaimed water consumptive billing rate is approximately 45 percent of the potable and irrigation rates. Therefore, reclaimed water represents a significant savings over the potable rates.

Water Reuse Policies

It is CORPUD's policy to provide reclaimed water to the appropriate non-potable demands to limit the growth in the potable water system, extend the life of existing raw water supplies, and meet nitrogen reduction goals for the Neuse River basin. Use of reclaimed water for irrigation is not subject to water conservation restrictions.

The City's reuse water ordinance sets forth regulations for the water reuse system as an alternative water source for non-potable water demands. In addition, the ordinance requires reclaimed water use as follows: "Where reuse water is available to a property, all new landscape irrigation system shall utilize reuse water."

In 2007, CORPUD applied to the NCDEQ for delegation authority for the reuse system. CORPUD was ultimately granted delegation permitting authority in 2008. Therefore, CORPUD has the authority to review and grant Reuse System Extension permits, as well as Reclaimed Water Utilization permits for bulk users, irrigation utilization, and non-irrigation utilization of the reclaimed water system.

1.4 Report Format

The remainder of the report is organized into the following sections:

Section 2 – Existing Water Reuse System Evaluation

Section 2 describes the reuse customer demands, hydraulic model evaluation, and water quality evaluation of the existing reuse system.

Section 3 – Future Water Reuse Demands

Section 3 describes the existing potable customer demands and future development demands that have the potential to be met with reclaimed water.

Section 4 – Evaluation of Non-Potable Water Reuse Alternatives

Section 4 describes the alternatives for expansion of the water reuse system to meet future non-potable demands, including hydraulic modeling and sizing of proposed infrastructure.

Section 5 – Evaluation of Potable Water Reuse Alternatives

Section 5 describes consideration for expansion of the water reuse system to implement potable reuse alternatives, including hydraulic modeling and sizing of proposed infrastructure.

Section 6 – Cost Estimates and Cost Benefit Analysis

Section 6 presents a cost benefit analysis including capital costs for all of the identified reuse system expansion alternatives.

Section 7 – Summary and Conclusions

Section 7 presents a summary of the findings of this Master Plan Update and discussion of the drivers to be considered for selecting future reuse alternatives. Next steps to evaluate the feasibility of potable reuse, including pilot testing, are also discussed.

Section 2

Existing Water Reuse System Evaluation

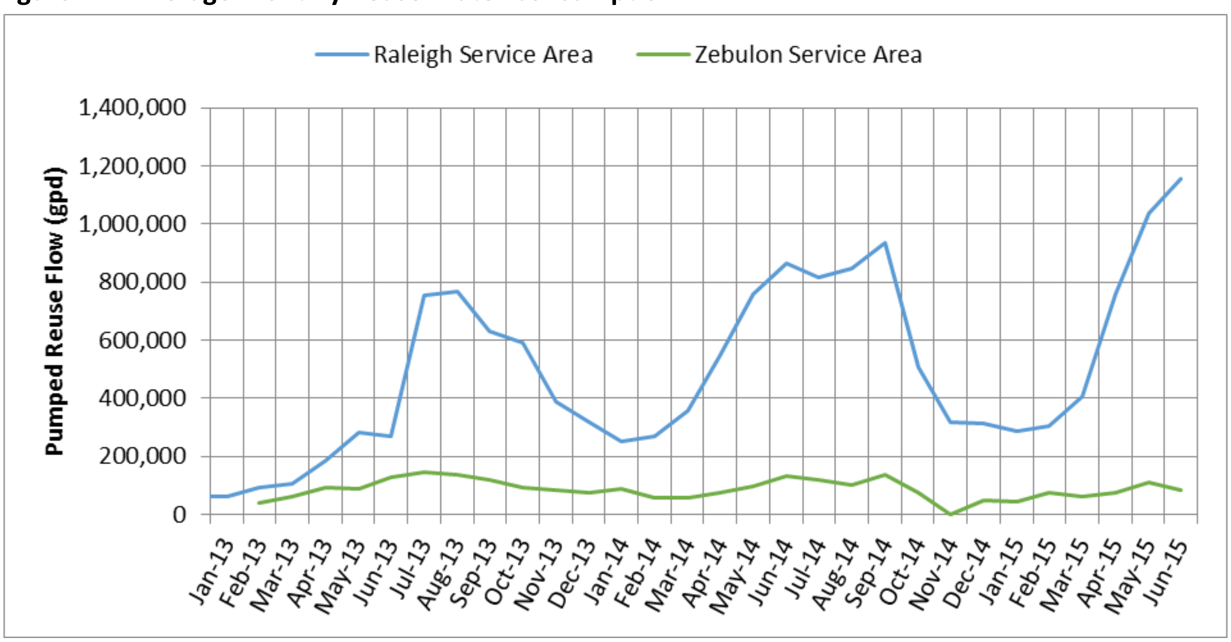
This section describes the evaluation of CORPUD's existing Raleigh and Zebulon water reuse distribution systems, which includes the following tasks:

- Analyzing pumping and billing records to determine existing demands on the systems.
- Conducting a hydraulic evaluation to determine the adequacy of the existing reuse distribution systems to meet peak customer demands.
- Evaluating water quality improvements for the Raleigh reuse system.

2.1 Water Reuse System Demands

Historical reuse water billing and pumping records were analyzed to determine current demands on the water reuse systems. **Figure 2-1** shows average monthly reuse water pumping for the Raleigh service area and Zebulon service area from January 2013 through June 2015. As shown in the figure, demands on the water reuse system are seasonal since they are primarily for irrigation and cooling water. Demands peak during the summer months and drop to a minimum during the winter months. Therefore, the system is not typically operated at an average annual flow; the seasonal and daily maximum/minimum flows are more important to consider for the evaluation of the reuse facilities. However, the average annual demand is used as a basis for projecting future demands on the system and for determining total annual revenue generated by the system.

Figure 2-1. Average Monthly Reuse Water Consumption



2.1.1 Raleigh Service Area Water Reuse Customers

Table 2-1 lists the current water reuse customers for the Raleigh service area along with usage type and average annual demand based on meter billing records from October 2014 through September 2015. The seasonal average use for summer (May through October) and maximum month use is also given over the same time period. It should be noted that the maximum month of consumption does not occur during the same month for all users.

Based on 2014/2015 billing records, the annual average metered demand from current customers within the Raleigh reuse service area is approximately 520,000 gallons per day (gpd) and the summer average metered demand is 784,000 gpd. Pumping records from the NRRRF off-site reuse pump station report an average annual reuse flow of 643,000 gpd and summer average flow of 883,000 gpd. The difference between the two (approximately 19 percent for average demands and 11 percent for summer demands) can be attributed to flushing performed at blow-off locations at the NRRRF, State Street, and near NCSU; and system loss.

The largest use, accounting for approximately 36 percent of the total average annual demand, is the administration building on the NRRRF site. This building uses reclaimed water for the cooling system, toilets, and a decorative pond. The cooling system is a once-through water cooled system (without recycle) which accounts for most of the administration building usage. The second largest user is the WakeMed Hospital cooling towers near the Sunnybrook tank. Approximately 11 percent of the Raleigh system reuse demand is for irrigation, with the remaining 89 percent for cooling, CORPUD lift station uses (including odor control system), and other non-irrigation uses.

In summer 2016, NCSU completed the on-campus reuse pipeline extension to bring reuse water to the Centennial Campus. NCSU began receiving reuse water for cooling tower use at the central utility plant and toilet flushing at the Hunt Library in late summer 2016. Demands for these uses, as well as additional irrigation at the Hunt Library and Lonnie Poole golf course, which are not yet using reclaimed water but expected to connect in the near future, are estimated in **Table 2-2**. With the NCSU Centennial Campus and Lonnie Poole golf course, summer average reuse demands are projected to increase by approximately 57 percent from 784,000 gpd to 1,229,000 gpd.

2.1.2 Zebulon Service Area Water Reuse Customers

Table 2-3 lists the water reuse customers for the Zebulon service area along with usage type and average annual demand based on meter billing records from October 2014 through September 2015. The seasonal average use for summer (May through October) and winter (November through April) are also given over the same time period.

Based on 2014/2015 billing records, the annual average demand from current customers within the Zebulon reuse service area is approximately 66,000 gpd. The summer average demand for this service area is 97,000 gpd. Pumping records from the Little Creek WWTP reuse pump station report an average annual reuse flow of 78,000 gpd and summer average flow of 105,000 gpd. The difference between the two (approximately 15 percent for average demands and 8 percent for summer demands) can be attributed to flushing and system loss.

Table 2-1. Raleigh Service Area Current Water Reuse Customers

Customer	Use Type	Annual Average Demand[1] (gpd)	Summer Average Demand (gpd)	Maximum Month Demand[2] (gpd)
NRRRF - Administration Building	Cooling, toilet flushing, fountain	189,700	355,100	526,000
WakeMed Hospital	Cooling tower	126,900	171,600	215,700
Walnut Lift Station	Odor control, miscellaneous	95,300	99,100	107,100
Crabtree Lift Station	Odor control, miscellaneous	47,700	47,200	62,800
Raleigh Country Club	Irrigation	40,300	76,800	116,400
Walnut Terrace	Irrigation	10,000	17,200	39,600
Walnut Creek Softball Complex	Irrigation	5,000	9,700	26,900
Walnut Creek Amphitheater	Irrigation, wash down	1,800	3,300	5,900
Wilders Grove Solid Waste Services	Toilet flushing, truck wash	1,400	1,500	2,800
Wake County Human Services (Swinburne Building)	Irrigation	900	1,700	2,800
Holly Hill Hospital	Irrigation	800	900	3,700
River Ridge Golf Course	Irrigation	100	100	800
Wake County Law Enforcement Training Center	Irrigation	100	100	500
Worthdale Park[3]	Irrigation	0	0	0
	TOTAL	**520,000**	**784,300**	**--**

1. Estimated from October 2014 through September 2015 billing data.
2. Maximum month does not occur during the same month for all users.
3. Worthdale Park did not have any billed usage from October 2014 to September 2015.

Table 2-2. Additional NCSU and Golf Course Demands

Customer	Use	Estimated Annual Average Demand[1] (gpd)	Estimated Summer Average Demand[2] (gpd)
NCSU Centennial Campus – Central Utility Plant	Cooling	130,000	182,000
NCSU Centennial Campus – Hunt Library	Irrigation	75,000	142,500
NCSU Centennial Campus – Hunt Library	Toilet Flushing	6,000	6,600
Lonnie Poole Golf Course	Irrigation	60,000	114,000
	TOTAL	**271,000**	**445,100**

1. From estimates provided in the January 2010 Kimley Horn Design Memorandum #5. Cooling demand assumed to be similar to WakeMed cooling use.
2. Summer average demands based on typical peaking factors discussed in Section 2.1.3.

GSK uses reclaimed water for cooling, irrigation, and toilet flushing and is the system's largest customer, accounting for 54 percent of the average annual usage on the system. Approximately 15 percent of the Zebulon system reuse demand is for irrigation, with 85 percent for cooling, toilet flushing, industrial uses, or CORPUD pump station use.

Table 2-3. Zebulon Service Area Current Water Reuse Customers

Customer	Use Type	Annual Average Demand[1] (gpd)	Summer Average Demand (gpd)	Maximum Month Demand[2] (gpd)
GSK	Cooling towers	30,400	43,100	58,700
GSK	Irrigation	4,000	7,800	15,500
GSK	Toilet flushing	1,100	1,300	1,500
US Foods	Cooling	11,900	18,600	24,900
Zebulon Pump Station	Pump station uses	10,300	10,600	13,100
Carolina Mudcats	Irrigation	5,000	8,900	13,500
Aimet	Cooling, industrial process	2,000	3,900	5,500
Town of Zebulon Municipal Complex	Irrigation	1,000	2,000	6,500
Sunrock	Concrete production	200	500	1,100
Walmart	Irrigation	200	500	1,500
	TOTAL	**66,100**	**97,200**	--

1. Estimated from October 2014 through September 2015 billing data.
2. Maximum month does not occur during the same month for all users.

2.1.3 Peaking Factors by Usage Type

The peaking factors discussed in the following paragraphs are applied to the annual average customer demands and used for evaluation and design of reuse facilities.

Seasonal Peaking Factors

The summer average peaking factors represent the reuse demand from May to October (irrigation and cooling season) divided by the annual average demand. The winter average peaking factors represent the reuse demand from November to April divided by the annual average demand. Seasonal demands are useful for determining system operations during high and low demand seasons and for evaluating water age and water quality concerns. For existing reuse customers, the seasonal peaking factors were determined using billing data from 2014 through 2015. **Table 2-4** presents seasonal peaking factors estimated for future customers. A summer peaking factor of 1.4 is assigned to cooling water demand, 1.9 is assigned to irrigation demands, and 1.0 is assigned to toilet flushing or other constant industrial usage demands. Correspondingly, the winter peaking factors for these water uses are 0.6, 0.1, and 1.0, respectively. These peaking factors are generally the same as those observed for CORPUD's current reuse customers.

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Table 2-4. Typical Peaking Factors

End Use of Water	Winter: Avg. Annual Peaking Factor	Summer: Avg. Annual Peaking Factor	Max Day: Avg. Annual Peaking Factor	Peak Hour: Avg. Annual Peaking Factor
Irrigation	0.1	1.9	3.0	7.8
Cooling	0.6	1.4	2.5	3.5
Toilet Flushing/ Industrial Use*	1.0	1.0	1.0	1.8

* Toilet flushing and industrial use assumes constant year-round usage, with daily peaks that do not coincide with other peak hour usage in the system (i.e. irrigation, etc.).

Maximum Daily Peaking Factor

The maximum day to average annual demand ratio (or max day peaking factor) is a key parameter for evaluating the reuse water system. Major elements of the distribution system are typically sized to deliver the maximum day demand reliably and consistently. In addition, reclaimed water supply is typically limited by the amount of water available to satisfy the maximum day demand, with hourly demands in excess of the maximum day satisfied through system storage.

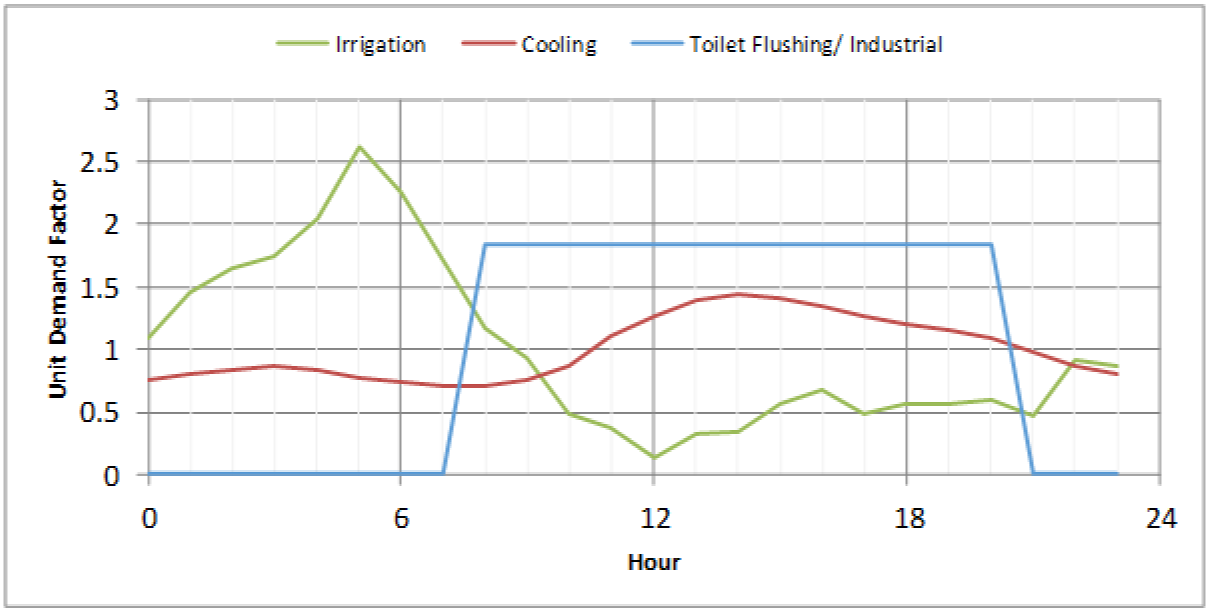
Customer billing data is only available on a monthly basis, therefore, max day peaking factors were determined based on typical peaking factors observed in other nearby communities for each end use of reclaimed water. The max day peaking factors applied to the existing and future customer demands are given in Table 2-4. For comparison, the overall max day peaking factor for the Raleigh and Zebulon reuse system, as determined from daily pumping records over 2013 to 2015, was approximately 2.5 to 3.1, which corresponds with the values in Table 2-4 for irrigation and cooling water uses that make up the majority of the existing system.

Diurnal Variations and Hourly Peaking Factors

Peak hour demand is the highest rate of reclaimed water consumption to occur during any one-hour period during a given year. Peak hour demand is often expressed as the ratio to the average annual demand. The reuse facilities are sized to convey peak hour flow and storage tanks are typically sized to equalize the system demand for all demand in excess of the maximum day, including the peak hour demand. If there is no system storage, the supply of reclaimed water and the reuse pumping capacity must be sufficient to meet this demand.

Diurnal curves representing the hourly variation in demand over a day were developed to account for peak hour and minimum hour demand conditions on the maximum day (**Figure 2-2**). Hourly metering data was not available for CORPUD's reuse customers, therefore, the diurnal curves for irrigation and cooling end uses were based on an individual customer metering analysis previously performed for similar customer types for the nearby Town of Cary's reclaimed water system. The toilet flushing demand curve is assumed to be constant from 8 a.m. to 8 p.m. since reuse water for toilet flushing is only applicable to commercial or industrial customers. The peak hour for irrigation occurs at 5:00 a.m. and the peak hour to max day flow ratio is 2.6, resulting in a peak hour to average annual flow ratio of 7.8. The peak hour for cooling use occurs in the afternoon and the peak hour to max day flow ratio is 1.4, resulting in a peak hour to average annual flow ratio of 3.5. The diurnal curves are used in the hydraulic model and correspond with the peak hour peaking factors presented in Table 2-4 for each end use.

Figure 2-2. Unit Diurnal Reclaimed Water Use Patterns



2.2 Hydraulic Modeling

Hydraulic model simulations were performed to evaluate existing system operations and the adequacy of the existing reuse system infrastructure to meet current and projected reuse demands. The hydraulic models of the reuse systems were subsequently used to evaluate the additional future demands on the reuse systems, as discussed in Section 4.

2.2.1 Model Development

For the Raleigh service area, CDM Smith converted CORPUD's steady-state hydraulic model of the reuse system previously developed in WaterCAD software into Innovyze InfoWater software, CORPUD's preferred water modeling software. The physical model includes all reuse pipes with length, diameter, and a Hazen-Williams roughness coefficient (C value), as well as ground elevations assigned at each modeled node. The model was updated to include the recently completed pipeline segment which extends to the distribution system from State Street through the Lonnie Poole golf course on the NCSU Centennial Campus. The model was also updated with pump curves provided by CORPUD for the off-site reuse pumps at the NRRRF. Operational controls based on set levels in the elevated storage tank were added to the modeled pumps to allow for extended period simulations (EPS) to represent the hour-to-hour changes that occur within the distribution system over the course of a day. The operational controls are consistent with the current system operating philosophy per discussions with CORPUD staff.

For the Zebulon service area, CDM Smith developed a hydraulic model of the reuse system in InfoWater software based on GIS data provided by CORPUD. All reuse pipes were modeled, with each pipe characterized in the model by length, diameter, and a C value assigned based on the diameter and material of construction of the pipe. Ground elevations were assigned at each modeled node based on topographic contour data for Wake County. The reuse pumps at the Little Creek WWTP were modeled using pump curves and operational controls based on set levels in the elevated storage tank per current system operations. The elevated storage tank was modeled with an overflow elevation of 462.6 feet.

2.2.2 Demand Allocation

The average day customer demands were assigned to the nearest pipe in the models, and then allocated to the appropriate node at the pipe end. For the Raleigh reuse system model, the demands from the old WaterCAD model were reallocated in their entirety based on recent billing data. Peaking factors specific to the reclaimed water end use (as presented in Table 2-4) were used in the model to adjust the average day water usage to maximum day demand conditions.

Diurnal curves representing the hourly variation in demand over a day were input into the model to account for peak hour and minimum hour demand conditions on the maximum day (Figure 2-2).

2.2.3 Evaluation Criteria

The evaluation criteria for assessing the existing reuse water systems includes system pressure, pipe velocity, pipe headloss, and system storage. In general, the following criteria was used for the evaluation:

- Minimum water supply pressure of 40 pounds per square inch (psi) during maximum day conditions, and 30 psi during peak hour conditions
- Maximum velocity of 10 feet per second (fps), with velocities less than 5 fps as the desirable range.
- Maximum head loss of 10 feet per 1,000 feet with head loss less than 5 feet per 1,000 feet as the desirable range.

2.2.4 Raleigh Distribution System Hydraulic Evaluation

The existing Raleigh reuse system was evaluated under maximum day demand conditions using EPS simulations with the updated hydraulic model. The Raleigh reuse system operates at a hydraulic grade line (HGL) elevation of 495 feet, similar to the potable water system pressure zone. Based on discussions with CORPUD staff, the reuse pumps at the NRRRF are typically operated to maintain elevated tank levels between approximately 25 and 35 feet (484 and 494 feet HGL elevation) during the summer.

The existing system was evaluated prior to the addition of the NCSU Centennial Campus demands. In the late summer of 2016, NCSU began using reuse water for central utility plant cooling makeup water as well as toilet flushing at the Hunt Library. Additional uses are expected for irrigation at the Hunt Library and the Lonnie Poole golf course; however, the irrigation systems were not on-line by summer of 2016. Therefore, a second near-term hydraulic evaluation was performed for the existing system with the addition of all anticipated NCSU and Lonnie Poole golf course demands.

Existing System (without NCSU demands)

Figures 2-3 and 2-4 show the pressures at all modeled nodes and modeled HGL profile, respectively, for maximum day demand conditions without the NCSU demands. The modeled maximum day demand on the system is 1.5 mgd. System pressures are greater than 75 psi, velocities are less than 4 fps, and headloss is less than 2 feet per 1,000 feet which are within acceptable ranges. As can be seen in the hydraulic profile, the lowest system elevations are generally located closest to the NRRRF where the HGL is highest, with elevations increasing and HGL decreasing toward the end of the system near NCSU. This results in the highest system pressures located nearest the NRRRF and lowest pressures at the far end of the system.

The lowest reuse pipeline elevation is located near the NRRRF site where the 24-inch diameter reuse pipeline crosses under a stream north of Law Enforcement Drive. The dual 72-inch diameter gravity wastewater interceptors that convey flow from the entire City of Raleigh collection system to the NRRRF are located within a land bridge constructed over the stream in the same easement as the reuse pipeline. This is a critical point for the reuse system, as it experiences the highest pressures in the reuse system. The consequence of failure of the reuse pipeline is very high at this location since it would impact CORPUD's primary wastewater transmission to the NRRRF. As such, pressures at this point of the reuse system are of key concern. Under existing conditions (without NCSU demands), one reuse pump is sufficient to fill the elevated tank on a maximum day. With a single reuse pump operating, the modeled pressures at the critical high pressure point are 140 to 155 psi.

Another critical point for reuse pressures is at the highest elevation of the current system near NCSU. This location experiences the lowest system pressures. However, peak hour modeled pressures during maximum day demands are 75 to 80 psi at this location (without the NCSU demand).

Near-Term System (with NCSU and Lonnie Poole golf course demands)

Figure 2-5 shows the modeled HGL profile for maximum day demand conditions with the estimated NCSU and Lonnie Poole golf course demands. The modeled maximum day demand on the system is 2.3 mgd. With these demands added to the end of the existing system, two reuse pumps operate at the NRRRF to meet maximum day demands. With two pumps operating, the discharge HGL of the pumps is higher and the modeled pressures at the critical high pressure point increase to 140 to 180 psi. This range of pressures may be of concern and CORPUD should continue to monitor pressures on the discharge side of the reuse pumps at the NRRRF as demands are added to the system and seasonal demands increase next summer.

At the critical low pressure point near NCSU, pressures during maximum day demands are 65 to 80 psi. Pipe velocities are all less than 4 fps and headloss is less than 3 feet per 1,000 feet.

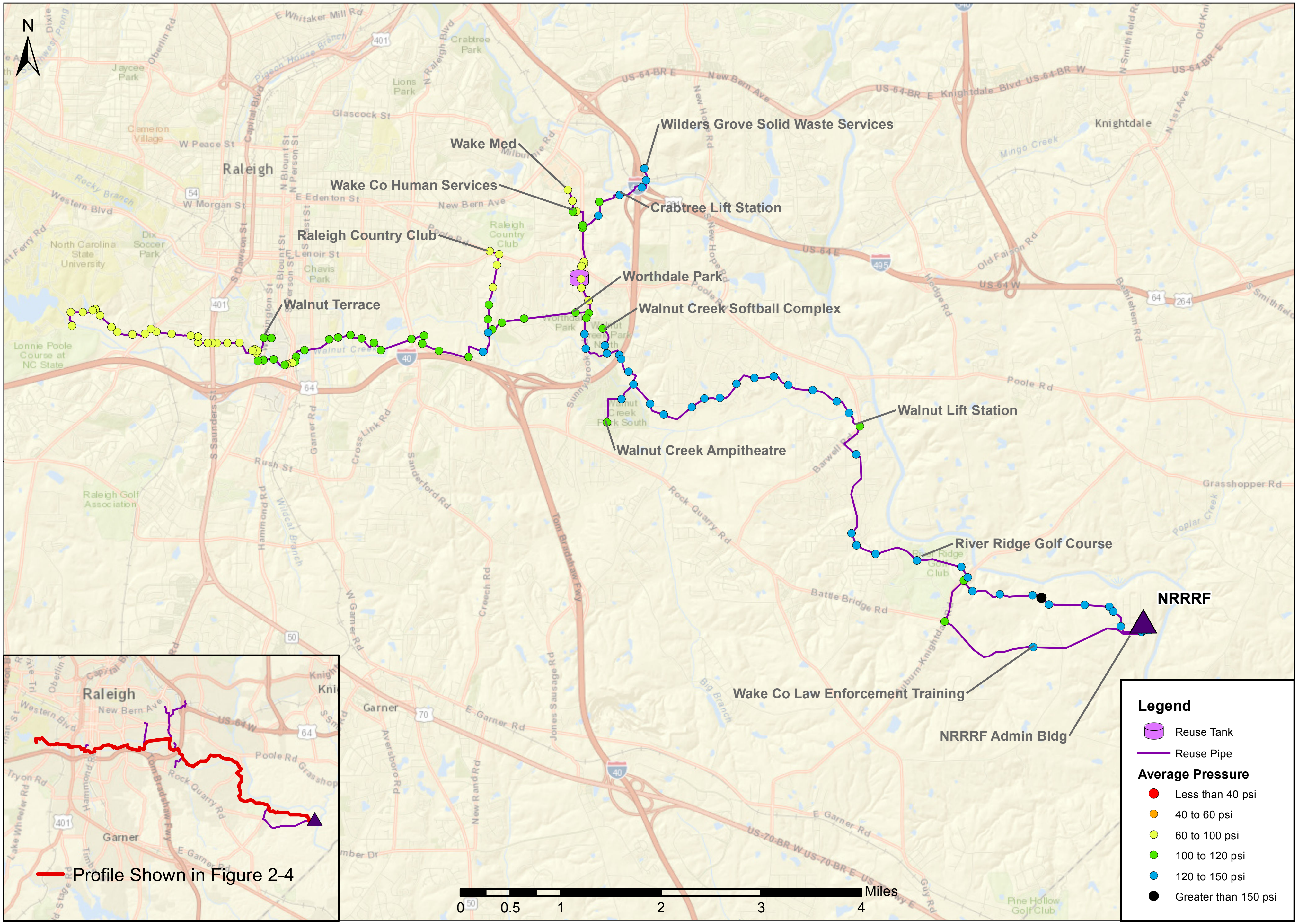


Figure 2-3
Existing Raleigh Reuse System (without NCSU) - Maximum Day Pressures

Figure 2-4. Existing Raleigh Reuse System HGL Profile (Max Day Demands)

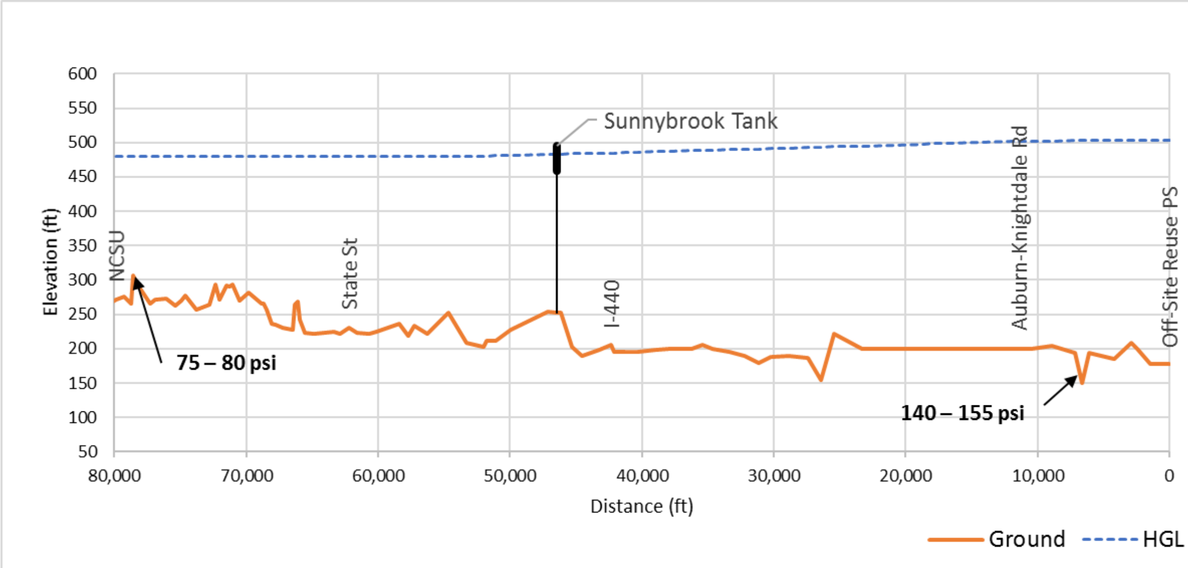
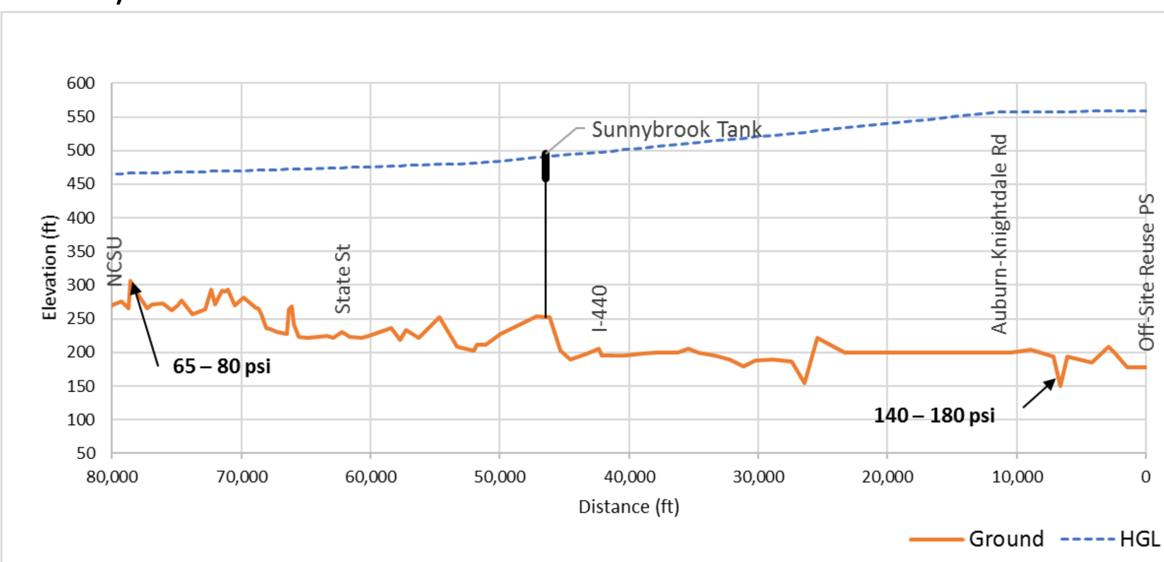


Figure 2-5. Raleigh Reuse System HGL Profile with NCSU and Lonnie Poole Golf Course (Max Day Demands)



Special Operating Conditions

Under normal operating conditions, the NRRRF reuse pumps are designed to fill the elevated tank, which supplies reuse water to the distribution system. However, recent maintenance issues with the elevated tank have brought up concerns of how to operate the system if the tank is out-of-service for routine or emergency maintenance. Hydraulic modeling was performed to determine special operations of the system with the tank out of service since the constant speed reuse pumps are oversized to supply normal system demands. Three operational scenarios were modeled under which the tank is out of service:

- Off-site reuse pumps used to supply system with continuous blowoff.
- Throttle valve downstream of off-site pumps to reduce pump head and continuous blowoff.

- Use on-site pump to supply NRRRF on-site reuse system and the reuse distribution system.

A summary of this analysis is included in **Appendix C**.

2.2.5 Zebulon Distribution System Hydraulic Evaluation

The existing Zebulon reuse system was evaluated under maximum day demand conditions using EPS simulations with the updated hydraulic model. The Zebulon reuse system operates at an HGL elevation of 462 feet, similar to the potable water system pressure zone. Based on discussions with CORPUD staff, the reuse pumps at the Little Creek WWTP are typically operated to maintain elevated tank levels between approximately 23 and 34 feet (449 and 460 feet HGL elevation).

Figures 2-6 and 2-7 show the pressures at all modeled nodes and the modeled HGL profile, respectively, for maximum day demand conditions. The modeled maximum day demand on the system is 240,000 gpd. Maximum day pressures are greater than 50 psi, velocities are less than 3 fps, and headloss is less than 3 feet per 1,000 feet, which are within acceptable ranges. Similar to the Raleigh reuse system, the lowest system elevations are generally located closest to the Little Creek WWTP where the HGL is highest, with elevations increasing and HGL decreasing toward the end of the system near GSK where the system pressures are lowest. In general, maximum day system pressures range from 50 psi at the western end of the system to 100 psi near the reuse pumps.

Figure 2-6. Existing Zebulon Reuse System Maximum Day Pressures

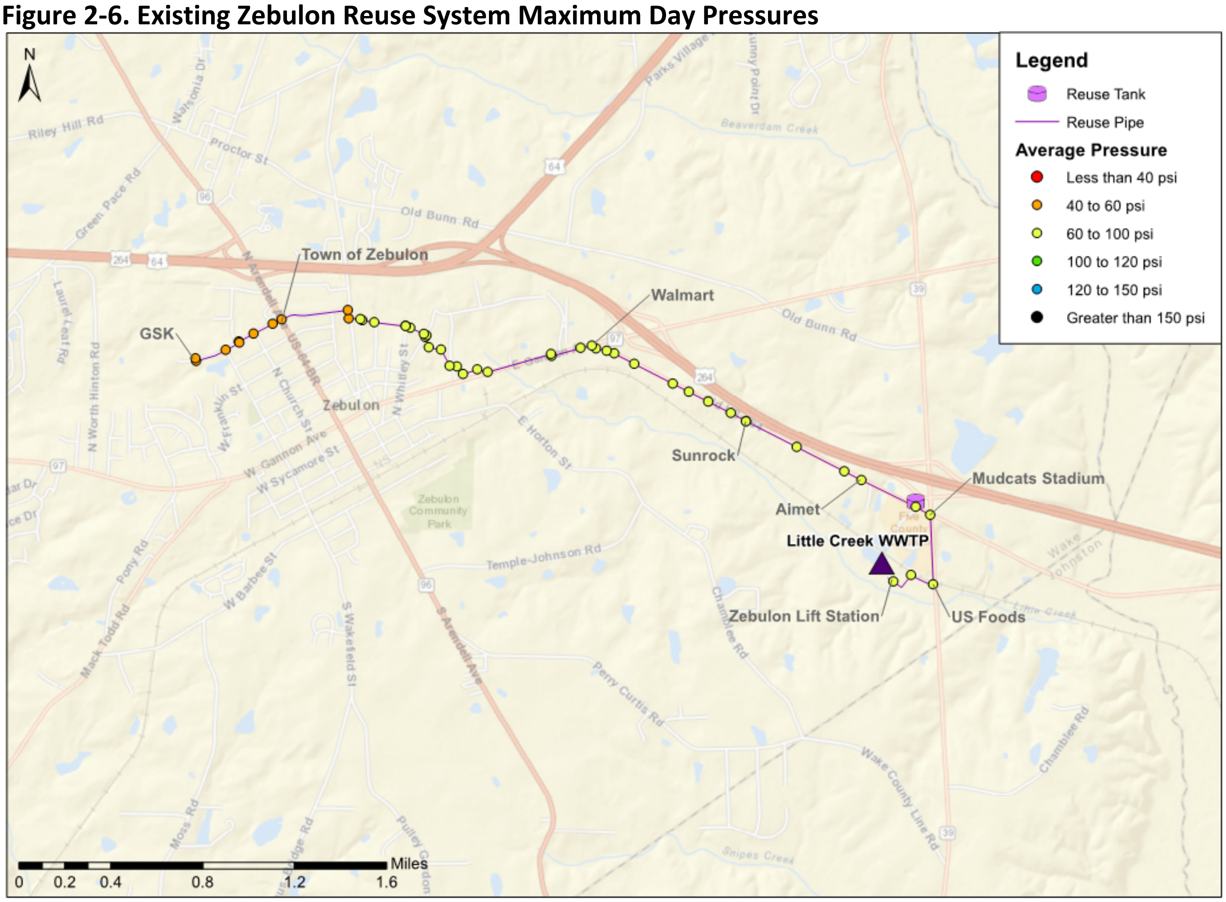
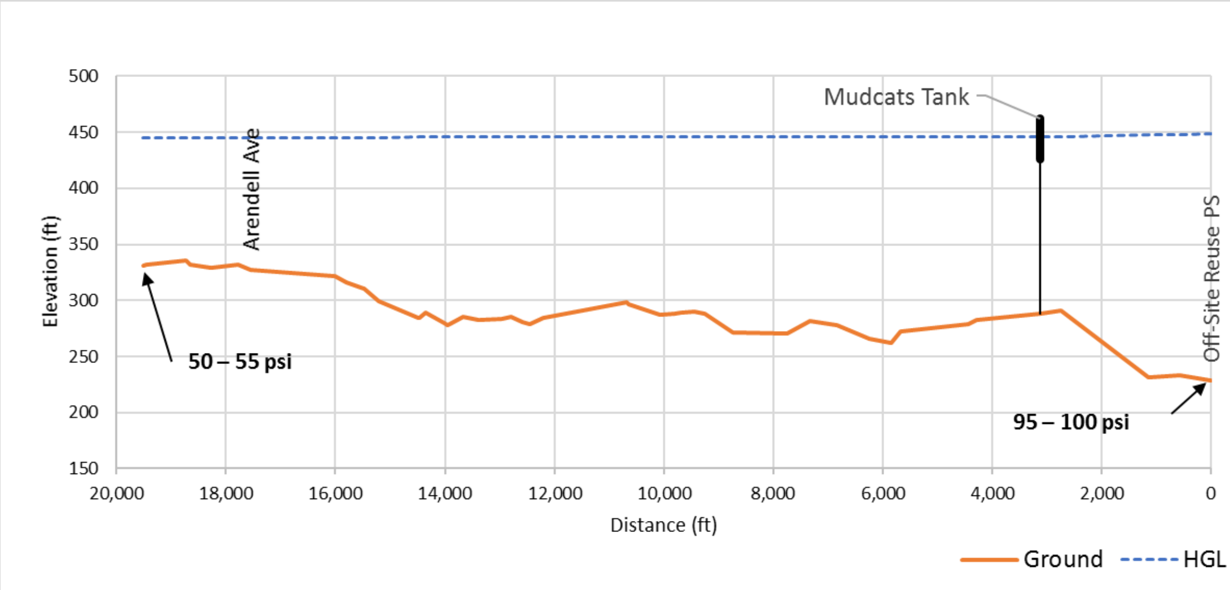


Figure 2-7. Existing Zebulon Reuse System HGL Profile (Max Day Demands)



2.2.6 Hydraulic Evaluation Summary

Based on the hydraulic model evaluation, the existing reuse infrastructure for the Raleigh and Zebulon reuse distribution systems is adequate to meet water transmission and storage needs for the existing customer demands and near-term NCSU and Lonnie Poole golf course demands. However, it is recommended that CORPUD continue to monitor pressures on the discharge side of the reuse pumps at the NRRRF as demands are added to the Raleigh reuse system to determine if improvements may be needed to reduce pressures at the critical high pressure point outside of the NRRRF. Alternatives 1 and 2 in Section 4 discuss improvements to address high pressures at this critical point.

2.3 Reuse Water Quality Evaluation

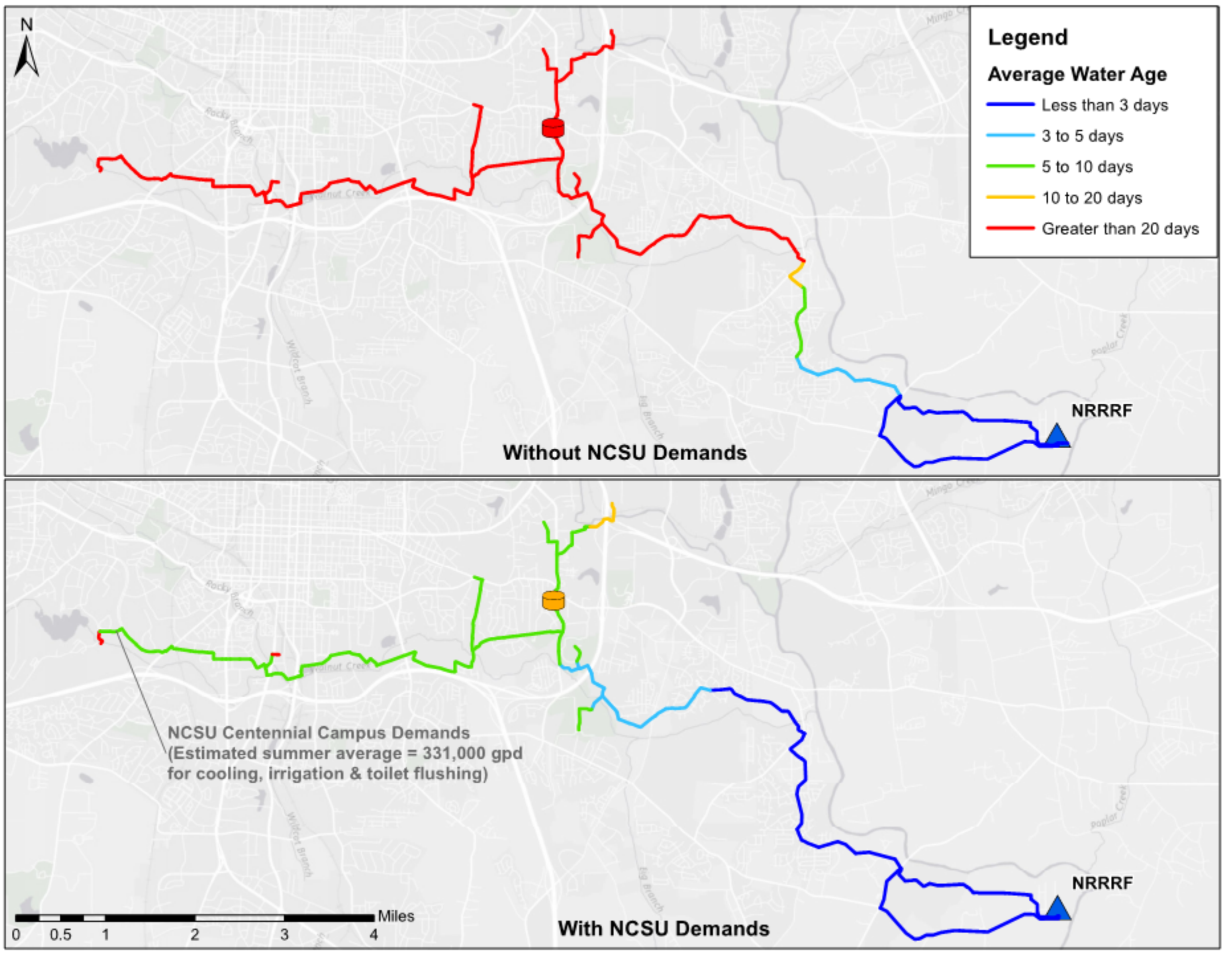
CORPUD has experienced difficulty in maintaining disinfectant residual and degradation of water quality in the Raleigh reuse distribution system. CDM Smith prepared a technical memorandum dated December 7, 2015 which discusses CORPUD's reuse system facilities and practices, and provides recommendations to preserve water quality within the Raleigh reuse distribution system. A summary of the key findings and recommendations follows. The full technical memorandum is included in Appendix A.

2.3.1 Key Reuse Water Quality Issues

The water quality study evaluated the existing hypochlorite feed system configuration, reuse distribution system water quality, and water age modeling results to identify the following key issues affecting water quality in the Raleigh reuse distribution system:

- **High water age and long detention times in the distribution system.** Time-of-travel simulations were performed using the hydraulic model of the reuse system to assess water age and storage tank turnover in the distribution system. **Figure 2-8** shows the model pipes color-coded by average water age for summer demand conditions. Prior to the addition of NCSU Centennial Campus demands on the system, the water age is very high (greater than 20 days) in most of the system due to the low demands relative to the size of the reuse tank and lack of demand on the system west of the reuse tank. With the full NCSU demands added, the water age is decreased to less than 5 days upstream of the tank and less than 10 days downstream of the tank for summer demands (Figure 2-8). Therefore, the recently added NCSU demands should help reduce water quality issues in the summer. However, water age is still excessive in the majority of the distribution system under the winter demand scenario.

Figure 2-8. Existing Raleigh Reuse System Water Age (Summer Average Demands)



- **Inability to maintain adequate chlorine residual in the distribution system.** A review of water quality data showed the chlorine residuals fall sharply in the reuse distribution system after leaving the NRRRF site. It is unlikely that the depletion of chlorine residuals is primarily due to reaction with ammonia-N. The rapid loss of chlorine residuals could potentially be the result of high reactivity of free chlorine, poor mixing, process not having reached steady state with reactions between chlorine and organic carbon/nitrogen and other chlorine demand, hypochlorite decomposition in the chemical storage tanks, or high chlorine consumption of the reuse water.

- **Need for additional disinfection system monitoring and improvements at the NRRRF.** The existing hypochlorite facilities feed multiple injection points for the on-site system, on-site high pressure irrigation system, and off-site reuse system. There is no on-line monitoring for the hypochlorite feed to the off-site wet well or residual analyzer for the off-site reuse system. In addition, short-circuiting in the off-site wet well (where the majority of the off-site hypochlorite dose is currently fed) may lead to insufficient mixing and chlorine contact time and the hypochlorite feed into the injection vault downstream of the reuse pumps is subject to frequent breaks and maintenance issues.

2.3.2 Water Quality Improvement Alternatives

Several improvement alternatives were identified to address water quality issues in the Raleigh reuse distribution system (see Appendix A for additional details).

Alternative 1

Add process monitoring including a flowmeter on the discharge of hypochlorite metering pump number 5 and total and free chlorine residual analyzers for the off-site system to provide direct confirmation of the hypochlorite feed to the off-site wet well and chlorine residual leaving the NRRRF site. Perform tracer testing or CFD modeling to confirm the efficiency of hypochlorite mixing and detention time in the off-site wet well. If mixing is insufficient, add a Chlor-A-Vac or similar mixing device to improve mixing of the chemicals in the wet well or consider the improvements to relocate the chlorine feed in Alternative 4.

Alternative 2

Use combined chlorine as a disinfectant instead of free chlorine to provide a more stable residual in the reuse distribution system without practicing breakpoint chlorination. The combined chlorine may persist sufficiently in the reuse system even without overcoming the oxidant demand since monochloramine is a much weaker oxidant. When switching to combined chlorine, perform periodic free chlorination for long-term control of biofilms. Limit the concentration of free ammonia in the system to less than 0.1 mg/L to eliminate nitrification issues.

Alternative 3

Use combined chlorine as a disinfectant instead of free chlorine and practice breakpoint chlorination to lower the oxidant demand before final disinfection using combined chlorine. Breakpoint chlorination will also prevent ammonia peaks from entering the distribution system, in the event of an upstream operational upset. Alternative 3 should be implemented in combination with improvements to the disinfection feed in Alternative 4. Bench-scale tests should be conducted to determine the breakpoint chlorine doses and disinfection decay curves at alternate temperatures for the treated effluent at the NRRRF. Effect of seasonal variation on disinfectant demand should also be evaluated. Further, monitoring of free chlorine residuals in the effluent from NRRRF should be conducted.

Alternative 4

Relocate the disinfection feeds from the injection vault 1 and off-site wet well to a single feed point in the 36-inch diameter reuse influent line between the junction box and the off-site wet well to address short circuiting and operational concerns. Add manholes on the 36-inch reuse influent line to feed, mix and monitor the disinfectant residuals. Monitoring for influent flow, free/ total chlorine and free ammonia should be conducted for process monitoring and control.

Alternative 5

Install a mixing system in the Sunnybrook reuse tank to eliminate thermal stratification. Mixing may include creating separate inlet and outlet pipes, adding recirculation pumps, or adding active mixing systems. Routine tank cleaning should be performed when improvements are installed.

Alternative 6

Add booster disinfection in the reuse distribution system at the Sunnybrook reuse tank.

2.3.3 Water Quality Recommendations

To improve water quality in the Raleigh reuse distribution system for the near-term, CORPUD is proceeding with implementing alternatives 5 and 6, which include adding a mixing system in the Sunnybrook reuse tank to reduce water quality deterioration in the tank and adding booster disinfection on the reuse tank site.

Implementing alternatives 1 and 4, which include process monitoring improvements and potential relocation of the chlorine feed at the NRRRF, are recommended as longer-term actions for improvement of reuse water quality.

In addition to the facility improvement alternatives above, the following general operational improvements are recommended for the Raleigh reuse system:

- Increase hypochlorite dose at the NRRRF with target chlorine residuals between 2 mg/L and 4 mg/L for the distribution system sample sites. Conduct bench-scale tests to determine the chlorine demand, breakpoint chlorine doses and disinfection decay curves at alternate temperatures for the treated effluent at the NRRRF. The effect of seasonal variation on disinfectant demand should also be evaluated.
- Consider diluting the bulk hypo to 6 percent to increase the shelf life of the chemical. Check strength of bulk hypochlorite solution in the storage tanks at least once a week to confirm that representative hypochlorite concentration is being used in chemical dose calculations.
- Control sediment accumulation in distribution system pipelines by conducting routine high velocity flushing. Where system limitations do not allow high velocity flushing, consider ice pigging to dislodge the biofilms on pipe walls.
- Perform annual cleaning and disinfection of the Sunnybrook reuse tank to prevent sediment buildup and microbial growth.

Section 3

Future Water Reuse Demands

The first phase of the Reuse Master Plan Update (documented in the July 2013 *Reuse Water System Master Plan Update Phase 1 Report*) identified several target areas for expansion of the current reuse system. This section describes the development of future reuse demand projections for expanding the system to those target areas. A hydraulic evaluation of the reuse system expansion alternatives and ability of the existing infrastructure to meet the future reuse demands is presented in Section 4.

3.1 Water Reuse Demand Target Areas

The target areas identified in Phase 1 of the Reuse Master Plan Update include a potential large concentration of non-potable water demands which could be met with reclaimed water and are anchored by one or more large users. Reuse target areas were identified based on potable water demand density mapping, which showed hot spots of potable water usage, and areas of anticipated future growth and new development within CORPUD's service area. The proximity to potential reuse sources was also considered. A series of interviews were conducted with large water users within the targeted demand areas to determine the facility's interest and applicability of the reuse system to meet existing water demands. Conceptual pipeline routing and/or satellite treatment plant options were developed to extend the reuse system to each of the target areas to determine which nodes are the most cost-effective to serve with the reuse system. After this screening process, it was determined that areas requiring satellite treatment facilities or that are located a long distance from the existing reuse pipelines are not cost-effective additions to the reuse system. The final non-potable demand target areas selected for detailed evaluation in Phase 2 of the Reuse Master Plan Update are shown in **Figure 3-1**. Additional details on development of the demand target areas are included in the *Reuse Water System Master Plan Update Phase 1 Report*.

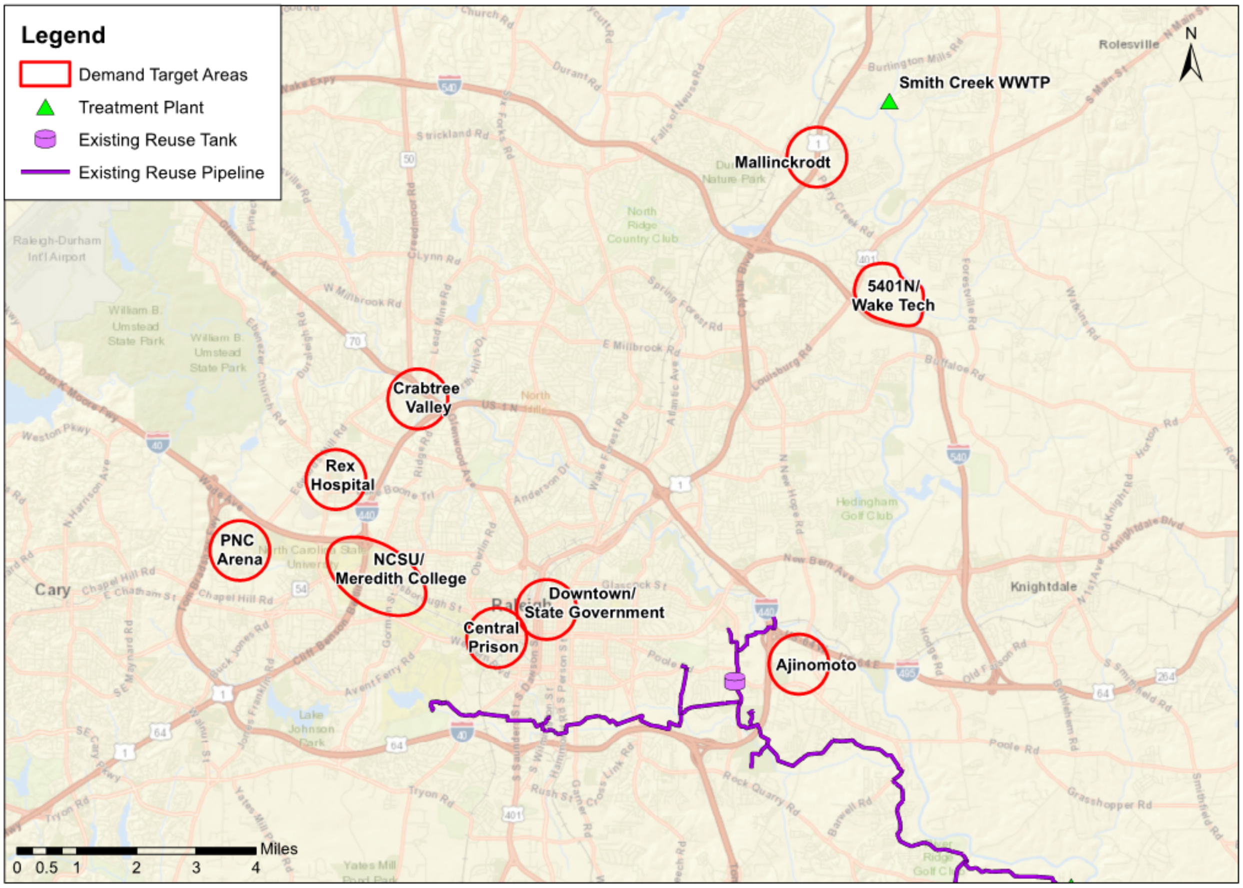
3.2 Water Reuse Demand Projections

The demand estimates developed in Phase 1 within each of the selected target areas were refined based on updated information from large users, potable water billing records, and other new information on future developments. In addition, infill demands from potable water customers with existing irrigation or other non-potable uses along the proposed pipeline route between target areas were added to the demand projections.

3.2.1 Assumptions

The reuse demand projections for existing potable water customers were developed based on the following assumptions:

Figure 3-1. Non-Potable Demand Target Areas for Potential Reuse Expansion



- Non-residential irrigation meters along the proposed pipeline extensions are included in the reuse demand projections. Average annual irrigation demand is estimated based on billed use for irrigation meters from 2011 through 2013 (average of the two highest years of consumption).
- For large users with cooling demands, the average annual reuse demands are estimated based on information provided from the customer interviews, or based on heated building area from the Wake County parcel data assuming 8.5 gallons per square foot per year (gal/sf/year) for cooling make-up water. This represents the low end of cooling water use presented in a Water Research Foundation study (*Commercial and Institutional End Uses of Water*, 2000) and is similar to cooling water usage data for existing reuse customers in Raleigh and nearby communities.
- Average annual demands for industrial or manufacturing processes by large users are estimated based on user interviews.
- Due to the cost and difficulties associated with retrofitting existing single-family residential irrigation meters, it is assumed that existing residential developments will not be added to the reuse system.

- The existing customer reuse water demands are assumed to remain constant in the future unless other specific projections were provided from the user interviews.

The reuse demand projections for buildout of future developments were based on the following assumptions:

- Irrigation demand is estimated assuming 10 percent of the developable land is available for irrigation with an average annual irrigation rate of 0.4 inches per week.
- For residential development in the 5401 North area, irrigation demand is estimated assuming an annual average of 168 gpd per single family residence (based on usage rates for Cary, NC and Falls River area irrigation meters). It is assumed that 50 percent of the single family homes will irrigate. In addition, irrigation is assumed for 10 percent of the site acreage for landscaping common space, apartment, commercial, etc. at an average annual irrigation rate of 0.4 inches per week.
- For office and mixed use development, 17,000 square feet of building area is estimated per acre of developable land. This estimate is based on an analysis of the City of Raleigh existing land use and building square footage from the Wake County parcel GIS database for parcels with current office and mixed use land uses.
- Average day cooling demand is estimated assuming 8.5 gal/sf/year. It is estimated that 50 percent of mixed use and office development will use reclaimed water for cooling.
- Average day cooling demand for hotels is estimated assuming cooling demands will be similar to cooling water use for Embassy Suites, which is a 273-room hotel in the Town of Cary that currently uses reclaimed water for cooling. Hotels are projected for the Blue Ridge Road redevelopment and 5401 North development. It is assumed that both will use reclaimed water for cooling.
- For hotels, it is assumed that laundry demand is similar to cooling demand (per data presented in EPA 'Saving Water in Hotels').
- Average day toilet flushing demand for new office, mixed use, hotel, and hospital development is estimated at 7.5 gal/sf/year. This estimate assumes 1 person per 300 square feet, 4 flushes per day per person, and 1.6 gallons per flush. It is estimated that 50 percent of office, mixed use, hotel, and hospital development will use reclaimed water for toilet flushing.

3.2.2 Raleigh Service Area Demand Projections

Figure 3-2 shows the existing Raleigh reuse distribution system pipelines, the proposed pipeline routing for extending the distribution system to the targeted demand nodes, and the locations of existing customer and future development reuse demands that could be added to the system.

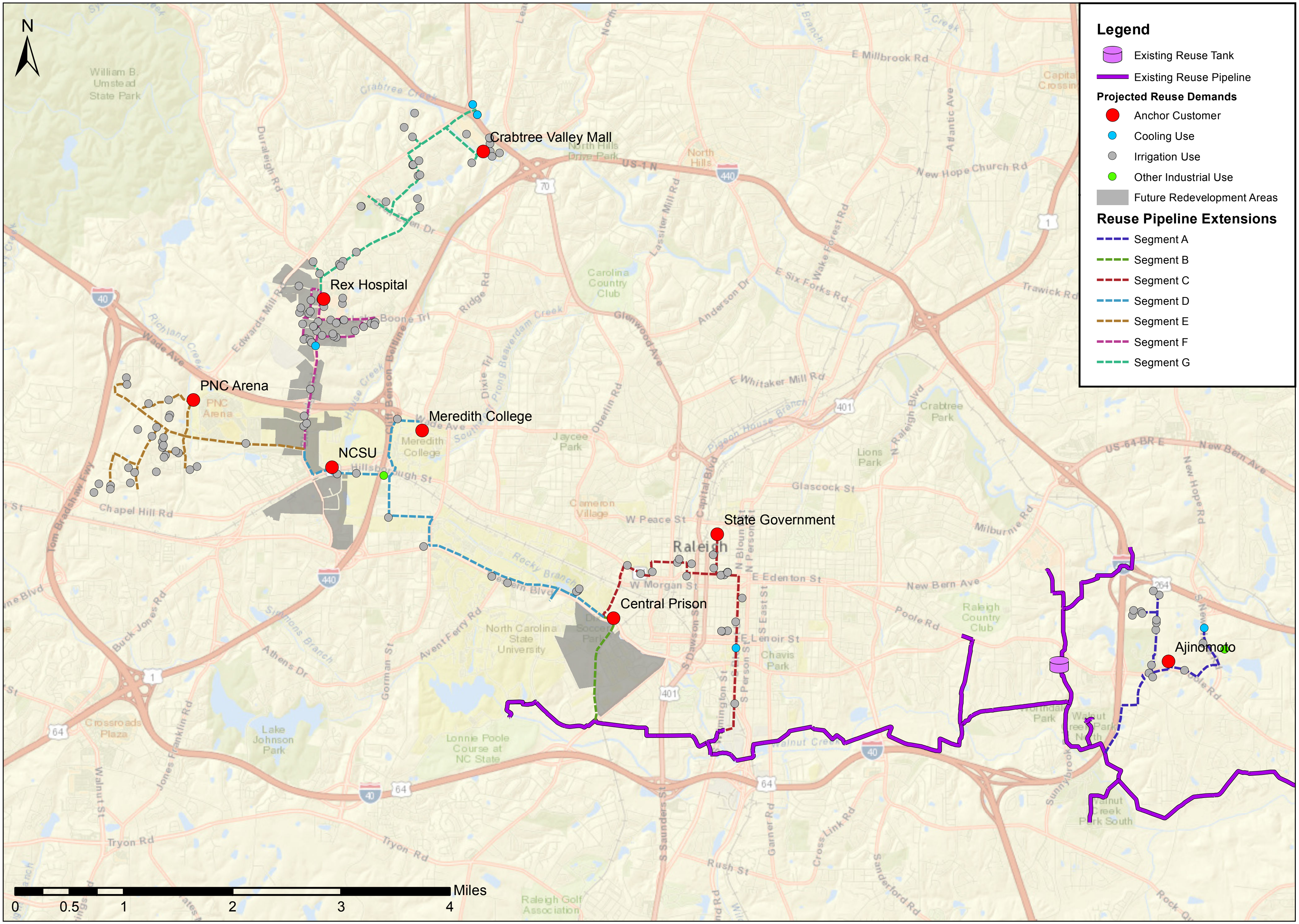


Figure 3-2
Raleigh Reuse System Potential Future Demands

The system extensions are divided into segments:

- **Segment A** – Existing reuse pipeline at I-440 to Ajinomoto area.
- **Segment B** – Existing reuse pipeline at Lake Wheeler Road through the Dorothea Dix property to Central Prison.
- **Segment C** – Loop around downtown Raleigh from the existing reuse pipeline at Fayetteville Street via Blount Street, Edenton Street, West Jones Street and Hillsborough Street to the segment at Central Prison.
- **Segment D** – Central Prison to Meredith College and NCSU Biomedical Campus via Western Boulevard, Gorman Street, Ligon Street, Method Road, Beryl Street, and Blue Ridge Road.
- **Segment E** – NCSU Biomedical Campus to the PNC Arena and surrounding area area via Trinity Road.
- **Segment F** - NCSU Biomedical Campus to Rex Hospital via Blue Ridge Road.
- **Segment G** – Rex Hospital to the Crabtree Valley Mall area via Blue Ridge Road, Glen Eden Drive, Parklake Avenue, and Creedmoor Road.

Table 3-1 presents the projected reuse demands for each segment listed above at buildout. Maximum day demand is determined using the peaking factors discussed in Section 2 (3.0 for irrigation, 2.5 for cooling, 1.0 for toilet flushing and other industrial uses). The total projected average annual reuse demand that could be added to the Raleigh reuse distribution system with construction of all of the proposed pipeline extensions is 1.01 mgd, with a corresponding maximum day demand of 2.63 mgd. This would almost triple the existing maximum day demand on the Raleigh reuse distribution system.

3.2.3 Zebulon Service Area Demand Projections

The Zebulon reuse system has limited opportunity for expansion due to the supply capacity of the Little Creek WWTP. However, extending the system to serve cooling demands for the BB&T data center near North Arendell Avenue and Green Pace Road was considered. **Figure 3-3** shows the existing Zebulon reuse distribution system pipelines and the proposed pipeline routing for extending the distribution system to the BB&T data center with the locations of existing customer demands that could be added to the system.

The projected annual average demand for the system extension is 35,800 gpd, with a maximum day demand of 91,000 gpd, as provided in **Table 3-2**. This would increase the existing demands by approximately 54 percent. Analysis of the reuse supply capacity versus projected reuse demands for the Zebulon distribution system is presented in Section 4.

Table 3-1. Projected Reuse Demands for the Raleigh Reuse Distribution System

Segment[1]	User	Estimated Average Annual Demand (gpd)				Estimated Summer Average[3] (gpd)	Estimated Max Day[3] (gpd)
		Irrigation	Cooling	Other[2]	Total		
A	Ajinomoto	0	90,000	0	90,000	126,000	225,000
	Other Existing Customers	18,000	18,200	0	36,200	59,700	99,500
	Segment A Total	***18,000***	***108,200***	***0***	***126,200***	***185,700***	***324,500***
B	Central Prison	0	35,000	0	35,000	49,000	87,500
	Future Redevelopment (Dorothea Dix)	100,000	0	0	100,000	190,000	300,000
	Segment B Total	***100,000***	***35,000***	***0***	***135,000***	***239,000***	***387,500***
C	State Government	7,200	50,000	0	57,200	83,700	146,600
	Other Existing Customers	9,800	8,000	0	17,800	29,800	49,400
	Segment C Total	***17,000***	***58,000***	***0***	***75,000***	***113,500***	***196,000***
D	Meredith College	0	40,000	0	40,000	56,000	100,000
	NCSU (Vet School & Future Biomedical Campus)	9,300	113,000	12,000	134,300	187,900	322,400
	Other Existing Customers	18,500	49,000	0	67,500	103,800	178,000
	Future Redevelopment	24,100	21,000	19,000	64,100	94,200	143,800
	Segment D Total	***51,900***	***223,000***	***31,000***	***305,900***	***441,900***	***744,200***
E	PNC Arena	7,000	33,000	0	40,000	59,500	103,500
	Other Existing Customers	70,900	0	0	70,900	134,700	212,700
	Segment E Total	***77,900***	***33,000***	***0***	***110,900***	***194,200***	***316,200***
F	Rex Hospital	3,600	38,800	0	42,400	61,200	107,800
	Other Existing Customers	31,100	0	0	31,100	59,100	93,300
	Future Redevelopment	17,400	35,000	28,000	80,400	110,100	167,700
	Segment F Total	***52,100***	***73,800***	***28,000***	***153,900***	***230,400***	***368,800***
G	Crabtree Valley Mall	5,800	30,000	0	35,800	53,000	92,400
	Other Existing Customers	56,200	11,000	0	67,200	122,200	196,100
	Segment G Total	***62,000***	***41,000***	***0***	***103,000***	***175,200***	***288,500***
	TOTAL	**378,900**	**572,000**	**59,000**	**1,009,900**	**1,579,900**	**2,625,700**

1. See Figure 3-2 for pipeline segments.
2. Other demands include toilet flushing, industrial, and laundry demands that are assumed to be constant over the year.
3. Summer seasonal and maximum day demands estimated using typical peaking factors presented in Table 2-4.

Figure 3-3. Zebulon Reuse System Potential Future Demands

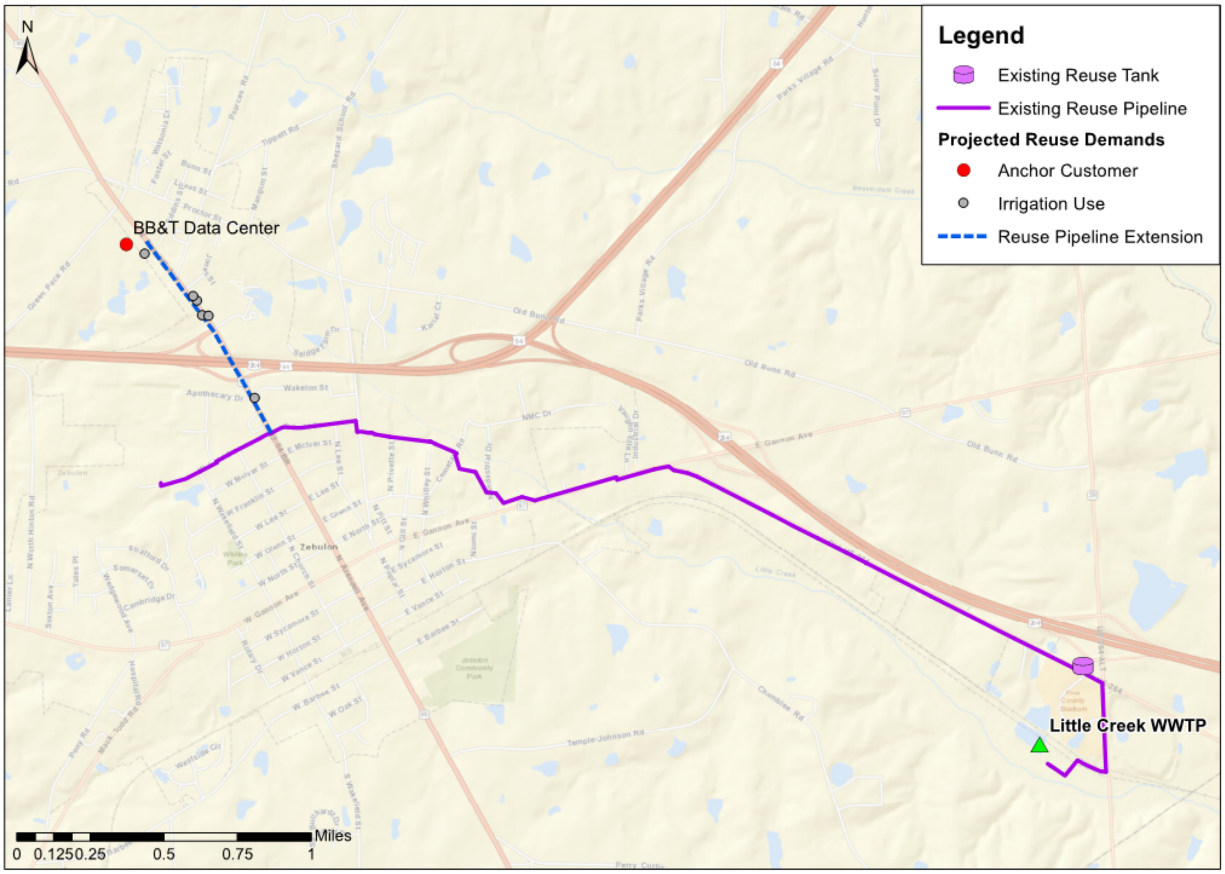


Table 3-2. Projected Reuse Demands for the Zebulon Reuse Distribution System

User	Estimated Average Annual Demand (gpd)				Estimated Summer Average[3] (gpd)	Estimated Max Day[3] (gpd)
	Irrigation	Cooling	Other[2]	Total		
BB&T Data Center[1]	0	32,800	0	32,800	45,900	82,000
Other Existing Customers	3,000	0	0	3,000	5,700	9,000
TOTAL	**3,000**	**32,800**	**0**	**35,800**	**51,600**	**91,000**

1. BB&T data center demands based on information provided by CORPUD.
2. Other demands include toilet flushing, industrial, and laundry demands that are assumed to be constant over the year.
3. Summer seasonal and maximum day demands estimated using typical peaking factors presented in Table 2-4.

3.2.4 New Smith Creek Service Area Demand Projections

The Smith Creek WWTP does not currently supply reuse water to off-site customers. However, as determined through meetings with large users and developers in the area, there is significant potential for supplying reuse water to nearby customers. Wake Technical Community College has already installed separate piping for toilet flushing in recently constructed buildings and for cooling towers at the northern campus regional utilities plants that can be readily converted to the reuse system. In addition, the 5401 North development is installing separate piping for irrigation systems. **Figure 3-4** shows the proposed new reuse distribution system pipeline routing from the Smith Creek WWTP to Mallinckrodt and the Wake Tech campus and 5401 North mixed use development, and the locations of existing customer and future development reuse demands that could be added to the system.

The projected annual average demand for this new system is 315,000 gpd, with a maximum day demand of 823,000 gpd, as given in **Table 3-3**. Analysis of the reuse supply capacity versus projected reuse demands and new reuse infrastructure for the Smith Creek distribution system are presented in Section 4.

Figure 3-4. Potential Future Smith Creek Reuse System Demands

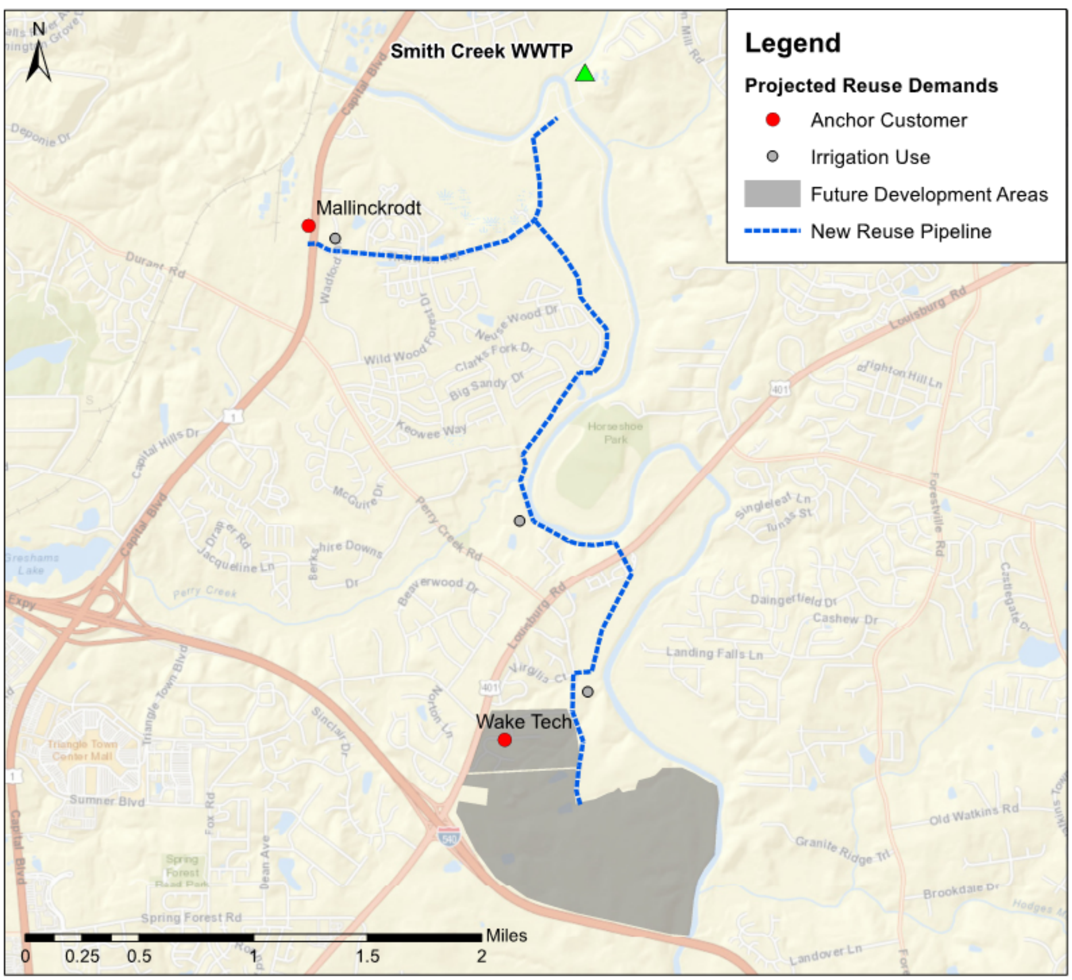


Table 3-3. Projected Reuse Demands for the New Smith Creek Reuse Distribution System

User	Estimated Average Annual Demand (gpd)				Estimated	Estimated
	Irrigation	Cooling	Other[1]	Total	Summer Average[2] (gpd)	Max Day[2] (gpd)
Mallinckrodt	0	115,000	0	115,000	161,000	287,500
Wake Technical Community College	0	23,800	8,000	31,800	41,300	67,500
Wake County Public Schools (Future)	0	5,000	0	5,000	7,000	12,500
Other Existing Customers	4,000	0	0	4,000	7,600	12,000
Future 5401 North Development	120,300	29,000	10,000	159,300	279,200	443,400
TOTAL	**124,300**	**172,800**	**18,000**	**315,100**	**496,100**	**822,900**

1. Other demands include toilet flushing, industrial, and laundry demands that are assumed to be constant over the year.
2. Summer seasonal and maximum day demands estimated using typical peaking factors presented in Table 2-4.

3.3 Future Water Reuse Demands at the NRRRF

In addition to the projected reuse demands for new customers of the reuse distribution systems, significant potential was identified for expanding the reuse system to meet non-potable demands at the NRRRF. CORPUD is currently evaluating new facilities at the NRRRF as part of a bioenergy recovery program. These new facilities will have a demand for non-potable water, most significantly as makeup water in the heat exchanger (HEX) for cooling of sludge from the thermal hydrolysis pretreatment (THP) process.

Table 3-4 summarizes the projected reuse demands related to the bioenergy recovery program for the facility size at startup and ultimate buildout, as well as the existing demands for the on-site reuse system. The largest single demand, for makeup water in the HEX for cooling of sludge from the THP process, is anticipated to be continuous (24 hours per day) and range from 350 to 2,500 gpm initially (350 to 3,300 gpm at buildout) based on loading, seasonal, and other factors. This demand alone will approximately double the on-site reuse at the NRRRF.

Evaluation of the options and recommendation for using the existing on-site reuse system at the NRRRF to meet the non-potable demands of the bioenergy recover program are presented in the February 10, 2016 Technical Memorandum included in **Appendix B**. The evaluation is summarized, along with the other options for expanding CORPUD's reuse systems, in Section 4.

Table 3-4. Projected Reuse Demands at the NRRRF[1]

Location	Initially Installed Equipment Demand (gpm)		Ultimate Buildout Demand (gpm)	
	Average	Maximum	Average	Maximum
Projected Bioenergy Recovery Demands				
Primary Sludge Degritting Tank – Water Cannon[2]	500	0	500	0
Primary Sludge Degritting Tank – Other[2]	104	4	104	4
Thickening Building	0	102	103	272
Pre-Dewatering & Sludge Screening Facility	155	273	225	438
Sludge Storage	1	1	1	1
THP – Sludge Cooling HEX	1,350	2,500	1,800	3,300
THP – Other	70	139	116	206
Final Dewatering Building	50	80	410	440
Sidestream Treatment	74	74	74	74
Gas Use and Storage	50	100	150	300
Bioenergy Recovery Subtotal	**2,354**	**3,273**	**3,483**	**5,035**
Existing On-Site Uses[3]	1,638	2,181	1,638	2,181
Existing High-Pressure Irrigation	0	4,500	0	4,500
Total Reuse Demand at NRRRF	**3,992 (5.7 mgd)**	**9,954 (14.3 mgd)**	**5,121 (7.4 mgd)**	**11,716 (16.9 mgd)**

1. Demands based on spreadsheet provided by Black & Veatch on December 22, 2015.
2. Assumes use does not coincide with other maximum demands on-site at the NRRRF.
3. Existing on-site system includes uses at the headworks/pretreatment facility, secondary clarifiers, centrifuge building, dewatering building, sludge thickening building, and miscellaneous wash down areas.

Section 4

Evaluation of Non-Potable Water Reuse Alternatives

Several alternatives were developed for expanding CORPUD's reuse program to meet additional non-potable demands within the service area. These alternatives are based on the demand projections and proposed pipeline routing presented in the previous section.

Section 4.1 summarizes the recommendations for meeting projected demands of the on-site reuse system at the NRRRF. Section 4.2 describes the evaluation and hydraulic modeling of the alternatives for expanding the reuse distribution systems and presents recommendations and sizing for the additional reuse infrastructure required to meet the projected non-potable demands.

4.1 Additional Water Reuse at the NRRRF for the Bioenergy Recovery Program

The additional non-potable water demand of the new bioenergy facilities proposed at the NRRRF will approximately triple the total on-site reuse demands. The largest portion of the new reuse demand (HEX makeup water) will be a continuous demand that is critical for the operation of the THP facilities. The evaluation of reuse water for bioenergy recovery is presented in the February 10, 2016 Technical Memorandum included in Appendix B. The evaluation considered various factors including: 1) reuse supply capacity for on-site and off-site uses at the NRRRF, 2) capacity of the existing pump systems (either off-site or on-site reuse pumping stations) to meet the bioenergy recovery demands, and 3) delivery pressures, disinfection requirements, and operational flexibility required for the bioenergy systems.

Although the supply of reclaimed water at the NRRRF was determined to be adequate to simultaneously meet future off-site and on-site demands, it was concluded that none of the existing reuse pumping facilities at the NRRRF have capacity to meet the proposed bioenergy demands without expansion or significant modifications.

The following improvements are recommended to add the bioenergy recovery program demands to the reuse system at the NRRRF:

- **Replace on-site reuse pump station**

  The bioenergy reuse demands should be added to the on-site reuse system and a new replacement on-site pump station is recommended to replace the existing on-site pump station. The existing high pressure irrigation pumps could remain as is and a new 5,500-gpm station could be built with adequate space for expansion to meet total future on-site reuse demands.

Addition of a hydropneumatic tank or pumps with variable frequency drives (VFDs) should be considered for the new on-site pump station to help maintain system pressures and minimize pump on/off cycles during periods of lower demand.

- **Reuse storage tank/wet well**

  Construction of a common reuse storage tank/wet well upstream of both the existing off-site and new on-site pump stations could provide benefits for mixing and dosing of hypochlorite to both systems. This facility could also provide some amount of storage for reliability of supply due to hourly fluctuations in effluent flow through the plant.

- **On-site reuse piping improvements**

  Based on the projected maximum demands, the existing 12-inch and 8-inch reuse pipe loop that comprises the on-site system will not provide sufficient capacity for both existing and additional on-site demands. A new on-site reuse pipeline from the new on-site pump station to the east side of the plant, where the new bioenergy facilities are proposed, will likely be necessary as part of the on-site reuse system upgrades. This pipeline can be looped with the existing on-site pipeline to provide redundancy and additional capacity.

4.2 Water Reuse Distribution System Expansion Alternatives

The remainder of alternatives to expand CORPUD's reuse program for non-potable uses involve new or expanded reuse distribution systems. These include the following:

- Alternative 1 – Extend Raleigh Reuse System to Blue Ridge Road
- Alternative 2 – Extend Raleigh Reuse System to Central Prison and Dorothea Dix Property
- Alternative 3 – Extend Zebulon Reuse System to the BB&T Data Center
- Alternative 4 – New Distribution System from Smith Creek WWTP

4.2.1 Approach and Evaluation Criteria

The alternatives were evaluated using the Innovyze InfoWater hydraulic model. New pipelines were added to the existing system models for the Raleigh and Zebulon service areas along the preliminary routes discussed in Section 3 and a new hydraulic model was developed for the Smith Creek WWTP distribution system. New pipelines are assumed to be ductile iron pipe (DIP) and are assigned a C value of 130. The projected demands are assigned to the nearest pipe in the model, and then allocated to the appropriate node at the pipe end. Extended period hydraulic model simulations were run with maximum day demands applied to the typical diurnal demand patterns for each end use presented in Section 2. Simulations were run for a duration of 72 hours to determine if tanks are able to fill during nighttime hours under maximum day demands.

The key criteria for evaluating the reuse distribution system expansion alternatives includes reuse supply capacity, storage requirements, system pressures, velocity, and head loss.

Reuse Supply Capacity

Capacity of the reuse supply sources is typically evaluated by using the minimum day wastewater flow to define the maximum day reuse available since reuse demands peak in the summer months when the weather is driest and hottest, but this period corresponds with the lowest wastewater flows. For this evaluation, an additional safety factor of 10 percent was subtracted from the minimum day wastewater flow when determining the available reuse supply to account for bulk reclaimed water uses and system losses.

Storage Volume Requirements

Storage requirements are based on the volume for equalizing supply and demand, and for emergency storage. The minimum supply/demand equalization storage is typically determined by comparing the 24-hour diurnal wastewater flow demand pattern on the minimum wastewater flow day with the 24-hour diurnal demand pattern on the maximum reuse demand day, specific to each service area. For those hours where the demand exceeds the supply, storage is used to meet the deficit.

The reliability required in CORPUD's reuse distribution system is not as great as that required in the potable water system, since the potable system may serve as a back-up to customers that need an uninterrupted supply. In addition, excess storage volume within a reuse distribution system can lead to high water age, contributing to water quality issues, especially during low demand periods. Therefore, storage within the reuse distribution system (as opposed to at the plant) was only considered when it would provide other hydraulic or operational benefits.

System Pressures

The adequacy of a reclaimed water distribution system is evaluated based on its ability to provide the volume of water required to satisfy the demands of the customers in the service area at adequate system pressures. Typically, a minimum water supply pressure of 40 psi during average and maximum day conditions, and 30 psi during peak hour conditions, is favorable for both potable and reclaimed water distribution systems. Therefore, this criterion was used to evaluate the reuse system alternatives. As a general rule, reuse system pressures should be similar to pressure in the potable system in order to maintain the level of service for existing potable customers converting to the reuse system. In particular, pressures in areas where the reuse system crosses the potable water system pressure zone boundary were considered.

In addition, for the Raleigh reuse distribution system, maximum pressures in the reuse pipeline where it is co-located in the easement with the dual 72-inch diameter gravity wastewater interceptors from the NRRRF to Barwell Road, are of key concern. The critical point along this section is located where the 24-inch diameter reuse pipeline crosses under a stream north of Law Enforcement Drive and the 72-inch gravity interceptors are located within a land bridge constructed over the stream in the same easement. This is a critical point for the reuse system, as it experiences the highest pressures in the reuse system and the consequence of failure of the reuse pipeline is very high since it would impact CORPUD's primary wastewater transmission to the NRRRF. Alternatives where pressures exceed the existing modeled maximum pressures (approximately 150 psi) at this critical point are identified along with potential improvements to reduce pressures.

Velocity and Head Loss

The reuse system evaluation is based on a maximum design velocity of 10 fps, with velocities less than 5 fps as the desirable range. The analysis is also based on a maximum head loss of 10 feet per 1,000 feet with head loss less than 5 feet per 1,000 feet as the desirable range for proposed pipes. These criteria are the same as the guidelines for potable water distribution systems.

4.2.2 Alternative 1 – Extend Raleigh Reuse System to Blue Ridge Road

The target demand areas identified for extending the Raleigh reuse system include demands through the Crabtree Valley Mall area at Creedmoor Road and Glenwood Avenue. However, the reuse system consists primarily of a single transmission main without any substantial looping. Therefore, as demands increase, head loss through the transmission main also increases and the capacity to extend the transmission main and still meet adequate system pressure requirements is limited.

Hydraulic modeling indicates that the system cannot be extended to the Crabtree Valley Mall area (Segment G, Figure 3-2) without upsizing the existing 16-inch reuse transmission pipeline from Auburn Knightdale Road through South Wilmington Street, which is approximately 11 miles of pipeline. Without upsizing the existing 16-inch pipeline, the furthest that the system can be extended is through the Rex Hospital area on Blue Ridge Road (Segment F, Figure 3-2). Therefore, Alternative 1 represents the maximum extension of the existing Raleigh reuse system (to Rex Hospital on Blue Ridge Road) without upsizing the existing reuse transmission main.

Table 4-1 lists the proposed pipeline, pumping, and storage improvements for Alternative 1. **Figure 4-1** shows the locations of the proposed facilities. The total maximum day demand for Alternative 1, including existing customers, is 4.6 mgd. Improvements are described in the paragraphs below.

Table 4-1. Alternative 1 Proposed Pipeline, Pumping, and Storage Improvements

Category	Description	Size	Quantity	
Pipelines	New Reuse Pipelines	6-inch diameter	11,400	LF
	New Reuse Pipelines	8-inch diameter	19,600	LF
	New Reuse Pipelines	12-inch diameter	46,800	LF
	New Reuse Pipelines	16-inch diameter	27,300	LF
		Total	**105,100**	**LF**
Pumping	New Booster Pump Station near Walnut Creek Park	4.3 mgd; 120 ft TDH	1	EA
	New Booster Pump Station near Pullen Park	2.2 mgd; 190 ft TDH	1	EA
	Modify NRRRF off-site pumps	Design TDH 300 ft	3	EA
	Add new off-site pump w/ VFD	1,100 gpm; 300 ft TDH	1	EA
Storage	New Elevated Reuse Tank for 595 ft zone	350,000 gallons	1	EA

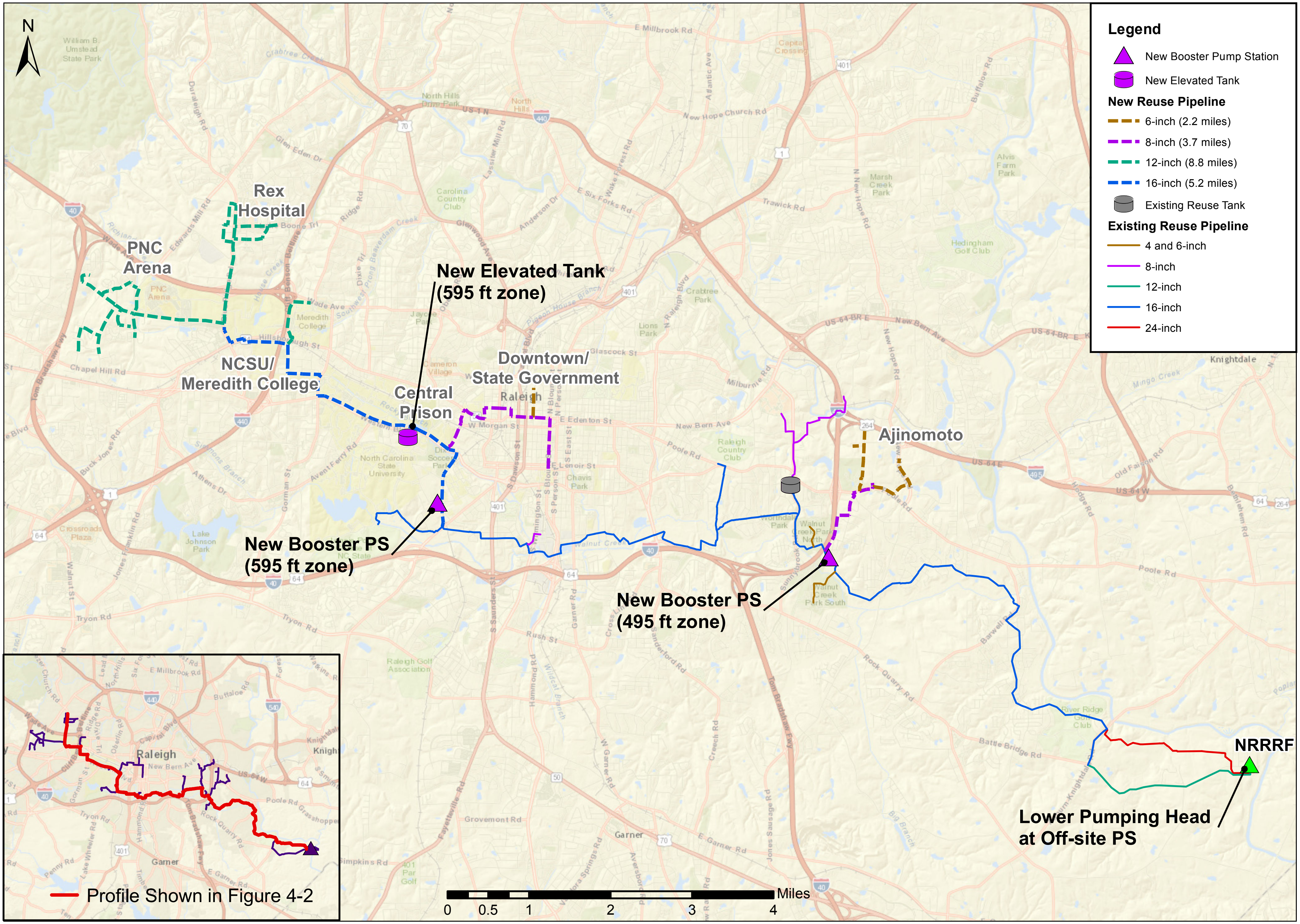


Figure 4-1

Proposed Improvements for Alternative 1 - Extend Raleigh Reuse System to Blue Ridge Road

Construct new pipelines

Alternative 1 includes 6.5 miles of new 16-inch and 12-inch transmission pipe from Lake Wheeler Road to Blue Ridge Road and 13.4 miles of new 6-inch through 12-inch branch pipelines.

Establish new 595-ft pressure zone

The proposed extension of the reuse transmission main crosses the boundary between the potable water 495-ft pressure zone and 595-ft pressure zone along Western Boulevard near Pullen Park. In order to maintain adequate system pressures and mimic the potable water pressures, a booster pump station and elevated storage tank are recommended to establish a new boosted pressure zone at an HGL of 595 feet. The proposed location of the booster pump station is in the vicinity of the State Farmer's Market near Barbour Drive. Since the elevations on the north side of downtown near the State government complexes are higher than those adjacent to the existing reuse pipeline near NCSU Centennial Campus, it is recommended downtown demands (Segment C) be included in the 595-ft booster pressure zone to provide adequate delivery pressure to the downtown customers. Therefore, this section of pipeline is not looped back to the 495-ft pressure zone.

Per discussions with CORPUD, the proposed location of the elevated tank is along Western Boulevard at the Dorothea Dix property, which was recently acquired by the City of Raleigh. The maximum ground elevations on this property in the area of the reuse pipeline are approximately 360 feet. Therefore, the tank height at this location would be greater than 235 feet. The high point of the reuse line is near the State Fairgrounds on Blue Ridge Road near the existing potable water tank. This is suggested as an alternate location for the reuse tank, since the required tank height would be significantly lower (approximately 95 feet to the high water level) and allow for improved pressures at the highest system elevations since there would be no system head loss between the tank and the highest system elevations. However, available land for siting a tank in this location is limited. Another option for storage if height is a constructability issue is a ground storage tank near the booster pump station instead of an elevated tank. Based on demands and the desire to maintain tank turnover for water quality issues, a tank volume of 350,000 gallons is recommended.

Establish lower pressure zone between the NRRRF and I-440

Once the projected buildout demands are added to the Raleigh reuse system, three pumps are required to run at the NRRRF off-site pump station to fill the Sunnybrook Tank during maximum day demand conditions. With three pumps on, the modeled pressures at the critical high pressure point where the reuse pipeline is co-located in the easement with the dual 72-inch diameter gravity wastewater interceptors are 160 to 200 psi. To reduce pressures at the critical point, it is recommended the off-site pumps at the NRRRF be modified to lower the discharge head to 300 feet TDH and establish a lower pressure zone near the NRRRF. A booster pump located near Walnut Creek Park and I-440 is recommended to boost pressures up to the 495-ft HGL and fill the Sunnybrook tank. This results in maximum pressures at the critical high pressure point of 120 to 140 psi, which is lower than the existing simulated maximum pressures with one off-site pump running.

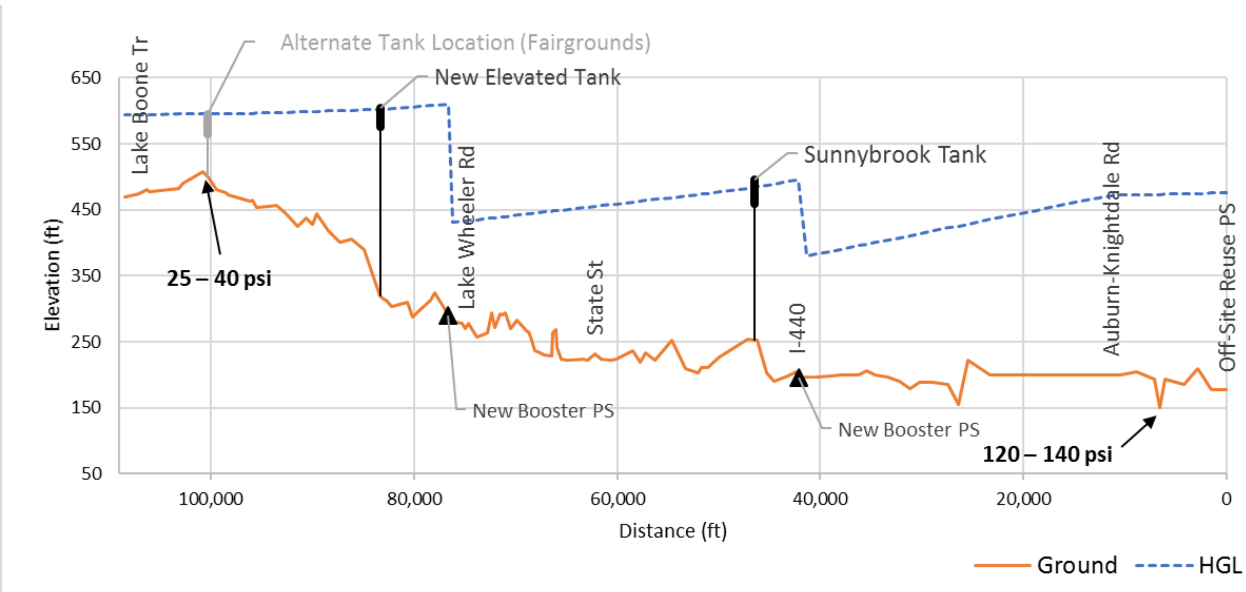
Alternatively, if the reuse pipeline can be relocated away from the dual 72-inch sewer interceptors, the consequence of a pipeline failure would be reduced and the high pressures may be acceptable. If relocated, the new pipeline should be designed to handle the expected high pressures.

Add pumping capacity at the NRRRF

The off-site reuse pump station at the NRRRF currently has three 1,100-gpm pumps, with space for a fourth pump. Since all three pumps are needed to meet projected maximum day demands, another pump should be added in the spare slot to provide firm capacity.

Figure 4-2 shows the hydraulic profile of the proposed Alternative 1 pipeline under maximum day demand conditions with the recommended improvements. The minimum system pressures near the State Fairgrounds on Blue Ridge Road are 25 to 40 psi, which is lower than the desired pressure criteria. However, no customer demands are located at the highest elevations and nearby customer demand nodes have a minimum pressure of at least 30 psi.

Figure 4-2. Alternative 1 HGL Profile (Max Day Demands)



4.2.3 Alternative 2 – Extend Raleigh Reuse System to Central Prison and Dorothea Dix Property

Alternative 2 extends the existing Raleigh reuse pipeline from Lake Wheeler Road to serve demands at the Central Prison and potential uses on the Dorothea Dix property. While it is unknown what development will ultimately take place on this City-owned property, an irrigation demand of 100,000 gpd, as noted in Section 3, was estimated for this evaluation.

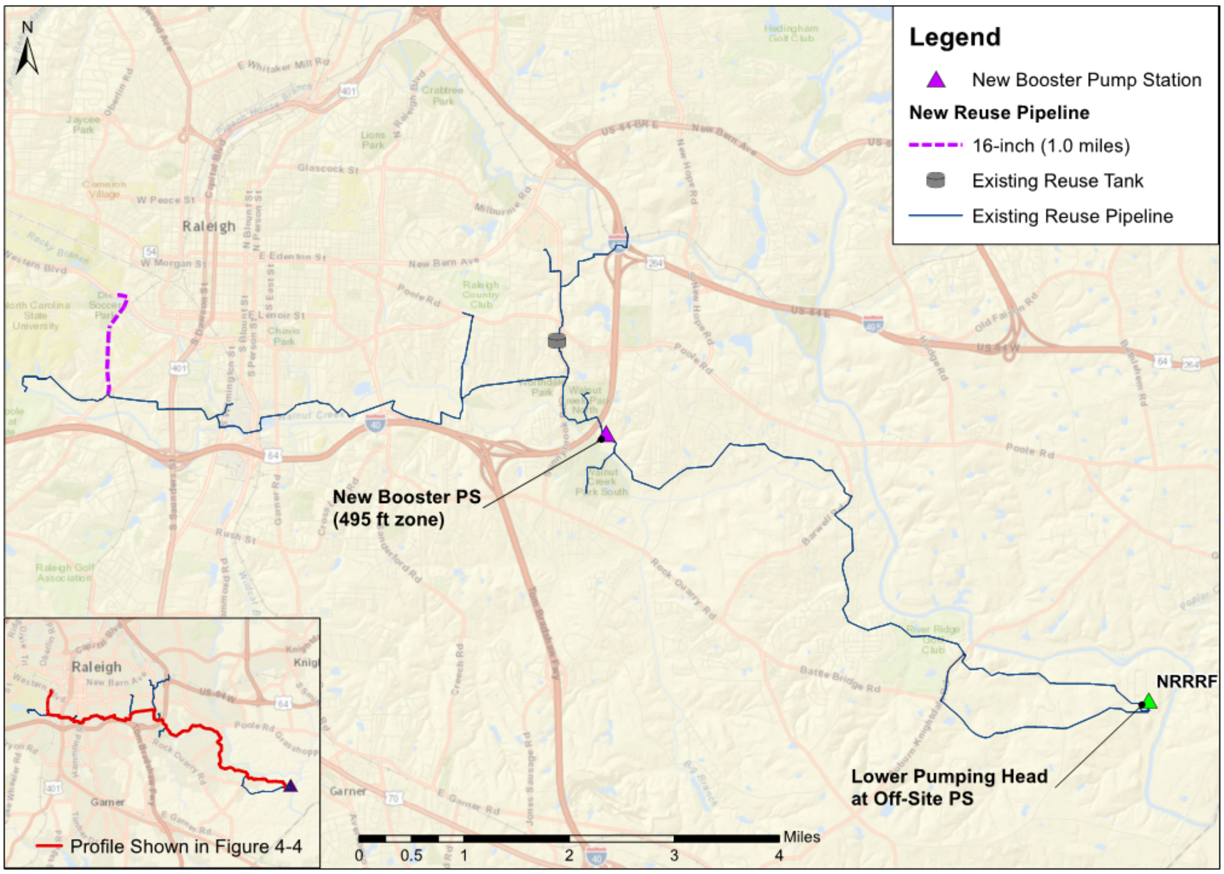
Although this system extension is near the boundary between the potable water 495-ft pressure zone and 595-ft pressure zone, hydraulic modeling results indicate that the proposed system can meet demands and provide adequate pressures operating with the current 495-ft HGL of the Sunnybrook tank.

Table 4-2 lists the proposed pipeline, pumping, and storage improvements for Alternative 2. **Figure 4-3** shows the locations of the proposed facilities. The total maximum day demand for Alternative 2, including existing customers, is 2.7 mgd. Improvements are described in the paragraphs below.

Table 4-2. Alternative 2 Proposed Pipeline and Pumping Improvements

Category	Description	Size	Quantity	
Pipelines	New Reuse Pipelines	16-inch	5,200	LF
Pumping	New Booster Pump Station near Walnut Creek Park	2.6 mgd; 120 ft TDH	1	EA
	Modify NRRRF off-site pumps	Design TDH 300 ft	3	EA

Figure 4-3. Proposed Improvements for Alternative 2



Construct new pipelines

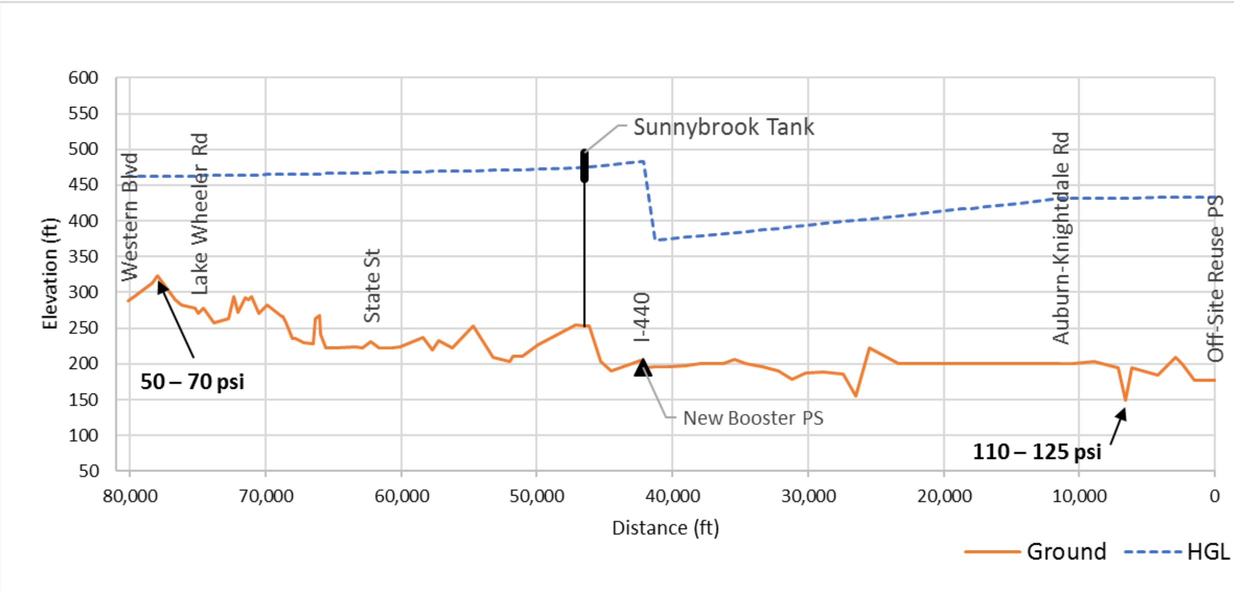
Alternative 2 includes approximately 1.0 mile of new 16-inch transmission pipe from Lake Wheeler Road to Western Boulevard.

Establish lower pressure zone between the NRRRF and I-440

For maximum day demands, two pumps are required to run at the NRRRF off-site pump station to fill the Sunnybrook Tank, resulting in modeled pressures at the critical high pressure point near the NRRRF of 140 to 180 psi. The same improvements as described for Alternative 1 to establish a lower pressure zone between the NRRRF and I-440 or relocate the reuse pipeline are also recommended for Alternative 2.

Figure 4-4 shows the hydraulic profile of the proposed Alternative 2 pipeline under maximum day demand conditions with the recommended improvements. The minimum system pressures along the Dorothea Dix property are 50 to 70 psi, which meets the desired pressure criteria.

Figure 4-4. Alternative 2 HGL Profile (Max Day Demands)



4.2.4 Alternative 3 – Extend Zebulon Reuse System to the BB&T Data Center

Alternative 3 extends the existing Zebulon reuse distribution system to supply non-potable water for cooling demands at the BB&T data center near North Arendell Avenue and Green Pace Road. The reuse capacity of the Little Creek WWTP was evaluated to determine if there is adequate supply to meet additional reuse demands. As listed in **Table 4-3**, the average annual wastewater flow is 0.83 mgd based on effluent flow for 2013 through 2015. Considering the minimum daily to average annual wastewater flow ratio of 0.6 at the Little Creek WWTP and a 10 percent factor-of-safety, the maximum day reuse supply capacity is 0.45 mgd, which exceeds the maximum day demand of 0.33 mgd for Alternative 3.

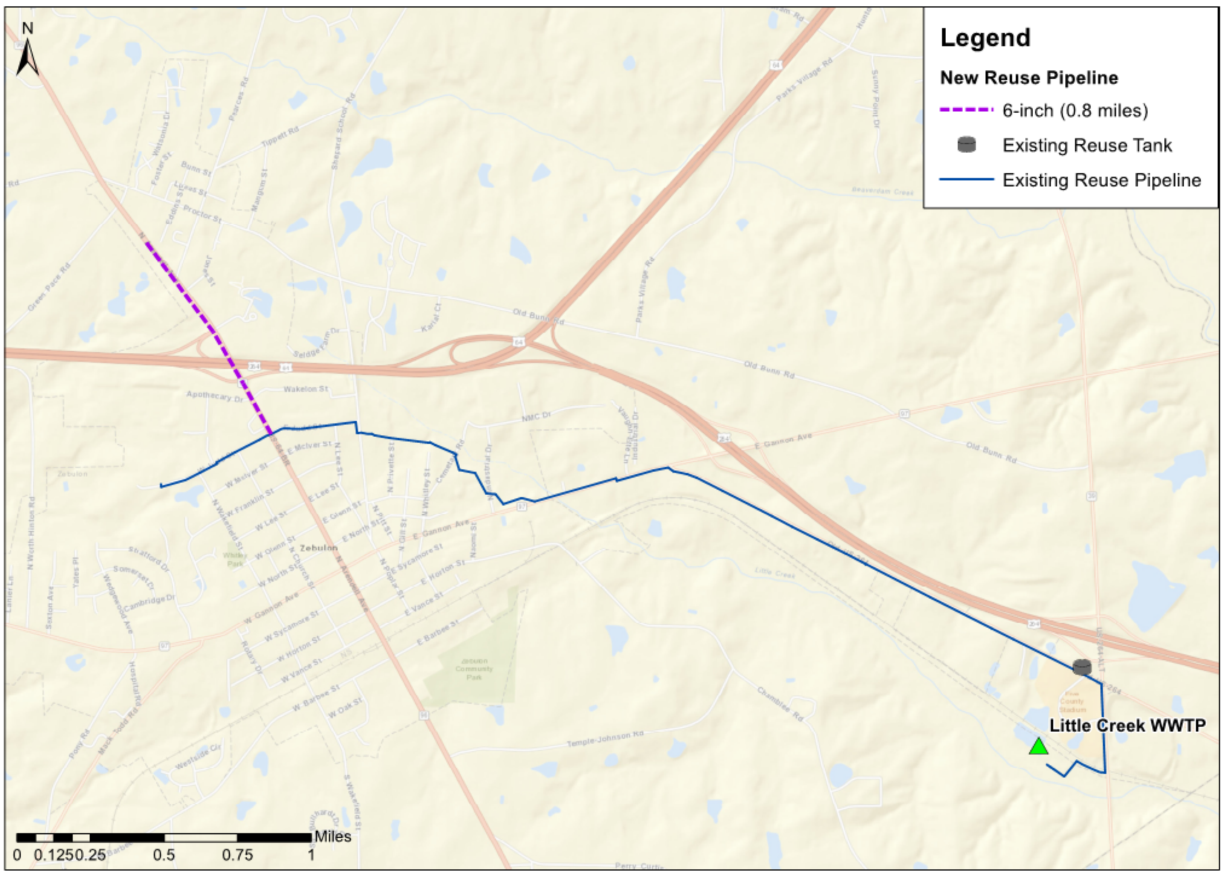
Table 4-3. Little Creek WWTP Reuse Supply Capacity

Supply Capacity Description	Flow
Little Creek WWTP Capacity	2.2 mgd
Average Annual Effluent (2013 – 2015)	0.83 mgd
Minimum Day: Average Annual Flow Ratio (2013 – 2015)	0.6
Minimum Day Effluent Flow	0.50 mgd
Miscellaneous Use/ Safety Factor (10%)	0.05 mgd
Maximum Day Reuse Supply	**0.45 mgd**

In addition, since Zebulon is at the extreme end of CORPUD's potable water service area, flushing is employed to maintain water quality. Water flushed from the potable system is used to fill a portion of the reuse system storage tank and supplement reuse supply from the Little Creek WWTP. This practice is anticipated to continue for the near term. Sufficient system storage is available with the 250,000-gallon elevated storage tank to meet peak hour demands that exceed the maximum day demand.

Alternative 3 includes 0.8 miles of new 6-inch pipeline along North Arendell Avenue as shown in **Figure 4-5**. No pumping or storage improvements are recommended. The total maximum day demand for Alternative 3, including the existing customers, is 0.33 mgd. Maximum day modeled pressures range from 45 psi near the BB&T data center to 100 psi at the Little Creek reuse pump station, which meets the desired pressure criteria.

Figure 4-5. Proposed Improvements for Alternative 3



4.2.5 Alternative 4 – New Distribution System from Smith Creek WWTP

Alternative 4 establishes a new reuse distribution system from the Smith Creek WWTP to serve nearby non-potable reuse demands. The reuse capacity of the Smith Creek WWTP was first evaluated to determine if there is adequate supply to meet additional reuse demands. As listed in **Table 4-4**, the average annual wastewater flow is 1.9 mgd based on effluent flow for 2015/2016. Considering the minimum daily to average annual wastewater flow ratio of 0.8 at the Smith Creek

WWTP and a 10 percent factor-of-safety, the maximum day reuse supply capacity is 1.4 mgd, which exceeds the maximum day demand of 0.82 mgd for Alternative 4.

Table 4-4. Smith Creek WWTP Reuse Supply Capacity

Supply Capacity Description	Flow
Smith Creek WWTP Capacity	3.0 mgd
Average Annual Effluent (2013 – 2015)	1.9 mgd
Minimum Day: Average Annual Flow Ratio (2013 – 2015)	0.8
Minimum Day Effluent Flow	1.52 mgd
Miscellaneous Use/ Safety Factor (10%)	0.15 mgd
Maximum Day Reuse Supply	**1.4 mgd**

Table 4-5 lists the proposed pipeline, pumping, and storage improvements for Alternative 4. **Figure 4-6** shows the locations of the proposed facilities. The maximum day demand for Alternative 4 is 0.82 mgd. Maximum day modeled pressures range from 120 psi near the Smith Creek WWTP to 65 psi at near Mallinckrodt, which meet the desired pressure criteria. Improvements are described in the paragraphs below.

Table 4-5. Alternative 4 Proposed Pipeline, Pumping, and Storage Improvements

Category	Description	Size	Quantity	
Pipelines	New Reuse Pipelines	6-inch	5,300	LF
	New Reuse Pipelines	12-inch	17,600	LF
	New Reuse Pipelines	16-inch	3,000	LF
		Total	**25,900**	**LF**
Pumping	New Reuse Pump Station at Smith Creek WWTP	1.3 mgd; 250 ft TDH	1	EA
Storage	New Ground Storage Tank at Smith Creek WWTP	500,000 gallons	1	EA
Other	Hypochlorite Feed System at Smith Creek WWTP	Approx. 0.8 mgd capacity	1	EA

Construct new pipelines

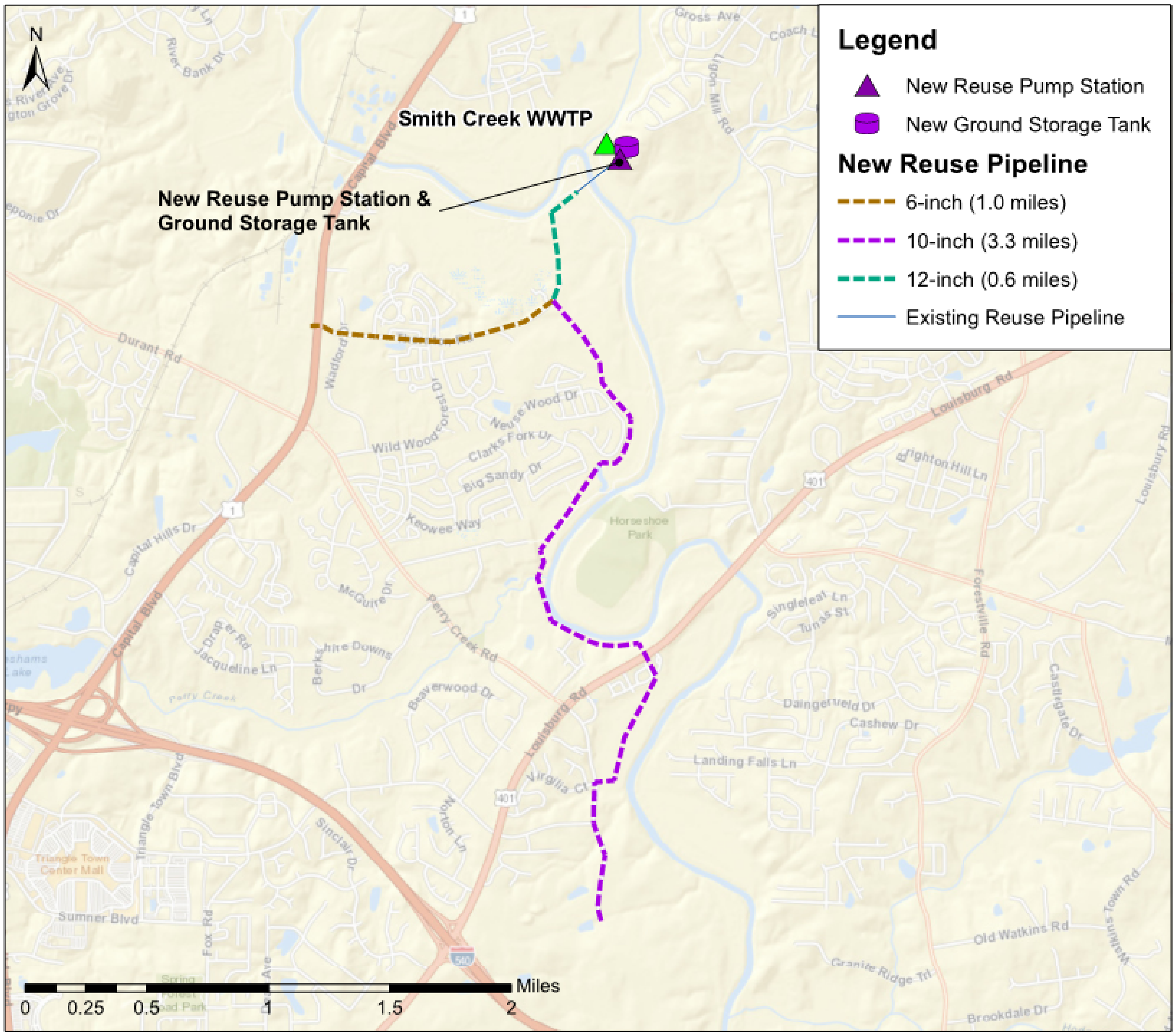
A dry pipeline from the Smith Creek WWTP across the Neuse River was installed as part of a previous project and could be utilized for the reuse system. This alternative includes an additional 3.4 miles of additional new 10-inch and 12-inch pipeline along the Neuse River gravity sewer interceptor easement and 0.6 miles of new 6-inch pipeline along Thornton Road.

New storage and pumping at the Smith Creek WWTP

Storage at the WWTP is needed to meet the peak hour demands, since the estimated peak hour (1.3 mgd) is close to the maximum day supply capacity at Smith Creek WWTP (1.4 mgd). A 24-hour diurnal wastewater effluent pattern for Smith Creek WWTP was not available, therefore, storage volume is estimated as 500,000 gallons to balance hourly variations in supply and demand and provide flexibility in maintaining water quality.

A new ground storage tank, new 1.3-mgd reuse pump station equipped with VFDs to meet varying demands, and hypochlorite feed system are recommended at the Smith Creek WWTP.

Figure 4-6. Proposed Improvements for Alternative 4



4.2.6 Summary

Table 4-6 provides a summary of the average annual, summer seasonal, and maximum day demands, along with the total length of additional reuse pipelines for Alternatives 1 through 4.

Table 4-6. Summary of Non-Potable Water Reuse Alternatives

	Alternative 1 Extend Raleigh Reuse System to Blue Ridge Road	Alternative 2 Extend Raleigh Reuse System to Central Prison / Dorothea Dix	Alternative 3 Extend Zebulon Reuse System to the BB&T Data Center	Alternative 4 New Distribution System from Smith Creek WWTP
Average Annual Demand				
Existing System* (mgd)	0.79	0.79	0.09	0.00
Additional Expansion (mgd)	0.91	0.14	0.04	0.32
Total (mgd)	***1.70***	***0.93***	***0.13***	***0.32***
Summer Average Demand				
Existing System* (mgd)	1.24	1.24	0.14	0.00
Additional Expansion (mgd)	1.40	0.24	0.05	0.50
Total (mgd)	***2.64***	***1.48***	***0.19***	***0.50***
Maximum Day Demand				
Existing System* (mgd)	2.26	2.26	0.29	0.00
Additional Expansion (mgd)	2.34	0.39	0.09	0.82
Total (mgd)	***4.60***	***2.65***	***0.38***	***0.82***
New Reuse Pipelines				
Total (miles)	***19.9***	***1.0***	***0.8***	***4.9***

* Existing System demands for Raleigh reuse system Alternatives 1 and 2 include NCSU Centennial Campus and Lonnie Poole golf course.

Section 5

Evaluation of Potable Water Reuse Alternatives

This section presents a brief summary of the current status of potable reuse in North Carolina and research performed by CORPUD to support the legislation allowing potable reuse, as well as the evaluation of two conceptual alternatives for potable reuse.

5.1 Potable Water Reuse in North Carolina

The use of reclaimed water for non-potable water demands is well established in the state. However, recent legislation, supported by CORPUD and passed by the North Carolina General Assembly in August 2014, allows the use of reclaimed water as a source water (i.e. potable reuse). The legislation sets out the following conditions for allowing the combination of reclaimed water with other raw water sources before treatment:

- Reclaimed water is water treated to highest standard established by NCDEQ (Type 2 reclaimed water).
- Reclaimed water and source water are combined in a pretreatment mixing basin sized with a volume equivalent to 5 days storage of the authorized operating capacity of the water treatment plant under normal operating conditions.
- The average daily flow of reclaimed water into the pretreatment mixing basin is no more than 20 percent of the total flow of source water into the pretreatment mixing basin.
- Water conservation and efficiency measures have been implemented to achieve water use reductions.
- Unbilled leakage from the potable water system is maintained below 15 percent of the annual average water consumption.
- A master plan has been developed that evaluated alternatives for reclaimed water use.
- Public notice is provided to potable water recipients with opportunity for public participation.

No utilities in North Carolina currently practice potable reuse, and regulations for potable reuse have not yet been established by the NCDEQ Division of Water Resources. However, as pressures increase on limited water supply resources, more utilities are considering potable reuse as valuable water resource alterative.

In the future, potable reuse may be a viable alternative to help CORPUD meet water supply needs. Therefore, options for potable reuse were evaluated and compared with non-potable reuse alternatives as part of this Master Plan Update.

5.2 Neuse River Water Quality Study

The Neuse River is the receiving water for highly treated effluent from CORPUD's NRRRF. In addition to the NRRRF, approximately 15 other large (greater than 1-mgd capacity) municipal water reclamation facilities discharge into the Neuse River basin. Five major drinking water treatment plants withdraw source water along the same 185-mile stretch of the Neuse River. Therefore, current practices within the basin may be characterized as *de facto* water reuse. To establish an understanding of this system, and form a basis for evaluating planned potable reuse, CORPUD and CDM Smith performed a study to document the characteristic water quality of the Neuse River and to consider the environmental fate and transport of potential contaminants in the river. The study is documented in the June 2014 *Neuse River Water Quality Sampling Report*.

The study examined trace wastewater constituents including 6 microorganisms, 110 chemical constituents, and bulk genotoxicity at eight locations along the Neuse River between Falls Lake and Goldsboro, with one sampling location at the point of discharge of the NRRRF.

The key findings and results from this study are:

- The Neuse River has acceptable water quality for use as a drinking water supply source.
- The NRRRF is not a significant source of microbial contamination of the river. Planned potable reuse would provide greater control of the microbiological water quality of source water than current water quality of the Neuse River, which receives pollution coming from roads and runoff.
- The river appears to be diluting but not degrading or removing most of the detected trace chemical constituents. Therefore, from a chemical perspective, no technical difference exists between using reclaimed water as a source water for planned potable reuse than using river water downstream of the discharge from a water reclamation plant.

Based on these results, it can be concluded that planned potable reuse would provide drinking water utilities with equal or greater control of the water quality of source water than current practice.

5.3 Potable Water Reuse System Alternatives

While treatment technologies, process monitoring, and public acceptance are all key issues of concern for potable reuse, this study focuses on hydraulic evaluation of conceptual options for conveyance of reclaimed water to serve as a source water within CORPUD's service area.

Two alternatives were identified to supply reclaimed water to CORPUD's water treatment plants for potable reuse:

- Alternative 5 – Supply Reclaimed Water from Raleigh Reuse System to Dempsey E. Benton WTP
- Alternative 6 – Supply Reclaimed Water from Smith Creek WWTP to E.M. Johnson WTP

Additional factors to consider for potable reuse, including piloting of treatment trains, are discussed in **Section 7**.

5.3.1 Alternative 5 – Supply Reclaimed Water from Raleigh Reuse System to Dempsey E. Benton WTP

CORPUD owns two buried pipelines that extend from the decommissioned E.B. Bain WTP, located adjacent to the existing 16-inch reuse transmission main near South Wilmington Street, to Lake Benson which is the raw water source for the Dempsey E. Benton (Benton) WTP. The first pipeline was installed in 1927 and consists of approximately 12,500 feet of 20-inch diameter cast iron pipe and 23,500 feet of 24-inch diameter cast iron pipe. The second pipeline was installed in 1953 and consists of approximately 36,500 feet of 24-inch diameter concrete pressure pipe. Use of both pipelines was discontinued in 1987 with the decommissioning of the E.B. Bain WTP.

Alternative 5 consists of pumping reclaimed water from the NRRRF through the existing Raleigh reuse distribution system and through one of the abandoned raw water pipelines (this evaluation assumes the newer 24-inch pipeline) to a planned raw water impoundment at the Benton WTP. CORPUD has purchased land and is planning to construct a raw water impoundment (up to 100-MG) for source water quality and reliability at the WTP. The impoundment could also serve as the required pretreatment mixing basin for blending of reclaimed and raw water.

An evaluation was performed with the hydraulic model of the Raleigh reuse system using the same general evaluation criteria as presented in Section 4. Maximum day and summer seasonal demand simulations were run to determine the maximum amount of reclaimed water that can be provided at the Benton WTP raw water impoundment while still meeting the non-potable demands of all existing reuse customers as well as the NCSU Centennial Campus and Lonnie Poole golf course. It is assumed that supply to the raw water impoundment will be provided during off-peak hours for the non-potable demands. Based on this evaluation, the existing reuse system can provide up to 1.5 mgd to the raw water impoundment on a maximum day and up to 2.0 mgd during summer seasonal demands (May through October). The limiting factor for flow to the Benton WTP is the capacity of the existing 16-inch reuse transmission main to handle existing reuse customer demands as well as additional flow to the raw water impoundment. Greater amounts of reclaimed water could be supplied during the winter season since the non-potable demands are typically low.

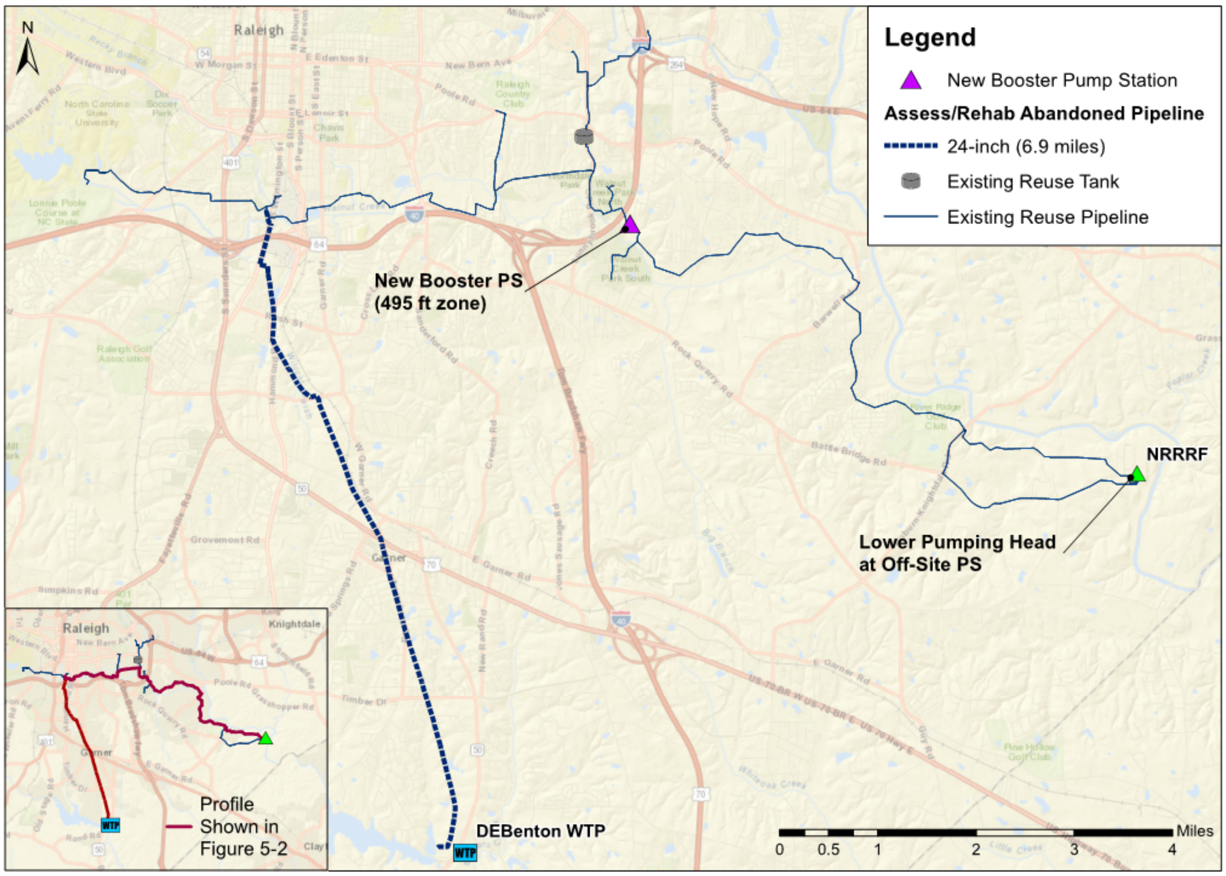
With a maximum allowable source water mixing ratio of 20 percent reclaimed water, the 2.0 mgd reclaimed water supply would allow for a total flow of at least 10 mgd to the Benton WTP.

Table 5-1 lists the proposed pipeline and pumping improvements for Alternative 5. **Figure 5-1** shows the locations of the proposed facilities. The total maximum day demand for Alternative 5, including existing customers, is 3.0 mgd. Even though the length of pipeline between the NRRRF and the Benton WTP is almost 7 miles, the model indicates that the average water age at the end of the pipeline is less than 5 days due to the constant demand at the raw water impoundment. Alternative 5 improvements are described in the paragraphs below.

Table 5-1. Alternative 5 Proposed Pipeline and Pumping Improvements

Category	Description	Size	Quantity	
Pipelines	Slipline Existing Raw Water Pipeline	24-inch diameter	36,500	LF
	New Reuse Pipelines	24-inch diameter	2,000	LF
		Total	**38,500**	**LF**
Pumping	New Booster Pump Station near Walnut Creek Park	2.9 mgd; 120 ft TDH	1	EA
	Modify NRRRF off-site pumps	Design TDH 300 ft	3	EA
	Add new off-site pump w/ VFD	1,100 gpm; 300 ft TDH	1	EA

Figure 5-1. Proposed Improvements for Alternative 5



Evaluate and rehabilitate the abandoned raw water pipeline

CORPUD previously investigated the condition of the pipeline route and collected known information about the probable condition of the 24-inch raw water main from E.B. Bain WTP to Lake Benson as part of an effort to restore the pipeline to usable condition for drought management purposes. Based on the information collected, CORPUD evaluated the following alternative approaches to rehabilitate the pipeline:

1. Rehabilitate the entire length of pipeline using pipe bursting methods with new 24-inch high density polyethylene (HDPE) pipe. Install approximately 2,000 feet of new 24-inch HDPE pipe to bypass buildings that are located over the current pipeline.
2. Rehabilitate the entire length of pipeline using sliplining methods with new 22-inch HDPE pipe. Install approximately 2,000 feet of new 24-inch HDPE pipe to bypass buildings that are located over the current pipeline.
3. Perform welded joint repairs as leaks are found and rehabilitate the pipeline using sliplining methods with new 22-inch HDPE pipe under major roads and densely constructed areas. This approach assumed approximately 692 welded joint repairs, 8,120 feet of sliplining, and 2,250 feet of new 24-inch HDPE pipe to bypass buildings that are located over the current pipeline.

Since the capacity of the 24-inch pipe is not the limiting hydraulic factor for Alternative 5, for this evaluation it is assumed that the second approach, including sliplining of the existing pipeline, would be used to rehabilitate the raw water main for use in conveying reclaimed water to the Benton WTP raw water impoundment.

Establish lower pressure zone between the NRRRF and I-440

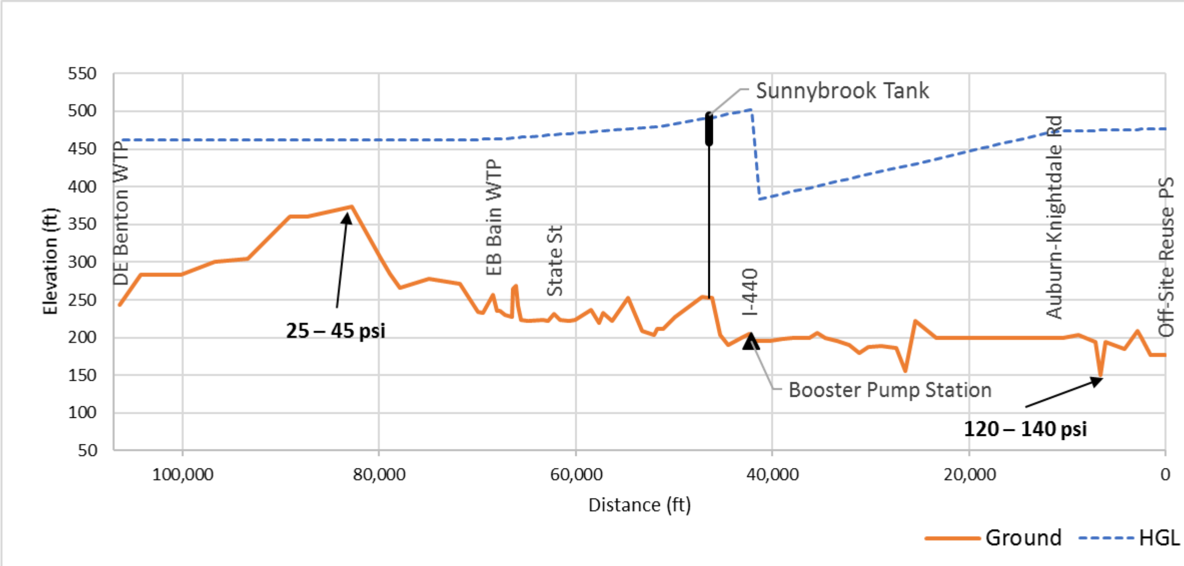
For maximum day demands, three pumps are required to run at the NRRRF off-site pump station to fill the Sunnybrook Tank and deliver water to the raw water impoundment, resulting in modeled pressures at the critical high pressure point near the NRRRF of 160 to 190 psi. The same improvement as described in Section 4 for Alternative 1 to establish a lower pressure zone between the NRRRF and I-440 by lowering the discharge head on the reuse pumps at the NRRRF and adding a booster pump station near Walnut Park is also recommended to reduce pressures at the critical point for Alternative 5.

Add pumping capacity at the NRRRF

The off-site reuse pump station at the NRRRF currently has three 1,100-gpm pumps, with space for a fourth pump. Since all three pumps are needed to meet projected maximum day demands, another pump should be added in the spare slot to provide firm capacity.

Figure 5-2 shows the hydraulic profile of the proposed Alternative 5 pipeline under maximum day demand conditions with the recommended improvements. The minimum system pressures on the old raw water pipe near Garner are 25 to 40 psi, which is lower than the desired pressure criteria. However, no customer demands are located along this pipeline and the pipeline discharge is into the raw water impoundment. Therefore, lower pressures along this pipeline are deemed acceptable, and even desirable in terms of minimizing pipeline leakage.

Figure 5-2. Alternative 5 HGL Profile (Max Day Demands)



5.3.2 Alternative 6 – Supply Reclaimed Water from Smith Creek WWTP to E. M. Johnson WTP

The Smith Creek WWTP is located in relatively close proximity to CORPUD's largest WTP, the E. M. Johnson WTP. Alternative 6 consists of pumping reclaimed water from the Smith Creek WWTP through a new reuse pipeline to the two existing 70-MG raw water impoundments at the E.M. Johnson WTP, as shown in **Figure 5-3**. The pipeline is sized for a capacity of 3.0 mgd, which is the capacity of the Smith Creek WWTP. Although the Smith Creek WWTP currently treats an average flow of approximately 1.9 mgd, CORPUD may decide to divert flow from the Neuse River gravity interceptor to the Smith Creek WWTP in the future to maximize reclaimed water supply capacity.

With a maximum allowable source water mixing ratio of 20 percent reclaimed water, the 3.0 mgd reclaimed water supply would allow for a total flow of at least 15 mgd to the E.M. Johnson WTP.

Table 5-2 lists the proposed pipeline and pumping improvements for Alternative 6, which includes 4.7 miles of new 16-inch reuse pipeline routed along Thornton Road and Durant Road, and a new 3.0-mgd reuse pump station and hypochlorite feed system at the Smith Creek WWTP. Due to the elevation difference between the Smith Creek WWTP and E.M. Johnson WTP (approximately 240 feet), the pressures on the discharge side of the reuse pump station will be around 150 psi and the reuse pipeline should be designed accordingly.

Figure 5-3. Proposed Improvements for Alternative 6

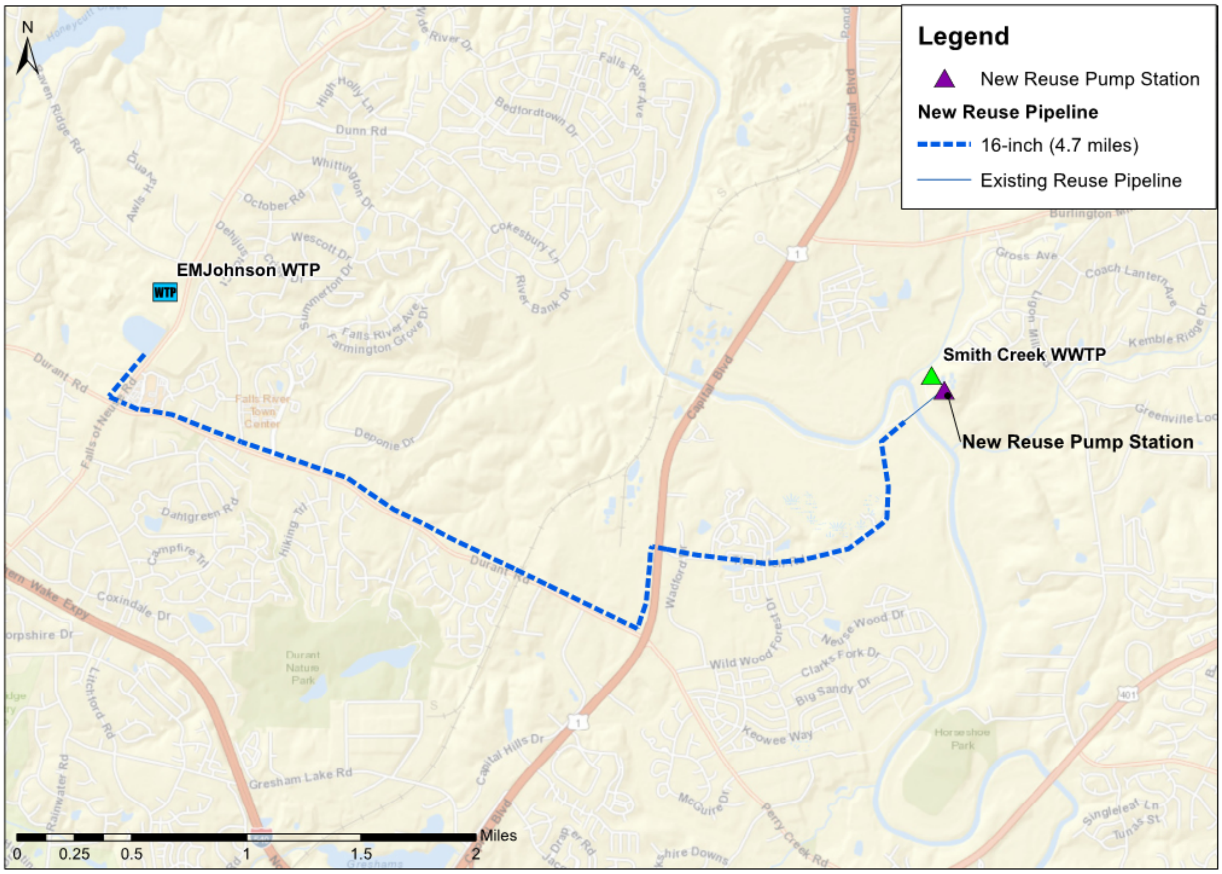


Table 5-2. Alternative 6 Proposed Pipeline and Pumping Improvements

Category	Description	Size	Quantity	
Pipelines	New Reuse Pipelines	16-inch diameter	24,800	LF
Pumping	New Reuse Pump Station at Smith Creek WWTP	3.0 mgd; 325 ft TDH	1	EA
Other	Hypochlorite Feed System at Smith Creek WWTP	3.0 mgd capacity	1	EA

5.3.3 Summary

Table 5-3 provides a summary of the average annual, summer seasonal, and maximum day demands, along with the total length of additional reuse pipelines for Alternatives 5 and 6.

Table 5-3. Summary of Potable Alternatives

	Alternative 5 Supply Reclaimed Water from Raleigh Reuse System to Benton WTP	Alternative 6 Supply Reclaimed Water from Smith Creek WWTP to E. M. Johnson WTP
Annual Average Demand		
Existing System (mgd)	0.79	0.00
Additional to WTP (mgd)	2.00	3.00
Total (mgd)	***2.79***	***3.00***
Summer Average Demand		
Existing System (mgd)	1.24	0.00
Additional to WTP (mgd)	2.00	3.00
Total (mgd)	***3.24***	***3.00***
Maximum Day Demand*		
Existing System (mgd)	1.52	0.00
Additional to WTP (mgd)	1.50	3.00
Total (mgd)	***3.02***	***3.00***
Reuse Pipelines		
New Pipeline (miles)	0.4	4.7
Rehabilitated Pipeline (miles)	6.9	0.0
Total (miles)	***7.3***	***4.7***

* Maximum day flows that can be conveyed to the Benton WTP for Alternative 5 are less than summer average flows due to peaks of the non-potable system demands. Therefore, the overall summer average flow conveyed is greater than the max day flow.

Section 6

Cost Estimates and Cost Benefit Analysis

This section presents estimated costs for the six water reuse system expansion alternatives presented in the previous sections of this report. The alternatives include non-potable and potable options for expanding the water reuse program and are not mutually exclusive, as several alternatives could be pursued by CORPUD concurrently:

- Alternative 1 – Extend Raleigh Reuse System to Blue Ridge Road
- Alternative 2 – Extend Raleigh Reuse System to Central Prison and Dorothea Dix Property
- Alternative 3 – Extend Zebulon Reuse System to the BB&T Data Center
- Alternative 4 – New Distribution System from Smith Creek WWTP
- Alternative 5 – Supply Reclaimed Water from Raleigh Reuse System to Benton WTP
- Alternative 6 – Supply Reclaimed Water from Smith Creek WWTP to E.M. Johnson WTP

In addition, a cost benefit analysis is presented later in this section. The cost benefit analysis is intended to provide additional consideration of the indirect costs and benefits associated with expansion of the reuse system. These benefits can be quantified in some cases, such as with the nutrient loading reduction benefits of expanding the reuse system; however, in other cases the benefits are difficult to quantify and thus are discussed in qualitative terms.

Expansion of the on-site reuse system at the NRRRF for the bioenergy recovery program was not included in the cost benefit analysis since it was determined that this use does not have an adverse impact on the ability to expand the reuse distribution systems and evaluation of the costs of reuse for the bioenergy program are assumed to be performed through separate projects.

6.1 Cost Estimates

The American Association of Cost Estimators (AACE) recommends four levels of accuracy for construction cost estimating. The level of cost estimation is dependent upon the stage and scope of the project. The four major categories are shown in **Table 6-1**.

The accuracy of construction cost estimates should increase as the project moves through the process from conceptual to detailed design and eventually to project bidding and actual construction. It can be expected that conceptual and study level estimates would have a wide range of accuracy relative to the actual construction cost because not all the design features and details that would impact the final cost have been addressed. The construction cost estimates prepared for this report are at the "Conceptual Estimate" level (Category 1). Since the assumptions and methodology for identifying the costs are common to all service areas and routes, this level of accuracy is appropriate for this comparative evaluation.

Cost estimates for this report were prepared using previous estimates for similar projects, historical data from comparable work, recent CORPUD bid tabs, and estimating guides and equipment costs. Factors such as competitive market conditions, actual site conditions, and implementation schedule cannot be quantified at the current level of detail, but can significantly impact the project cost.

Projecting costs into the future is speculative, as inflation rates for energy prices, building materials, and construction labor fluctuate constantly. A "constant dollar" approach was used in developing capital costs for the primary alternatives. All costs shown are in 2016 values and reference an ENR Construction Cost Index (CCI) for October 2016 of 10,434. Care should be taken during future updates to index costs for each year based on the inflation rate experienced over the update year.

Table 6-1. Level of Cost Categories

Category Level	Accuracy
Category 1 – Conceptual Estimate	+50% to -30%
Category 2 – Study Estimate	+30% to -20%
Category 3 – Preliminary Estimate	+20% to -10%
Category 4 – Detailed Estimate	+15% to -5%

6.1.1 Unit Pipeline Construction Costs

For the purposes of this memorandum, the costs of pipeline installation were divided into three broad categories:

1. Unit costs to cover open-cut trench excavation and installation of new reuse pipelines in easements or parallel to roadways,
2. Unit costs to cover trench excavation and installation of new reuse pipelines in the downtown and more densely developed urban areas, and
3. Unit costs to cover trenchless installation methods (horizontal directional drilling, microtunneling, jack and bore) that may be required for road crossings and stream crossings.

The unit costs, presented in **Table 6-2**, consider the labor, equipment, and materials typically used to install pressurized pipelines. The unit costs for pipelines also include installation of fittings, gate valves, air release valves, and blow-offs. Blow-offs are assumed to be located every 6,000 feet.

The cost for rehabilitation of the existing 24-inch concrete raw water pipe using sliplining is assumed to be $150 per linear foot, with a pre-rehabilitation assessment cost for CCTV of $3 per linear foot and $10,000 per access pit assuming one access point is required every 2,500 linear feet.

Table 6-2. Pipeline Construction Unit Costs

Diameter (in)	Construction Cost ($/LF)		
	Open-Cut[1,2]	Downtown[3]	Trenchless[1,4]
6	$75	$114	$315
8	$100	$152	$380
10	$120	$183	$480
12	$140	$213	$500
16	$170	$259	$650
24	$260	$395	$995

1. Assumes restrained joint ductile iron (pressure class 350) for all sizes of pressure pipe. Purple polyethylene wrap included for DIP.
2. Assumes normal dewatering; 10% of pipeline length will require rock excavation; 4 feet cover; valves located every 1,000 LF; air relief valves every 3,000 LF, blowoffs every 6,000 LF, and DI fitting every 1,000 LF.
3. Unit costs based on bid tabs for water main installation in downtown project areas. Assumes restrained joint ductile iron (pressure class 350) for all pipe sizes.
4. Assumes ductile iron carrier pipeline. Unit costs include carrier pipe, grout and casing pipe; rock excavation not included.

6.1.2 Land Acquisition

It is assumed that even though road rights-of-way will be used for most of the pipelines, some additional easement will have to be obtained. The estimated land acquisition costs assume one-half the length of the project will require additional easements 20 feet wide at a cost of $20,000 per acre. Land costs for new pump stations and storage tanks are also assumed at $20,000 per acre.

6.1.3 Potable Water Reuse Assumptions

For this analysis, the capital costs for potable reuse Alternatives 5 and 6 are based on the cost of pipelines and pumping to convey reclaimed water to serve as a source water at CORPUD's WTPs. Costs for the required source water pretreatment mixing basin are not included since CORPUD already has planned or existing raw water impoundments at the WTPs that could also serve as pretreatment mixing basins.

Costs for additional treatment trains or modifications at the WTPs are not included. The treatment requirements for potable reuse alternatives would need to be confirmed with pilot testing, as discussed in Section 7. However, additional process monitoring will be required to ensure system reliability and treatment performance. There are no established requirements for potable reuse by the NCDEQ at this point, so it is unknown how much monitoring would be required. For this analysis, a placeholder cost of $500,000 is included for installing additional process monitoring under Alternatives 5 and 6.

6.1.4 Contingencies, Engineering, Legal, and Administrative Fees

Total construction cost of the alternatives is calculated by applying a 30-percent construction contingency to the subtotal construction cost. The total capital costs are calculated by applying a 20-percent allowance for engineering, legal, and administrative fees to the total construction cost.

6.1.5 Summary of Capital Costs

Table 6-3 provides a summary of the conceptual capital costs for Alternatives 1 through 6. Due to the amount of new reuse infrastructure that is required to extend the Raleigh reuse system to Blue Ridge Road, Alternative 1 has a significantly higher capital cost than the other alternatives.

6.2 Water Reuse Benefits

To compare the reuse alternatives, the benefits of the reuse system were also considered. These include demand reduction on the potable water system and water supply sources, reduction of the nutrient loading in the wastewater discharge, and impacts of offsetting demand on the water treatment and distribution infrastructure.

6.2.1 Water Supply Benefits

An important benefit of CORPUD's reuse system is reduction in demand on the potable water system and water supply sources. CORPUD's water sources include Falls Lake and the Lake Benson/Lake Wheeler system. These sources have a combined available water supply of 77.3 mgd, as defined by the reliable yield during a fifty-year drought based on the period of record. As shown in **Table 6-4**, with the projected average day demands, additional water supply sources are projected to be needed by **2030**.

Table 6-4. Potable Water Supply and Demand Projections

Year	2020	2025	2030	2035	2040	2045
Available Water Supply (mgd)	77.3	77.3	77.3	77.3	77.3	77.3
Average Day Water Demand[1] (mgd)	66.5	73.4	80.1	86.4	92.8	97.9
Additional Supply Needed (mgd)	0	0	2.8	9.1	15.5	20.6

1. Based on supply and demand information provided by CORPUD in September 2016

CORPUD has evaluated multiple options for future water supply, including construction of a new reservoir on the Little River, reallocation of storage in Falls Lake, and withdrawal of water from the Neuse River either just above the NRRRF or just below Falls Lake with quarry storage. The US Army Corps of Engineers is currently evaluating the option to reallocate storage within the Falls Lake conservation pool from water quality to water supply, which would increase CORPUD's available water supply from Falls Lake.

Although water reuse alone would not eliminate the need for new water supply sources in the future, it could delay the need to implement some options until further in the future. **Table 6-5** presents a summary of the reduction in potable water supply demand for each alternative based on average annual reuse demands. The two potable reuse options have the greatest benefits for the deferring future water supply needs.

Table 6-3. Capital Costs of Water Reuse Alternatives

	Non-Potable Reuse Alternatives				Potable Reuse Alternatives	
	Alternative 1	**Alternative 2**	**Alternative 3**	**Alternative 4**	**Alternative 5**	**Alternative 6**
Reuse Pipelines						
Pipeline (Open-Cut)	$ 11,990,000	$ 800,000	$ 250,000	$ 2,820,000	$ 520,000	$ 4,050,000
Downtown Area	$ 2,070,000	$ -	$ -	$ -	$ -	$ -
Trenchless Road, Railroad & Stream Crossings	$ 2,430,000	$ 330,000	$ 250,000	$ 450,000	$ -	$ 650,000
Land Acquisition	$ 480,000	$ 20,000	$ 20,000	$ 120,000	$ 10,000	$ 110,000
Raw Water Pipeline Assessment and Rehab	$ -	$ -	$ -	$ -	$ 5,730,000	$ -
Pipeline Subtotal	***$ 16,970,000***	***$ 1,150,000***	***$ 520,000***	***$ 3,390,000***	***$ 6,260,000***	***$ 4,810,000***
Pumping						
Distribution Booster Pump Station	$ 4,880,000	$ 1,950,000	$ -	$ -	$ 2,180,000	$ -
Reclaimed Water High Service Pumping at WRF	$ 130,000	$ 30,000	$ -	$ 80,000	$ 130,000	$ 2,250,000
Land Acquisition	$ 20,000	$ 10,000	$ -	$ -	$ 10,000	$ -
Pumping Subtotal	***$ 5,030,000***	***$ 1,990,000***	***$ -***	***$ 980,000***	***$ 2,320,000***	***$ 2,250,000***
Storage						
Ground Storage Tank at WRF	$ -	$ -	$ -	$ 500,000	$ -	$ -
Elevated Storage in Distribution System	$ 1,750,000	$ -	$ -	$ -	$ -	$ -
Land Acquisition	$ 10,000	$ -	$ -	$ -	$ -	$ -
Storage Subtotal	***$ 1,760,000***	***$ -***	***$ -***	***$ 500,000***	***$ -***	***$ -***
Other						
Hypochlorite Feed System	$ -	$ -	$ -	$ 500,000	$ -	$ 500,000
Additional Treatment Process Monitoring	$ -	$ -	$ -	$ -	$ 500,000	$ 500,000
Other Subtotal	***$ -***	***$ -***	***$ -***	***$ 500,000***	***$ 500,000***	***$ 1,000,000***
Subtotal Construction Cost	$ 23,760,000	$ 3,140,000	$ 520,000	$ 5,370,000	$ 9,080,000	$ 8,060,000
Total Construction Cost w/30% Contingency	$ 30,890,000	$ 4,080,000	$ 680,000	$ 6,980,000	$ 11,800,000	$ 10,480,000
Engineering, Legal, Administration (20%)	$ 6,180,000	$ 820,000	$ 140,000	$ 1,400,000	$ 2,360,000	$ 2,100,000
Total Capital Cost[1]	**$ 37,100,000**	**$ 4,900,000**	**$ 800,000**	**$ 8,400,000**	**$ 14,200,000**	**$ 12,600,000**

1. Rounded to the nearest $100,000

Table 6-5. Water Supply Offset with Reuse Alternatives

Reuse Alternative	Water Supply Offset[1] (mgd)	Potential Deferment of New Water Supply[2] (years)
Alternative 1 – Extend Raleigh Reuse System to Blue Ridge Road	0.91	<1
Alternative 2 – Extend Raleigh Reuse System to Central Prison and Dorothea Dix Property	0.14	<1
Alternative 3 – Extend Zebulon Reuse System to the BB&T Data Center	0.04	<1
Alternative 4 – New Distribution System from Smith Creek WWTP	0.32	<1
Alternative 5 – Supply Reclaimed Water from Raleigh Reuse System to Benton WTP	2.00	1.5
Alternative 6 – Supply Reclaimed Water from Smith Creek WWTP to E.M. Johnson WTP	3.00	2.3

1. Based on annual average demand shifted from the potable water system to the water reuse system with each alternative.
2. Years that need for new water supply could potentially be delayed with expansion of the water reuse system assuming average day potable demand increase of approximately 1.3 mgd per year based on water demand projections provided in Table 6-4.

6.2.2 Nutrient Loading Reductions

Another benefit of expansion of the reuse program is to reduce CORPUD's total nitrogen loading to the Neuse River basin. In 1998, the NCDEQ implemented the Neuse Nutrient Sensitive Waters Management Strategy that was aimed at reducing nitrogen in the Neuse River basin. As part of this strategy, NPDES dischargers to the Neuse River basin, including CORPUD's NRRRF, Smith Creek WWTP, and Little Creek WWTP, are subject to a set nitrogen discharge allocation given as an annual average mass load of total nitrogen. Expanding the reuse program would reduce the overall amount of treated wastewater discharged to the Neuse River basin, and therefore help CORPUD meet allocated total nitrogen limits as flows increase in the future.

For the purposes of determining nutrient load reductions associated with reclaimed water use, only irrigation demands are considered. The majority of the nutrient loads for water used in cooling applications are expected to return to the wastewater treatment plants when blowdown is discharged into the sewer, so nutrient reduction credit was not taken for these uses. Toilet flushing uses are also returned directly to the sewer. Similarly, no nutrient load reductions are assumed for the potable reuse alternatives. Although the reclaimed water for potable reuse is not discharged to the Neuse River basin, the nutrients are returned to the system and required to be treated at the wastewater treatment facilities.

These reductions can be monetized by considering that nutrient credits can be traded within each watershed. The value of the nutrient credits that could be offset by expanding the reuse system are estimated on an annual basis for each alternative as presented in **Table 6-6** and are based on the following assumptions:

- The average effluent total nitrogen (TN) concentration for this analysis is based on the average concentrations for July 2015 through June 2016 (3.1 mg/L for NRRRF, 3.4 mgd/L for Smith Creek WWTP, 1.7 mgd/L for Little Creek WWTP).

- Average TN concentrations are applied to the average annual reuse irrigation demands to determine pounds of nitrogen load reduction per year.
- The trading value of the nitrogen credit for the NRRRF and Smith Creek WWTP is $21.37 per pound, per year (for Neuse River basin 8-digit HUC 03020201). The trading value of the nitrogen credit for the Little Creek WWTP is $12.86 per pound, per year (for Neuse River basin 8-digit HUC 03020203). These represent the credit values established by NCDEQ as of September 2016.

As provided in Table 6-6, the nutrient reductions with the reuse alternatives do not have a significant impact on the overall nitrogen discharges at the treatment plants. Smith Creek Alternative 4 has the greatest impact with respect to the discharge permit limit for total nitrogen. Raleigh reuse Alternative 1 has the highest value associated with nutrient credits at approximately $64,000 per year. Although the current nitrogen credit values (in dollars per pound per year) are used for this evaluation, the credits are expected to become more valuable in the future as development continues to occur within the Neuse River basin.

Table 6-6. Nutrient Load Reductions with Reuse Alternatives[1]

	Alternative 1	Alternative 2	Alternative 3	Alternative 4
Average Day Irrigation Demand (gpd)	316,900	100,000	3,000	124,300
Average Total Nitrogen Concentration[2] (mg/L)	3.1	3.1	1.7	3.4
Annual Total Nitrogen Reduction (lbs/yr)	2,992	944	16	1,287
Total Nitrogen Permit Limit (lbs/yr)	687,373	687,373	26,660	70,814
Reduction as a % of Permit Limit	0.44%	0.14%	0.06%	1.82%
Value of Nitrogen Credits[3] ($/lb TN)	$21.37	$21.37	$12.86	$21.37
Credit Amount with Water Reuse[4] ($/year)	$63,939	$20,173	$206	$27,503

1. Potable water reuse Alternatives 5 and 6 are not included since the potable reuse water is returned to the sewer system.
2. Based on the average TN effluent concentrations reported for July 2015 through June 2016.
3. Credit values established by NCDEQ as of September 2016.
4. Calculated as the annual total nitrogen reduction x value of nitrogen credits.

6.2.3 Water Treatment Impacts

By expanding the reuse program and shifting non-potable demands with high peaking factors, such as irrigation, to the reuse system, CORPUD may be able to benefit from cost savings of deferring improvements at the WTPs. The E.M. Johnson WTP is rated for 87 mgd. The Benton WTP is rated for 16 mgd, but a study to uprate to 20 mgd is underway. Based on the potable water demand projections in Table 6-4 and assuming a maximum day to average day peaking factor for the potable system of approximately 1.46, the water treatment capacity may need to be increased to meet maximum day demands by 2025. **Table 6-7** lists the maximum day demand that could be offset from the potable system to the reuse system with each of the alternatives. The potable reuse alternatives require re-treatment at the WTPs and therefore do not provide any offset of water treatment requirements. The Raleigh reuse Alternative 1 and Smith Creek Alternative 4 provide the greatest potential reduction in treatment of maximum day demands.

Table 6-7. Maximum Day Water Treatment Demand Offset with Reuse Alternatives

Reuse Alternative	Maximum Day Demand Offset[1] (mgd)
Alternative 1 – Extend Raleigh Reuse System to Blue Ridge Road	2.34
Alternative 2 – Extend Raleigh Reuse System to Central Prison and Dorothea Dix Property	0.39
Alternative 3 – Extend Zebulon Reuse System to the BB&T Data Center	0.09
Alternative 4 – New Distribution System from Smith Creek WWTP	0.82
Alternative 5 – Supply Reclaimed Water from Raleigh Reuse System to Benton WTP	0.00
Alternative 6 – Supply Reclaimed Water from Smith Creek WWTP to E.M. Johnson WTP	0.00

1. Based on maximum day demand shifted from the potable water system to the water reuse system with each alternative.

6.2.4 Potable Water Distribution Impacts

Expansion of the non-potable reuse system would decrease peak demands on the potable water system, and thus allow greater capacity for future development within the existing potable distribution infrastructure. It may also delay when a potential distribution or transmission system capacity improvement is needed. While this could provide some savings in certain areas of the system, the benefits are difficult to quantify and may be insignificant relative to other reuse benefits.

6.3 Cost Benefit Summary

A summary of the cost benefit analysis is presented in **Table 6-8**. The conceptual capital costs and value of nutrient offset credits are presented for each alternative on a cost per gallon-per-day of average annual reuse demand for a relative comparison between alternatives as well as a comparison to CORPUD's other water supply resource alternatives. The two potable reuse alternatives (Alternative 5 and 6) are most cost-effective on a capital cost per gpd basis. All of the non-potable alternatives are equal to or greater than $20 per gpd. Due to the high capital cost of the infrastructure required to extend the Raleigh reuse distribution system to Blue Ridge Road, Alternative 1 is the most expensive both in total capital cost and capital cost per gpd. Additional considerations and drivers for selecting and implementing the most effective reuse alternatives are discussed in Section 7.

Table 6-8. Summary of Cost Benefit Analysis

	Non-Potable Reuse Alternatives				Potable Reuse Alternatives	
	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5	Alternative 6
Total Average Annual Demand[1] (gpd)	910,000	140,000	40,000	32,000	2,000,000	3,000,000
Total Capital Cost[2] (million $)	$37,100,000	$4,900,000	$800,000	$8,400,000	$14,200,000	$12,600,000
Capital Cost per gpd	**$40.77**	**$35.00**	**$20.00**	**$26.25**	**$7.10**	**$4.20**
Value of Nitrogen Credits[3] ($/year)	$63,939	$20,173	$206	$27,503	$0	$0

1. Average annual demand added to the reuse system with each alternative. See Table 4-6 for alternatives 1 through 4 and Table 5-3 for alternatives 5 and 6.
2. See Table 6-3 for calculation of capital cost.
3. See Table 6-6 for calculation of nitrogen credit value.

Section 7

Summary of Future Water Reuse Considerations

This section presents a summary of the existing water reuse system evaluation and key factors that should be considered in determining the preferred alternative for expanding CORPUD's water reuse program. If CORPUD decides to pursue potable reuse alternatives, this section also presents general considerations and recommendations for pilot testing.

7.1 Existing Water Reuse Program

CORPUD's reuse program includes two reuse distribution systems (to serve customers in southeast Raleigh and Zebulon) for non-potable water uses, with a combined annual average demand of 0.6 mgd and maximum day demand of 1.7 mgd in 2015. The combined maximum day demand is expected to increase by approximately 2.5 mgd with the additional of the NCSU Centennial Campus and Lonnie Poole golf course demands on the Raleigh reuse distribution system.

Hydraulic modeling of the water reuse distribution systems confirms that the existing infrastructure is adequate to meet the anticipated demands. However, due to high water age and long detention times in the distribution system, CORPUD has experienced some water quality issues in the Raleigh reuse distribution system. While those issues are expected to decrease with increasing demand on the system, it is recommended that a mixing system be added in the Sunnybrook reuse tank and a booster disinfection station be added on the reuse tank site to maintain disinfection residual throughout the distribution system, especially during lower demand conditions.

7.2 Driving Factors for Expansion of the Reuse Program

Six alternatives were developed as the most feasible options for expanding the reuse program (outside of on-site uses at the treatment facilities) based on existing and anticipated customer demands and proximity to the reclaimed water supply sources. Four of the alternatives include expansion of reuse distribution systems to supply reclaimed water to CORPUD's customers for non-potable water use. Two of the alternatives consider how reclaimed water could be conveyed to the WTPs for potable reuse. A total capital cost per gallon per day ($/gpd) of annual average reclaimed water demand is calculated for a relative comparison between alternatives as well as a comparison to CORPUD's other water resource alternatives.

Table 7-1 lists the alternatives considered in this study and the conceptual capital cost per gpd of average annual demand. The alternatives range from $4.20/gpd to $40.77/gpd.

Table 7-1. Reuse Alternative Capital Cost per GPD of Average Annual Demand

Reuse Alternative	Average Annual Demand[1] (gpd)	Capital Cost[2] ($/gpd)
Alternative 1 – Extend Raleigh Reuse System to Blue Ridge Road	910,000	$40.77
Alternative 2 – Extend Raleigh Reuse System to Central Prison and Dorothea Dix Property	140,000	$35.00
Alternative 3 – Extend Zebulon Reuse System to the BB&T Data Center	40,000	$20.00
Alternative 4 – New Distribution System from Smith Creek WWTP	32,000	$26.25
Alternative 5 – Supply Reclaimed Water from Raleigh Reuse System to Benton WTP	2,000,000	$7.10
Alternative 6 – Supply Reclaimed Water from Smith Creek WWTP to E.M. Johnson WTP	3,000,000	$4.20

1. Average annual demand added to the reuse system with each alternative. See Table 4-6 for Alternatives 1 through 4 and Table 5-3 for Alternatives 5 and 6.
2. Capital cost per gallon-per-day of annual average demand. See Table 6-3 for calculation of planning level capital cost.

While the capital cost of implementing each alternative is an important factor in considering expansion of the reuse program, the benefits of reuse are not always measured strictly on a cost recovery basis. Reuse can be an important contributor to meeting other utility goals. Changing regulations and regulatory climate, service area growth and water usage patterns, and customer attitudes about reuse all play into which alternatives CORPUD may consider moving forward with in the future. The selection of a preferred reuse alternative(s) should consider the following key driving factors.

Water Supply Resources

It is estimated that additional water supply sources will be needed to meet the water demands of CORPUD's service area by 2030. Should CORPUD's preferred options for future water sources, including an increase in allocation of water supply from Falls Lake that is currently under consideration, become more difficult to achieve, reuse alternatives that supplement source water supply or reduce the most potable water supply demand may become favorable.

The two most cost-effective alternatives for reducing or deferring future water supply needs are the potable reuse Alternatives 5 and 6. Regulatory and customer attitudes about potable reuse will have a large impact on the success of implementing these alternatives. Additional considerations for potable reuse are discussed in Section 7.3.

Nutrient Loading to the Neuse River Basin

As CORPUD's wastewater flow to the Neuse River basin increases in the future, the ability of the treatment facilities to meet stringent nutrient loading limits imposed as part of the Neuse Nutrient Sensitive Waters Management Strategy will be an important consideration in CORPUD's planning and operations.

If reduction in nutrient loading is the key driving factor for implementing additional reuse, the alternatives with the highest irrigation demands would become more favorable since irrigation uses remove nutrients without returning them to the sewer system. Alternatives 1, 2, and 4 have the largest reduction, in pounds per year, of TN load to the Neuse River basin. Alternative 4 has the highest percent of TN load reduction relative to the allocated discharge load at the wastewater treatment plant (1.8 percent) and is more cost effective on a $/gpd basis.

In addition, if nutrient load reduction is the key driving factor for reuse, CORPUD should look for additional opportunity to serve irrigation demands for future development that may occur in the vicinity of the existing reuse systems.

Reduction of Peak Water Demands on the Potable Treatment and Distribution System

Since treatment and distribution infrastructure is sized to meet the peak water demands, reduction of peak demand can allow greater capacity for future development within the existing infrastructure and potentially delay capacity improvements. Non-potable water uses that can be met with reclaimed water, in particular irrigation and to some extent cooling makeup water, tend to have high peaking factors during the hotter summer months. Therefore, expansion of the system to meet demands with the highest peaking factors would be more favorable for the goals of reducing peaks on the potable system. Alternatives 1, 2, 3, and 4 all offset demands with peaking factors greater than 2.0 from the potable water system. Alternatives 3 and 4 are the most cost effective of these on a $/gpd basis. However, the additional maximum day demand offset from the potable system with any of these alternatives is relatively small when compared with CORPUD's overall water demands.

Operations of the Reuse System

While meeting irrigation demands with reclaimed water can provide multiple benefits for reducing peaks on the potable system and reducing nutrient loads to the receiving water, maintaining a balance of more continuous uses, such as cooling water, on the reuse system is also important for reuse system operations. The continuous uses help attenuate high peaks on a reuse system which drive the sizing and cost of reuse piping, pumping, and storage. In addition, more continuous uses help keep water moving through the system to reduce water quality issues associated with high water age. Therefore, balancing high peak uses on the reuse system should also be considered when determining the preferred options for system expansion.

7.3 Considerations for Potable Reuse

If CORPUD decides to pursue potable reuse alternatives, public outreach, regulatory requirements, and treatment effectiveness will all need to be carefully considered. A literature search focusing on treatment technologies and water quality, as well as regulatory and public relations issues experienced by other municipalities considering potable reuse was included in the June 2014 *Neuse River Water Quality Sampling Report*. One of the preliminary steps in the process to support all of these considerations is pilot testing to demonstrate the reliability and resiliency of the potable reuse treatment process. In addition, a rigorous public outreach and public education program would be required to engage local elected officials and citizen stakeholder groups in this important policy decision.

7.3.1 Treatment Processes

Providing reclaimed water from the NRRRF as a source water to the Benton WTP (Alternative 5) is the most likely option for potable reuse due to the existing advanced treatment processes in place at NRRRF and Benton WTP.

NRRRF

The NRRRF is CORPUD's largest wastewater treatment facility, with a treatment capacity of 60 mgd. CORPUD is currently expanding the capacity to 75 mgd. The treatment process stream includes preliminary screening and grit removal, primary clarifiers, conventional activated sludge with biological nutrient removal through a 4-stage process with an internal nitrified recycle flow for nitrogen removal and capability of a 5-stage process mode for phosphorous removal, secondary clarifiers that are equipped with chemical feed for phosphorus removal, tertiary filters, and low pressure-high output UV disinfection. Sodium hypochlorite is used to provide residual chlorine for water pumped to the reuse distribution system.

The plant performance is exceptional as demonstrated by the facility's Platinum 13 Award issued by the National Association of Clean Water Agencies achieved for 13 consecutive years of 100 percent compliance with permit limits.

Benton WTP

The Benton WTP is CORPUD's newest water treatment facility which began operations in April 2010. The Benton WTP treats raw water from Lake Benson. The plant is designed with a 20-mgd maximum treatment capacity and 16-mgd permitted treatment capacity. CORPUD is currently performing an uprating study to pursue permission for 20 mgd maximum operations. The treatment process at the Benton WTP consists of raw ozonation, mechanical in-line flash mixers, Superpulsator clarifiers, granular activated carbon (GAC) filters, dual-media final filters, and a UV disinfection system.

Applicability of Ozone-Biologically Active Filtration (BAF) for Potable Reuse

Ozone coupled with biologically active granular activated carbon (GAC) filtration (BAF) is currently practiced at the Benton WTP. In addition to physical removal of particles, GAC biofilters provide additional removal benefits through biodegradation or biotransformation mechanisms and adsorption. Ozone decreases concentrations of contaminants of emerging concern, inactivates pathogens, and also increases the bioavailability of organic carbon, making it an excellent pretreatment to biological filtration. Ozone-BAF with GAC is a common technology in potable water treatment, and it has been successfully employed in wastewater applications. It is being used in multiple locations as an alternative treatment process to the full advanced treatment model (microfiltration/ ultrafiltration, reverse osmosis, ultraviolet light disinfection, and advanced oxidation multi-barrier process) for potable reuse. Ozone-BAF with GAC is already in use for indirect potable reuse (IPR) in Gwinnett County, Georgia and El Paso, Texas. Ozone-BAF has generally been found to be less expensive and energy intensive than the full advanced treatment model, particularly for inland locations where brine disposal is difficult.

Several studies are currently underway looking at ozone-BAF for potable reuse application. CDM Smith is currently performing pilot testing with ozone-BAF treatment for direct potable reuse at Gwinnett County (associated with Water Reuse Research Foundation project WRRF 15-11 and Water Research Foundation project WRF 4555). The Upper Occoquan Service Authority (UOSA) in Virginia already uses GAC for IPR. CDM Smith is performing pilot testing with UOSA to provide more sustainable, cost-effective use of the GAC by adding ozone-BAF to extend the life of the GAC. Both of these studies are applicable to pilot testing that would be performed by CORPUD for potable reuse.

7.3.2 Pilot Study

Based on CDM Smith's experience with Gwinnett County, UOSA, and other recent pilot studies, the following paragraphs provide general recommendations for pilot testing potable reuse with the current treatment processes at the NRRRF and Benton WTP.

As discussed in Section 5, reclaimed water and source water will be required to be combined in a pretreatment mixing basin with a volume equivalent of 5-days storage. Therefore, for pilot testing, the NRRRF effluent should be mixed with Lake Benson source water at the maximum allowable ratio of 20 percent (and possibly additional mixing ratios) in a tank with 5-days storage to simulate the pretreatment basin. The treatment train to simulate the current treatment technologies should include ozone, conventional coagulation, sedimentation, GAC filters, final dual media filters, UV disinfection, and final chlorine and chloramine disinfection. **Figure 7-1** shows the basic configuration of the pilot plant at Gwinnett County, which has a similar treatment train. Conventional coagulation/ flocculation/ sedimentation is suggested since the conventional processes can provide similar treatment as the Superpulsators and the Superpulsators are difficult to pilot at small scale. A pilot Superpulsator is a proprietary process that can be rented for pilot testing, but it requires over 10 times the flow of the conventional clarification process so the pilot testing cost would be much greater. For these reasons, it is common to substitute conventional (often with tube settlers) sedimentation to simulate the sedimentation step when pilot testing for a plant with Superpulsators.

For pilot-scale testing with conventional tube settler clarification, a minimum flowrate of 5 to 10 gpm should be considered based on the loading rates through 4 or 6-inch diameter filters. Similar sized pilot plant filters for UOSA are shown in **Figure 7-2**. Higher flowrates such as with a pilot Superpulsator could be considered and would add to the overall cost of the project. CORPUD could also consider a larger demonstration-scale plant at 1 mgd if such a facility would be desired to provide educational and outreach opportunities for the public. Water reuse demonstration facilities, such as the San Diego water purification demonstration project, have been helpful in building public support and comfort level with potable reuse. We recommend reaching out to the regulatory agencies to discuss pilot testing options and reach consensus on expectations prior to developing the final testing plan.

Figure 7-1. Basic Configuration of the Gwinnett County Reuse Pilot Plant

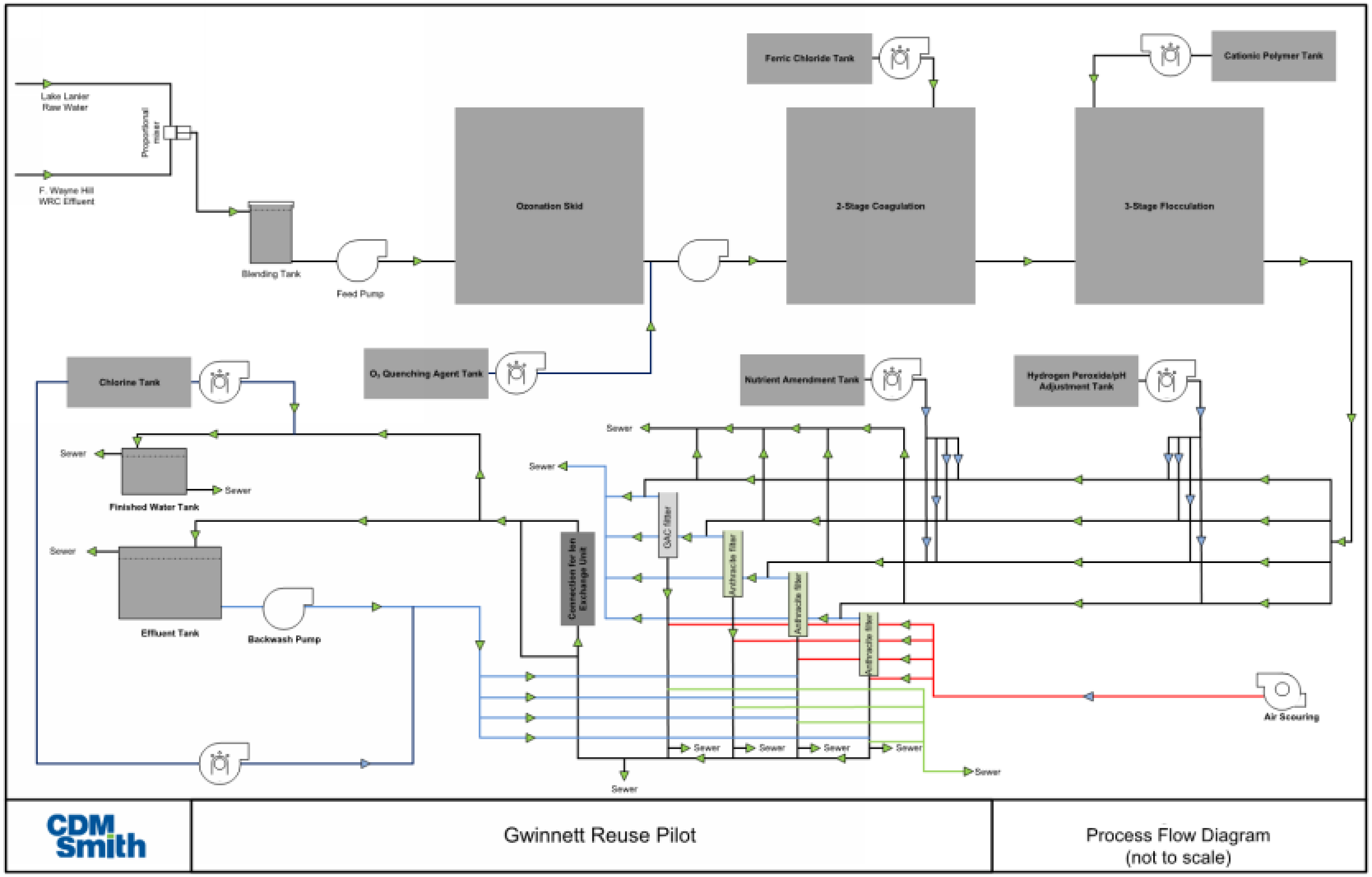
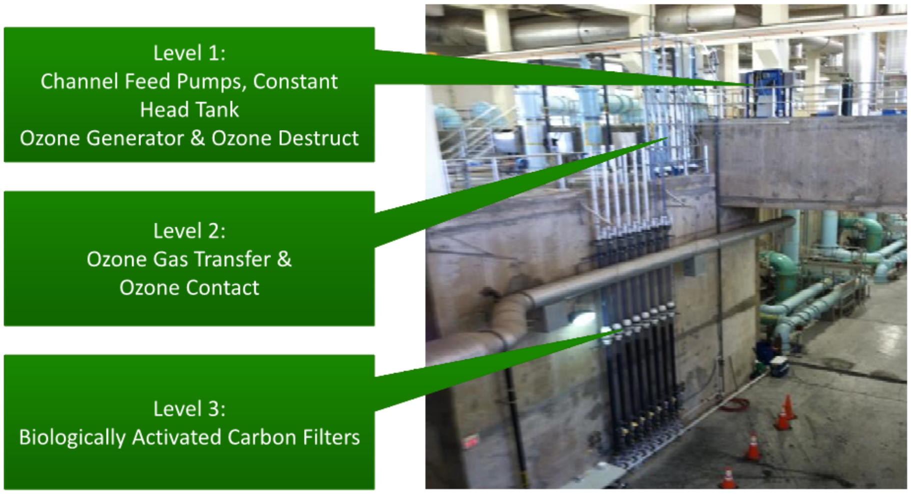


Figure 7-2. UOSA Pilot Testing



At a minimum, the sampling parameters should include all regulated drinking water contaminants and secondary drinking water standards under the National Primary Drinking Water Regulations (NPDWR) as well as the contaminants that are being considered for regulation on the contaminant candidate list (CCL) and other contaminants of emerging concern. Reclaimed water will be required to meet NCDEQ Type 2 standards (at a minimum), which calls for pathogen removal of at least log 6 or greater reduction of E. coli; log 5 or greater reduction of coliphage; and log 4 or greater reduction of clostridium perfringens. Therefore, all three indicator organisms should be included in the testing. As an example, a sampling plan and list of sampling parameters for the Gwinnett County pilot project is included in **Appendix D**. Sampling should occur at multiple points throughout the treatment train and also be compared with corresponding samples collected from full-scale current operations of the Benton WTP for benchmarking.

The recommended duration of testing is one year to evaluate seasonal changes in water quality. Based on similar size pilot-scale testing performed for other utilities, the cost for such a study is expected to be approximately $2 million including construction and operations of a 5 to 10 gpm pilot plant, engineering, sampling, and laboratory analyses. Additionally, there is opportunity for CORPUD to participate in ongoing or planned research projects through a pilot-scale study.

Pilot testing could take place at either the NRRRF or Benton WTP depending on available facilities, piping, etc. However, since piloting would use a blend of Lake Benson source water and reclaimed water from the NRRRF, water conveyance would need to be considered for either option. At a maximum blend of 20 percent reclaimed water, conveyance of reclaimed water to the WTP site may be more cost-effective. General recommendations for pilot testing are summarized in **Table 7-2.**

Table 7-2. General Pilot Testing Recommendations

Parameter	Recommendation
Duration	1 year
Flowrate	~ 5-10 gpm (assuming 4 or 6-inch filters)
Reuse Mixing Ratio	Maximum ratio of 20% based on regulations; possibly additional ratios < 20%
Treatment Train	5-day mixing -> ozone -> coagulation/flocculation/tube settlers -> GAC filters -> final filters -> UV disinfection pending consensus discussions with regulators. Two trains to allow side-by-side testing with and without reuse.
Operational Variables	% reuse mixing ratio, chemical doses, GAC type and age, loading rates, potential supplements such as nutrients or peroxide to enhance biofiltration
Sampling Parameters	Regulated drinking water contaminants, contaminants under consideration for regulation, other contaminants of emerging concern
Budgetary Cost	$2,000,000 pending consensus discussion with regulators

7.4 Conclusions

The second phase of the Reuse Water System Master Plan Update examines options for improving the water quality of the existing reuse system and expanding the water reuse system to serve either non-potable or potable uses. The following are the main conclusions and recommendations of the study:

- Based on the hydraulic model evaluation, the existing reuse infrastructure for the Raleigh and Zebulon water reuse distribution systems is adequate to meet water transmission and storage needs for the existing customer demands. However, it is recommended that CORPUD continue to monitor pressures on the discharge side of the reuse pumps at the NRRRF as NCSU and Lonnie Poole golf course demands are added to the end of the Raleigh reuse distribution system to determine if improvements may be needed to reduce pressures at the critical high pressure point outside of the NRRRF.
- To address water quality issues in the Raleigh reuse distribution system, it is recommended that a mixing system be added in the Sunnybrook reuse tank and a booster disinfection station be added on the reuse tank site to maintain disinfection residual throughout the distribution system, especially during lower demand conditions. Water quality issues are also expected to decrease with increasing demand on the system.
- The proposed bioenergy recovery program at the NRRRF is projected to have significant demand for non-potable water that would approximately triple the on-site reuse water demand. The supply of reclaimed water at the NRRRF is adequate to simultaneously meet the increased on-site reuse demand of the bioenergy facilities and future off-site reuse customer demands. However, improvements to the on-site reuse system including replacement of the on-site reuse pump station, additional storage/wet well capacity, and improvements to the on-site reuse piping are recommended.
- Six alternatives were developed as the most feasible options for future expansion of the reuse program (outside of on-site uses at the treatment facilities). These alternatives were

developed considering existing and anticipated customer demands and proximity to the reclaimed water supply sources. Of these, expanding the Raleigh reuse water distribution system to Blue Ridge Road (Alternative 1) is the most expensive on the basis of capital cost per annual average demand ($40.77/gpd). The two alternatives that consider conveying reclaimed water to the WTPs for potable reuse (Alternatives 5 and 6) are the least expensive on the basis of capital cost per average annual demand (both less than $8/gpd). Costs for additional treatment trains or modifications at the WTPs are not included in the potable reuse alternatives.

- While the capital cost of implementing each alternative is an important factor in considering expansion of the reuse program, the benefits of reuse are not always measured strictly on a cost recovery basis. Reuse can be an important contributor to meeting other utility goals. As CORPUD considers how to expand the water reuse program in the future, key driving factors in meeting utility objectives should be considered. For instance, the potable reuse alternatives may be the most cost-effective alternatives for reducing or deferring future water supply needs. However, if reduction in nutrient loading to the Neuse River basin is the key driving factor, the alternatives that provide reclaimed water for the highest irrigation demands would become more favorable since irrigation uses remove nutrients without returning them to the sewer system.
- If CORPUD decides to pursue potable reuse alternatives, public outreach, regulatory requirements, and treatment effectiveness would all need to be carefully considered. One of the preliminary steps in the process to support all of these considerations is pilot testing to demonstrate the reliability and resiliency of the potable reuse treatment process to regulators and other stakeholders. In addition, a rigorous public outreach and public education program would be required to engage local elected officials and citizen stakeholder groups in this important policy decision.

Appendix A

Reuse System Water Quality Technical Memorandum

CDM Smith

Memorandum

To: *City of Raleigh Public Utilities Department*

From: *CDM Smith*

Date: *December 7, 2015*

Subject: *Reuse System Water Quality*

The City of Raleigh Public Utilities Department (CORPUD) provides reclaimed water from the Neuse River Resource Recovery Facility (NRRRF) through a reuse distribution system in southeast Raleigh for irrigation, cooling water, toilet flushing, and other non-potable uses. CORPUD has experienced difficulty in maintaining disinfectant residual and degradation of water quality in the reuse distribution system. This Technical Memorandum discusses CORPUD's current reuse system facilities and practices, and provides recommendations to preserve water quality within the off-site reuse distribution system.

1.0 Existing Reuse System Overview

The reuse facilities at the NRRRF pump reuse water through three separate systems: 1) on-site reuse system for plant and other on-site uses, 2) on-site high pressure irrigation system for irrigation of the agricultural fields near the NRRRF, and 3) off-site distribution system to provide reuse water for public utility facilities, parks and recreational fields, golf courses, and commercial/industrial uses. This memorandum focuses on water quality issues in the off-site distribution system.

Per the reclaimed water permitting program issued by the North Carolina Department of Environmental Quality (NCDEQ) dated February 5, 2010 and amended on April 26, 2010, the City is required to only monitor monthly average pumped flow, fecal coliforms and total chlorine residual in the off-site reuse distribution system. A copy of the permit is attached under **Appendix A**.

1.1 Treatment and Pumping at Neuse River Resource Recovery Facility

The wastewater treatment process stream at the NRRRF includes primary treatment, activated sludge secondary treatment with biological nutrient removal, tertiary filters, and ultraviolet (UV) disinfection. Reuse water for both on-site and off-site systems is supplied from the UV effluent pipeline. A sodium hypochlorite (hypo) feed system is used to provide residual chlorine in the distribution system. The existing hypo feed system is described in detail in Section 2.

The high service pump station for the off-site reuse system consists of three 1,040 gallon per minute (gpm) vertical turbine pumps. Existing operations typically involve only one pump running at a time, based on levels in the elevated storage tank in the off-site reuse distribution system.

A bulk reuse truck filling station is located on the NRRRF site and is supplied from the 24-inch off-site pipeline downstream of the hypochlorite injection vault. Use at the bulk station is sporadic and generally accounts for less than one percent of the off-site system demand.

1.2 Reuse Distribution System

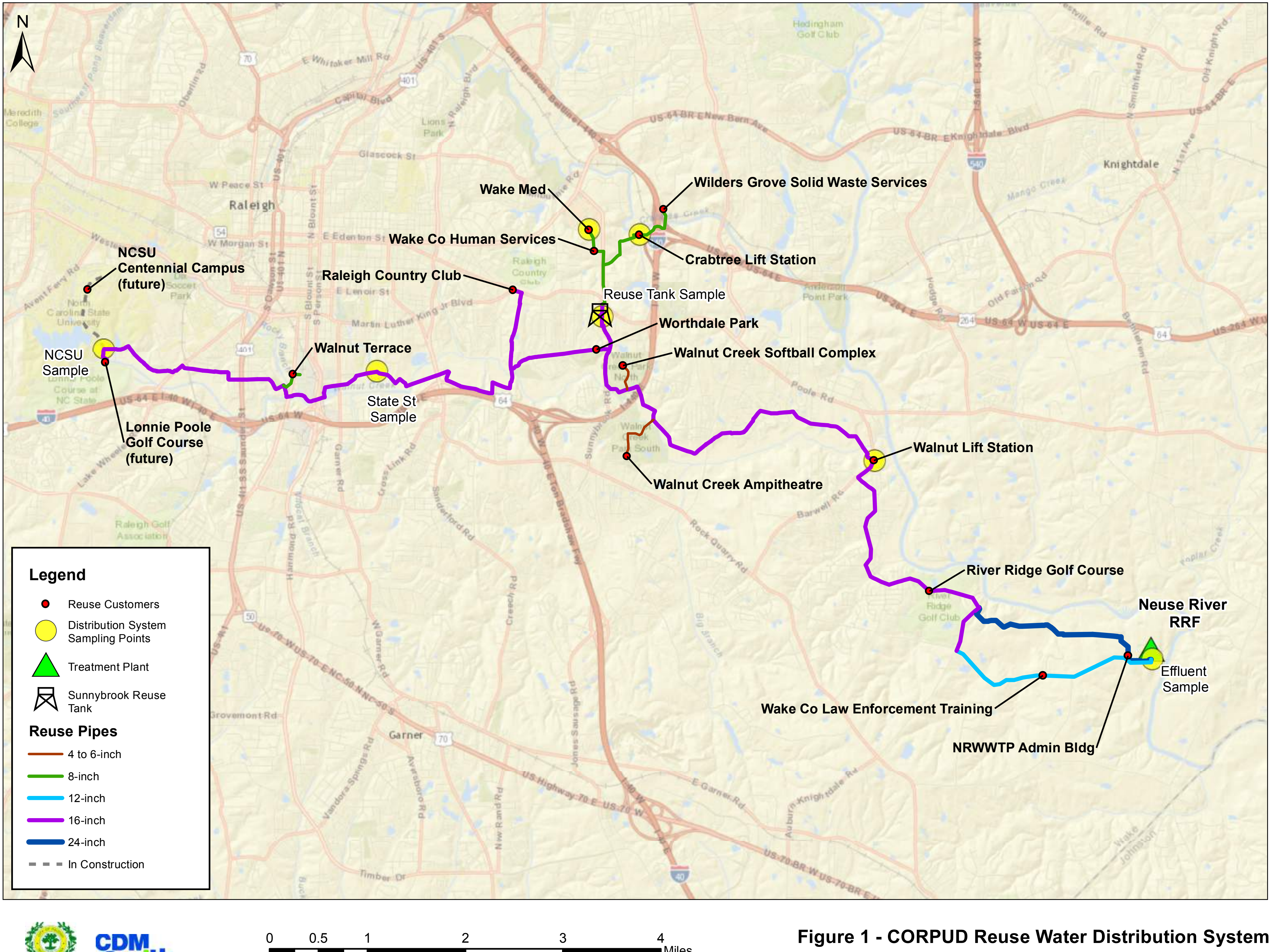
The off-site reuse distribution system from the NRRRF consists of approximately 23 miles of 4-inch diameter through 24-inch diameter pipeline from the high service pumps to the North Carolina State University (NCSU) Centennial Campus and the Lonnie Poole Golf Course (**Figure 1**). The most recent distribution system segment from State Street to the Lonnie Poole Golf Course was placed in service in summer 2015. NCSU is currently constructing a pipeline extension to bring reuse water to the Centennial Campus central utility plant for cooling tower use, irrigation, and toilet flushing at the Hunt Library. NCSU is expected to begin using reuse water in January 2016.

Storage

A 750,000 gallon elevated storage tank is located on Sunnybrook Road. The tank site is in the middle of the current reuse distribution system, approximately 9 miles downstream of the high service pumps. This Sunnybrook tank is a composite elevated tank with a single inlet/outlet pipe, a head range of approximately 36 feet, and an overflow elevation of 495 feet. CORPUD staff report that the tank is typically operated between 25 and 35 feet in the summer and adjusted to a lower level (15 to 25 feet or lower) seasonally based on system demands. A drain line from the Sunnybrook tank to the sewer is currently being designed to provide CORPUD more flexibility in maintaining and flushing the tank.

Reuse Customers

The location of the current reuse customers is shown in Figure 1. The largest reuse customers are listed in **Table 1** with current seasonal average demands for summer (May through October) and winter (November through April). Almost half of the current summer demand is located on the NRRRF site at the administration building (supplied from the off-site reuse system). The administration building uses reclaimed water for the cooling system, toilets, and a decorative pond. The cooling system is a once-through water cooled system (without recycle) which accounts for most of the administration building usage. The second largest user is the WakeMed cooling towers near the Sunnybrook tank. Once Centennial Campus is connected to the reuse system, summer average demands are projected to increase by about 40 percent. With Centennial Campus and Lonnie Poole Golf Course, demands are projected to increase by about 60 percent.



CDM Smith

Figure 1 - CORPUD Reuse Water Distribution System

Table 1. Reuse Customer Demands

User	Summer ADD[1] (gpd)	Winter ADD[2] (gpd)
NRRRF - Administration Building	360,000	19,000
WakeMed	178,000	76,000
Walnut Lift Station	95,000	95,000
Raleigh Country Club	77,000	4,000
Crabtree Lift Station	48,000	48,000
Other Customers	40,000	7,000
Total Existing	**798,000**	**249,000**
NCSU Centennial Campus (estimated)	331,000	91,000
Lonnie Poole Golf Course (estimated)	114,000	6,000
Total Future	**1,243,000**	**346,000**

1. Summer average day demand is the average demand from May through October
2. Winter average day demand is the average demand from November through April

Distribution System Maintenance

Maintenance activities performed by CORPUD to maintain distribution system water quality include flushing of the reuse distribution system and cleaning of the elevated storage tank. Monthly flushing is performed at system blow-offs near State Street and NCSU; however, the system has limited capacity to blow-off at other locations. The ability to achieve scouring velocity to flush the 16-inch diameter distribution main is limited by the capacity of the pump station and potentially damaging pressures at the low point of the pipeline near the NRRRF.

The Sunnybrook tank is cleaned regularly during the low demand period in the winter. An analysis of samples collected during the tank cleaning in February 2014 noted heavy bacterial activity and biofilm deposits. CORPUD staff suspect stratification may be occurring in the tank. The reuse tank water quality data is further discussed in Section 3.

2.0 Existing Sodium Hypochlorite Storage and Feed Facilities

Free chlorine is used as a disinfectant for CORPUD's reuse system. Free chlorine is supplied in the form of hypo solution. The hypo facility at the NRRRF consists of two (2)-10,000 gallons hypo storage tanks, five (5)-61.8 gallons per hour (gph) diaphragm metering pumps, a transfer pump to circulate the contents of the storage tanks, piping and appurtenances. Hypo is purchased at bulk concentration of 12.5 percent and is diluted to approximately 10 percent while filling the two storage tanks. CORPUD staff check the hypo concentration in the storage tanks once after every delivery.

The hypo metering pumps feed hypo from the storage tanks to the off-site reuse system, on-site reuse system, and to the on-site high pressure irrigation system. **Figure 2** is a schematic of the reuse pumps and hypo feed system at the NRRRF. For the off-site system, the hypo application points are at the following two locations:

- Wet well of the off-site reuse water pump station. Hypo solution is fed using diffusers located across the opening of 36-inch reuse water influent pipe.
- 24-inch reuse water pumped discharge pipe in the hypochlorite injection vault 1, which is located approximately 600-feet downstream of the off-site reuse water pump station.

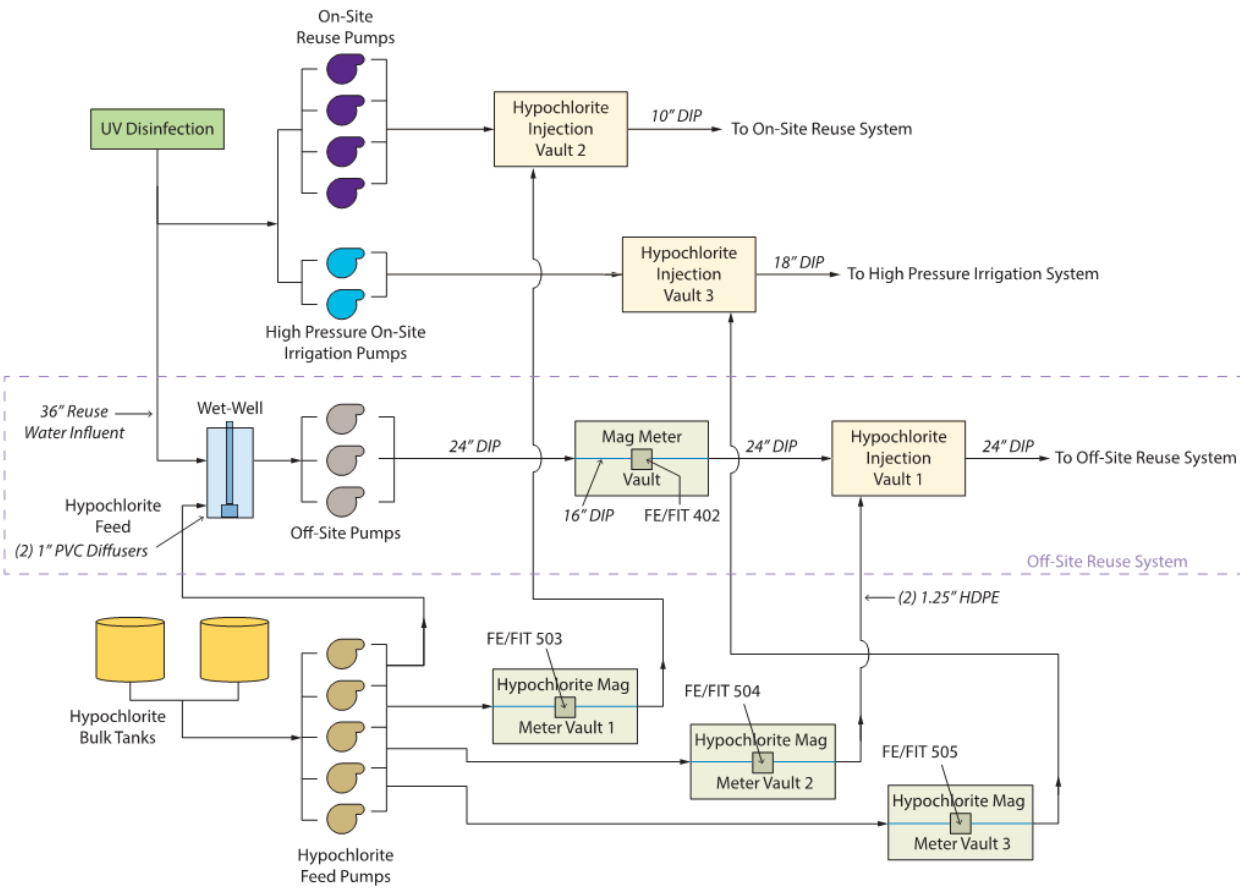


Figure 2. Schematic of Reuse Pumps and Hypochlorite Feed System at the NRRRF

CORPUD staff indicated that the hypo feed line to the hypochlorite injection vault 1 is subject to frequent breaks. Per CORPUD staff, the hypo metering pumps are rated for 200 psi and the backpressure on pump discharge side is approximately 100 psi to 120 psi. No carrier water is being used.

2.1 Historical Hypo Dose

Per CORPUD staff, the majority of the hypo dose for the off-site system is currently fed in the wet well. As shown in Figure 2, flowmeters are installed on all hypo metering pump discharge pipes except for the pump feeding the off-site wet well. Since record drawings for the process and instrumentation diagrams for hypo feed system were not available, CDM Smith contacted CITI, LLC, who is the system's integrator for the NRRRF. Per CITI, hypo feed to the various application points is flow paced per following:

- For the metering pumps that include a flowmeter on the pump discharge piping, CORPUD calculates the hypo flow rate based on the following formula:

$$\text{Calculated Hypo Flow Rate (gpm)} = \frac{\text{Reuse Water Pumped Flow (gpm)} * \text{Hypo Dose} \left(\frac{\text{mg}}{\text{L}}\right) * 8.34 \left(\frac{\text{lbs}}{\text{gal}}\right)}{\text{Bulk Hypo Concentration} \left(\frac{\text{lbs}}{\text{gal}}\right)}$$

  The calculated flow rate is compared to the actual chemical flow meter reading and pump speed is adjusted until the calculated flow rate matches the actual chemical pumped flow rate.

- For the off-site wet well, CORPUD calculates the hypo flow rate using the above formulae but since there is no pacing flowmeter on metering pump discharge, use the maximum pump capacity to calculate the percent speed that the pump should be run to match the calculated flow rate.

Limited historical hypo consumption data is available for the off-site system, which was used to calculate the historical hypo dosages. The calculated hypo dosages are presented in **Table 2**.

Table 2. Summary of Monthly Hypo Usage for Off-Site Reuse System (Bulk Hypo Concentration ~ 10%)

Month	Monthly Reuse Flow[1]	Average Daily Reuse Flow	Monthly Hypo Consumption[1]	Average Daily Hypo Consumption	Average Hypo Dose
	(MG)	(MGD)	(gal)	(gal/day)	(mg/L)
Mar-15	12.64	0.41	926	29.9	8.5
Apr-15	22.76	0.76	1,198	38.6	5.9
May-15	32.21	1.04	1,218	39.3	4.4
Jun-15	34.75	1.16	1,410	45.5	4.6
Jul-15	34.08	1.14	1,416	45.7	4.7
Aug-15	32.32	1.08	1,634	52.7	5.7

[1] Data provided by CORPUD

Per Table 2, the average hypo dose for the off-site reuse system has ranged between 4.4 and 8.5 mg/L since March 2015. However, per discussions with CORPUD staff, the actual hypo doses have been much higher (13 to 15 mg/L) and the calculated doses in Table 2 are in the ballpark for the off-site hypochlorite injection vault 1 only. Since the hypo bulk tanks feed both on-site and off-site systems and hypo feed rate to the off-site wet well cannot be monitored on-line, it is possible that the hypo feed rates for the on-site system were provided in lieu of the off-site system. Per CITI, based on historical data for hypo storage tank levels, metering pump run times and total pumped flows for on-site reuse, on-site irrigation and off-site hypo injection vault 1, hypo feed rates for the off-site wet well can be calculated. If such detailed data can be provided by CORPUD, CDM Smith can calculate the hypo dose at the off-site wet well.

2.2 Chlorine Contact Time

Table 3 presents the available theoretical chlorine contact times in the off-site wet well, where the majority of the chlorine dose is applied for the off-site reuse system.

Depending on the water surface elevation in the wet well with two pumps operating at 2,300 gpm (3.3 mgd), the theoretical chlorine contact time varies between 16.9 minutes to 24.7 minutes. This is a conservative estimate considering the typical existing and projected (w/ Centennial Campus and Lonnie Poole Golf Course) summer average demands can be met with one pump in operation. However, since there are no baffles in the off-site wet well, the influent flow can short circuit, thereby reducing the theoretical detention times calculated in Table 3.

The baffling factor is used to account for poor circulation in a tank/ wet well. **Table 4** presents the baffling factors as published in *Long Term 1 Enhanced Surface Water Treatment Rule* (*LT1ESWTR) Disinfection Profiling and Benchmarking* by USEPA (2003).

Per Table 4, the baffling description for the off-site wet well can be characterized as unbaffled to poor with baffling factors ranging between 0.1 and 0.3 as presented in Table 4. Therefore accounting for the baffling factor, the effective chlorine contact time can be calculated per the following:

$$\text{Effective Chlorine Contact Time (minutes)} = \text{Baffling Factor} * \text{Theoretical Chlorine Contact Time (minutes)}$$

With a baffling factor of 0.1, the effective chlorine contact time in the off-site wet well ranges between 1.7 minutes to 2.5 minutes. The effective chlorine contact time increases to 5.1 minutes to 7.4 minutes with a baffling factor of 0.3. Tracer testing or computational fluid dynamics (CFD) modeling can be conducted to confirm the baffling factor.

Table 3. Available Theoretical Chlorine Contact Times for Off-Site Wet Well

Wet Well Dimensions		
Length	38	feet
Width	29	feet
Water Depth	5.32 to 7.5[1]	feet
Concrete Bays[2]		
Number	10	-
Length	6	feet
Width	1	feet
Height	11	feet
Wet Well Volume[3]		
Minimum	38,900	gallons
Maximum	56,900	gallons
Pump Station		
Number of Pumps	3	
Max Pumped Flow[4] (with 2 pumps)	2,300	gpm
Hypo Feed Location	Across the opening of the 36-inch reuse water influent pipe	-
Available Theoretical Chlorine Contact Time[5]		
Minimum	16.9	minutes
Maximum	24.7	minutes

1 Water surface elevation of 172.0-feet in the Off-Site wet well based on the minimum water surface elevation (169.82-feet) and adding the headloss in the outfall pipe at average day flow.
2 Structural drawings for the Off-Site wet well were not provided; dimensions scaled from Record M-drawings for the Neuse River Wastewater Treatment Plant DeNite Filter Addition and Off-Site Reuse Pump Station by Hazen and Sawyer dated Dec 2010.
3 Rounded off to the nearest hundred; does not include volume occupied by the concrete bays.
4 Per CORPUD staff, all three pumps are not operated at the same time due to system limitations. Therefore, the detention time is calculated based on two pumps operating.
5 Assumes no short circuiting in the wet well.

Table 4. Baffling Factors per LT1ESWTR Disinfection Profiling and Benchmarking by USEPA (2003).

Baffling Condition	Baffling Factor	Baffling Description
Unbaffled	0.1	None, low length to width ratio, high inlet and outlet velocities
Poor	0.3	Single or multiple unbaffled inlet or outlets, no intra basin baffles
Average	0.5	Baffled inlet or outlet with some intra basin baffles
Superior	0.7	Perforated inlet baffles, serpentine or perforated intra basin baffles, outlet weirs or launders
Plug Flow	1.0	Pipe flow, perforated inlet and outlet, intra basin baffles

3.0 Water Quality Data

This section provides an evaluation of numerous historical water quality parameters for the off-site reuse distribution system. This analysis examines water quality data covering the period from January 2014 through October 2015. The water quality sampling locations in the distribution system are shown in Figure 1.

3.1 pH and Alkalinity

Summary of available data for pH and alkalinity is presented in **Table 5** and **Table 6**, respectively. Data for pH was available only for the treated effluent at the NRRRF and for the Sunnybrook reuse tank. At the NRRRF, the pH varied from 6.08 mg/L to 7.40 mg/L with an average pH of 6.84±0.11 mg/L. At the reuse tank, pH ranged from 6.15 mg/L to 7.19 mg/L with an average pH of 6.66±0.22 mg/L. A slight decrease in the average pH values was observed between the NRRRF and the reuse tank.

Table 5. Summary of pH in Treated Effluent at NRRRF and Reuse Tank

	pH				
Site	Data Points	Average	Std. Dev.	Min	Max
NRRRF	405	6.84	0.11	6.08	7.40
Reuse Tank	44	6.66	0.22	6.15	7.19

The average alkalinity of the treated effluent at the NRRRF ranged between 42.0 and 176.0 mg/L as $CaCO_3$ with average alkalinity of 76.7±11.1 mg/L as $CaCO_3$. In general, alkalinity increased between the NRRRF and the system extremities, with the NCSU sampling location having the highest alkalinity water. The average alkalinity at NCSU was 109.6±5.7 mg/L as $CaCO_3$. However, limited data is available at NCSU considering it was connected to CORPUD's off-site reuse system in summer 2015 and the system has not been active at that location.

Table 6. Summary of Alkalinity and Quartile Analysis for Off-Site Reuse Distribution System

Alkalinity (mg/L as $CaCO_3$)										
Site	Data Points	Mean	Std. Dev.	Min	25%ile	50%ile	75%ile	90%ile	95%ile	Max
NRRRF	252	76.7	11.1	42.0	70.0	77.0	83.0	87.0	90.0	176.0
Walnut LS	51	87.1	10.7	57.0	83.0	91.0	93.5	99.0	99.5	101.0
Reuse Tank	50	87.4	7.8	62.0	82.3	89.5	93.8	96.0	96.6	98.0
Crabtree LS	51	88.5	7.1	71.0	84.0	89.0	94.0	97.0	99.5	102.0
State Street	48	93.7	6.6	79.0	90.0	96.0	98.3	101.0	101.7	105.0
NCSU	5	109.6	5.7	101.0	107.0	111.0	114.0	114.6	114.8	115.0

3.2 Biochemical Oxygen Demand (BOD)

Biochemical oxygen demand (BOD) is the amount of oxygen used by aerobic bacteria to oxidize the organic matter. Data for BOD was available only for the treated effluent at the NRRRF. The average BOD in the treated effluent was low (2.7±0.6 mg/L). Approximately 95 percent of the samples were below the detection limit (<2.0 mg/L).

No data related to chemical oxygen demand (COD), biodegradable dissolved organic carbon (BDOC) or assimilable organic carbon (AOC) was available for the off-site reuse distribution system.

3.3 Turbidity

Water turbidity is a means of assessing quality of water from the aesthetic perspective. In reuse water, high turbidity is typically attributed to the presence of organic matter, corrosion products, sediments, and microscopic organisms. As shown in **Figure 3**, in general, turbidity increased at the lift stations potentially related to flow changes disturbing sediments or due to accumulation of sediments and biogrowth. Treated NRRRF effluent water had an average turbidity of less than 1 nephelometric turbidity units (NTU) at all times. However, average water turbidity increased to 2 NTU at the Walnut and Crabtree lift stations. The data was distributed over a wider range of values as indicated by the high standard deviations. The increasing turbidities could be attributed to the presence of colloids and sloughing off of biofilms. The water turbidities in the reuse tank, at State Street, and at NCSU were comparable to the treated effluent turbidities at the NRRRF. This could be explained by the extended detention time in the reuse tank, which could result in settlement of the suspended particles, an auto-flusher at State Street, and newly installed piping between State Street and NCSU. Routine flushing of the system should be practiced to prevent the accumulation of the sediments.

3.4 Inorganic and Total Kjeldahl Nitrogen (TKN)

Figure 4 presents the variation of average inorganic and total Kjeldahl nitrogen (TKN) in the off-site reuse distribution system. The TKN is used to measure the sum of organic nitrogen and ammonia-nitrogen (N). Therefore, the difference between the TKN and ammonia-N will provide an estimate of organic nitrogen present.

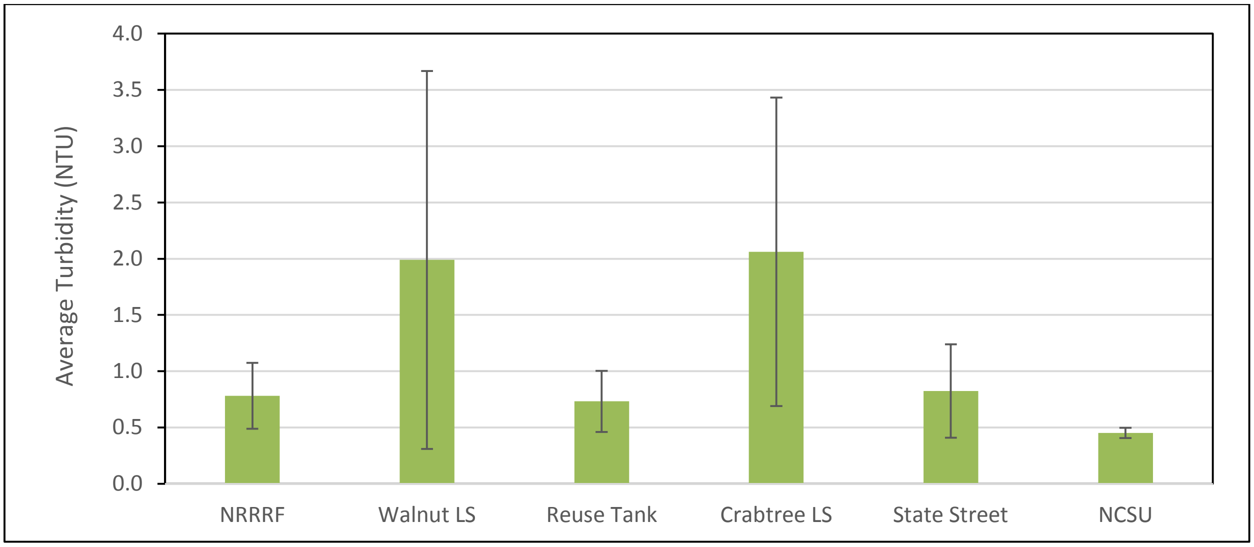


Figure 3. Variation of Turbidity in Off-Site Reuse Distribution System

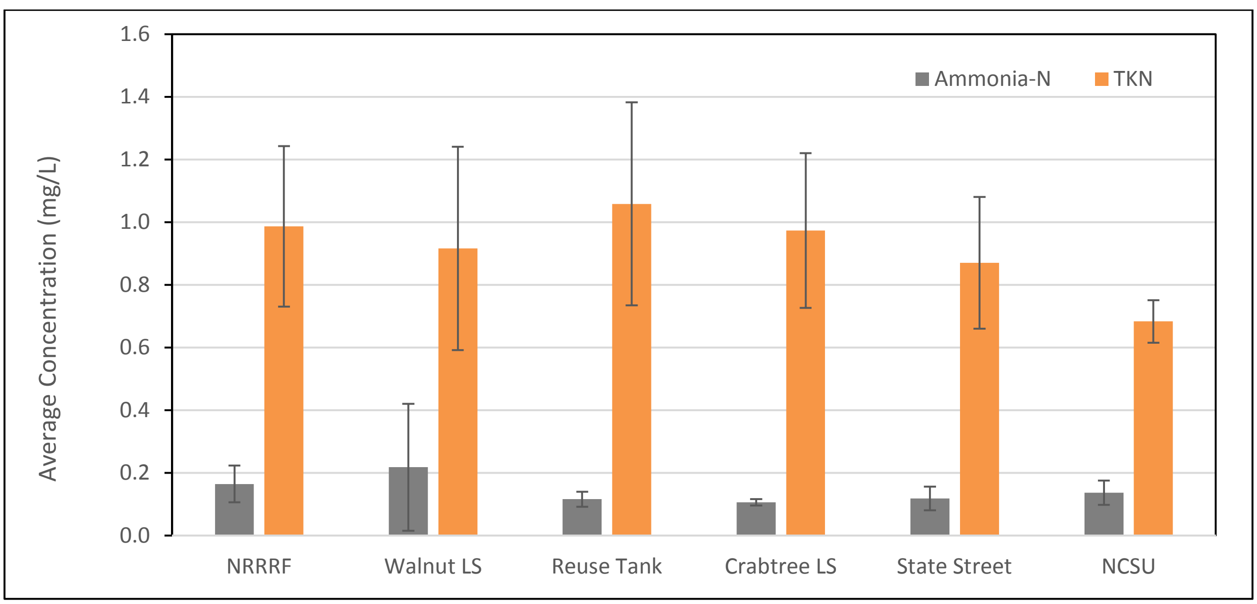


Figure 4. Variation of Average Inorganic and Total Kjeldahl Nitrogen in Off-Site Reuse Distribution System

The monthly average permitted limit for ammonia-N in the reclaimed water for on-site irrigation system at the NRRRF is 4 mg/L (Appendix A). The average ammonia-N levels in the treated effluent are relatively low (0.17±0.06 mg/L), indicating the reliability of operations at the facility. CORPUD does not practice break point chlorination and the treated effluent TKN concentrations varied between 0.50 mg/L to 1.70 mg/L with average values of 0.99±0.26 mg/L.

3.5 Disinfectant Residuals and Fecal Coliforms

Chlorine is used as a disinfectant for the reuse system. Free chlorine combines with ammonia-N present in the treated effluent to form combined chlorine. The total chlorine residual is composed of both free and combined chlorine residuals. **Figure 5** presents the variation of free and total chlorine residuals in the off-site reuse distribution system. The data shows that chlorine residuals fall sharply in the distribution system and the high standard deviation indicates that the data points are spread out over a wider range of values. Figure 5 also indicates that the free chlorine and total chlorine residuals are quite comparable, indicating that the available ammonia-N levels in the treated effluent are relatively low. An exception is the reuse tank where the free chlorine residuals have decreased significantly but the total chlorine residuals are slower to drop.

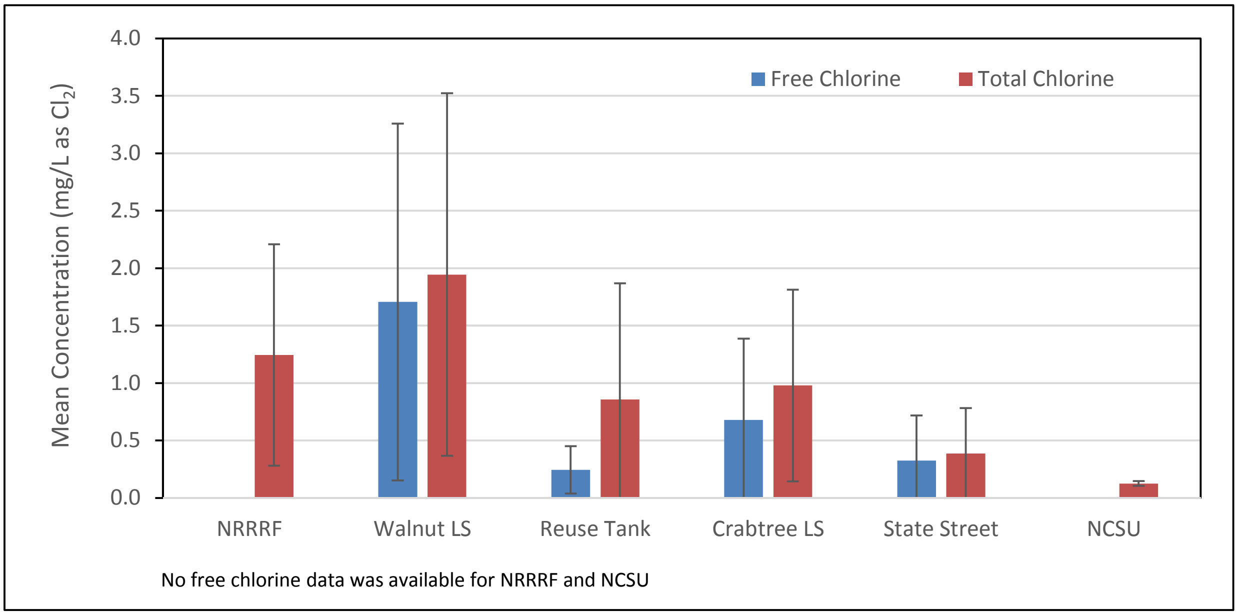


Figure 5. Disinfectant Residuals in Off-Site Reuse Distribution System

Disinfectant residuals and stability in reuse water systems are affected by disinfectant demand from ammonia, organic nitrogen, organic carbon, corrosion products, temperature, pH, etc. Comparison of Figures 4 and 5 indicates that it is unlikely that the depletion of chlorine residuals is primarily due to reaction with ammonia-N. The rapid loss of chlorine residuals could potentially be the result of:

- Free chlorine being highly reactive.
- Poor mixing.

- Process not having reached steady state owing to reactions between chlorine and organic carbon/ nitrogen (Figure 4) and other chlorine demand.
- Hypo decomposition in the storage tanks. Hypo decomposes over time especially when stored at 10 to 12 percent concentrations. If the hypo dose is calculated throughout the period of usage using the bulk hypo concentration at delivery (10 to 12 percent), the applied chlorine dose will be less than the calculated dose.
- High chlorine consumption. Long detention times with no measurable chlorine residuals can result in high biofilm development on pipe/ tank walls, which can lead to demand reactions between chlorine and attached biofilm or with the suspended bacteria in the water phase.

Table 7 presents the disinfectant concentrations and quartile analysis for the off-site reuse distribution system. At the Walnut lift station and at the reuse tank, 19 percent and 18 percent of the free chlorine residuals were below the detection limit of 0.10 mg/L, respectively, and 12 percent of the free chlorine residual data was below the detection limit at the Crabtree lift station. At State Street, 72 percent of free chlorine residuals were below the detection limit and samples collected at NCSU did not indicate any free chlorine residuals. At the NRRRF, no free chlorine residual data for the treated effluent was available.

Table 7: Summary of Disinfectant Concentrations and Quartile Analysis for Off-Site Reuse Distribution System

Free Chlorine (mg/L as Cl_2)[1,2]									
Site	Data Points	Average	Min	25%ile	50%ile	75%ile	90%ile	95%ile	Max
Walnut LS	38	1.71	0.11	0.36	1.26	2.68	3.82	5.00	5.00
Reuse Tank	9	0.24	0.11	0.11	0.14	0.30	0.42	0.58	0.74
Crabtree LS	43	0.68	0.11	0.18	0.42	0.97	1.44	1.91	3.18
State Street	13	0.33	0.10	0.14	0.27	0.29	0.40	0.89	1.59
Total Chlorine (mg/L as Cl2)[1]									
NRRRF[3]	138	1.24	0.15	0.56	1.00	1.60	2.50	2.80	6.80
Walnut LS	49	1.94	0.13	0.63	1.24	2.99	4.42	5.00	5.00
Reuse Tank	51	0.86	0.10	0.26	0.43	1.15	1.81	2.84	4.78
Crabtree LS	52	0.98	0.16	0.38	0.71	1.31	1.98	2.51	4.00
State Street	46	0.39	0.10	0.20	0.26	0.42	0.65	0.76	2.45
NCSU[4]	2	0.13	0.11	-	-	-	-	-	0.14

1. Minimum Detection Limit of 0.10 mg/L
2. No free chlorine residuals data was available for NRRRF effluent; 100 percent of data for NCSU was below the detection limit
3. Data for January 2015 to September 2015
4. Data since September 2015

Fecal coliform data was available only for the treated effluent at the NRRRF. Approximately 90 percent of the samples were below the detection limit of 1.0 cfu/100mL. Average fecal coliforms detected were 7.1±3.3 cfu/100mL.

3.6 Nutrients

Tables 8 through 11 summarize the inorganic nutrient levels in the off-site reuse distribution system. The average concentrations of nitrate-N, sulfate, and total phosphate in the treated effluent at NRRRF were 0.34±0.19 mg/L, 70.1±3.8 mg/L, and 1.65±0.71 mg/L, respectively. Nitrite-N data was not available for the NRRRF effluent. No significant variation was observed in the average nutrient concentrations at various sampling locations in the reuse distribution system except for NCSU, where the data points are too few to be of significance.

Table 8. Summary of Nitrate-N Concentrations and Quartile Analysis for Off-Site Reuse Distribution System

NO_3-N (mg/L as N)[1]										
Site	Data Points	Average	Std. Dev.	Min	25%ile	50%ile	75%ile	90%ile	95%ile	Max
NRRRF	340	0.34	0.19	0.01	0.20	0.30	0.45	0.61	0.71	0.94
Walnut LS	51	0.32	0.22	0.00	0.12	0.27	0.43	0.62	0.69	1.00
Reuse Tank	52	0.35	0.17	0.00	0.23	0.34	0.43	0.58	0.65	0.75
Crabtree LS	51	0.36	0.16	0.07	0.23	0.34	0.44	0.51	0.60	0.96
State Street	47	0.31	0.15	0.09	0.17	0.30	0.40	0.48	0.60	0.71
NCSU	5	0.64	0.10	0.56	0.57	0.62	0.62	0.74	0.78	0.82

[1] Minimum Detection Limit of 0.10 mg/L.

Table 9. Summary of Nitrite-N Concentrations and Quartile Analysis for Off-Site Reuse Distribution System

NO_2-N (mg/L as N)[1]										
Site	Data Points	Mean	Std. Dev.	Min	25%ile	50%ile	75%ile	90%ile	95%ile	Max
NRRRF	0	-	-	-	-	-	-	-	-	-
Walnut LS	15	0.02	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02
Reuse Tank	11	0.02	0.03	0.01	0.01	0.01	0.02	0.02	0.06	0.10
Crabtree LS	6	0.02	0.01	0.01	0.02	0.02	0.02	0.03	0.03	0.03
State Street	12	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02
NCSU	5	0.03	0.01	0.01	0.02	0.04	0.04	0.04	0.04	0.04

[1] Minimum Detection Limit of 0.01 mg/L.

Table 10. Summary of Sulfate Concentrations and Quartile Analysis for Off-Site Reuse Distribution System

SO_4 (mg/L)										
Site	Data Points	Mean	Std. Dev.	Min	25%ile	50%ile	75%ile	90%ile	95%ile	Max
NRRRF	66	70.1	3.8	61.1	68.0	70.4	72.2	73.7	75.5	81.4
Walnut LS	51	74.5	6.2	62.3	71.0	73.9	77.7	81.6	84.5	95.7
Reuse Tank	49	73.6	4.3	60.9	71.0	73.7	76.4	79.2	80.5	81.9
Crabtree LS	51	73.7	3.8	67.1	70.9	73.7	76.2	78.5	80.1	81.5
State Street	48	74.1	5.2	63.5	71.2	74.4	77.5	80.1	81.2	93.1
NCSU	5	73.0	1.1	71.4	72.5	73.2	73.4	74.0	74.2	74.5

Table 11. Summary of Total Phosphate Concentrations and Quartile Analysis for Off-Site Reuse Distribution System

Total PO_4 (mg/L as P)										
Site	Data Points	Average	Std. Dev.	Min	25%ile	50%ile	75%ile	90%ile	95%ile	Max
NRRRF	82	1.65	0.71	0.44	1.15	1.60	2.09	2.54	2.94	3.80
Walnut LS	51	1.79	0.74	0.57	1.23	1.59	2.41	2.56	3.05	3.94
Reuse Tank	49	1.79	0.59	0.58	1.34	1.82	2.23	2.54	2.82	2.93
Crabtree LS	50	1.84	0.69	0.71	1.28	1.85	2.31	2.76	3.06	3.40
State St.	47	1.61	0.55	0.73	1.24	1.42	2.01	2.37	2.71	2.98
NCSU	4	1.33	0.09	1.22	1.28	1.34	1.38	1.41	1.41	1.42

3.7 Metals

CORPUD monitors barium, cadmium, chromium, copper, lead, molybdenum, nickel, zinc, calcium, sodium, magnesium and potassium in the treated effluent at the NRRRF. In addition to these metals aluminum, iron and manganese are also monitored at various sampling locations in the off-site reuse distribution system. The concentration of heavy metals (barium, cadmium, chromium, copper, lead, and molybdenum) have been below the respective detection limits in the NRRRF treated effluent and hence do not pose any concern. A summary of iron and manganese data for the off-site reuse distribution system is presented in **Table 12** and **Table 13**, respectively. No significant variation in the average iron and manganese levels in the reuse distribution system are observed, however the maximum concentrations at the Walnut LS and at the reuse tank were high.

Table 12. Summary of Iron Concentrations and Quartile Analysis for Off-Site Reuse Distribution System

Iron (mg/L)										
Site	Data Points	Mean	Std. Dev.	Min	25%ile	50%ile	75%ile	90%ile	95%ile	Max
NRRRF	0	-	-	-	-	-	-	-	-	-
Walnut LS	40	0.12	0.07	0.05	0.08	0.10	0.15	0.22	0.27	0.35
Reuse Tank	40	0.16	0.26	0.06	0.08	0.09	0.11	0.29	0.41	1.42
Crabtree LS	40	0.18	0.16	0.06	0.10	0.14	0.19	0.32	0.35	1.01
State Street	37	0.10	0.03	0.06	0.08	0.09	0.11	0.14	0.15	0.24
NCSU	1	0.07	-	-	-	-	-	-	-	-

Table 13. Summary of Manganese Concentrations and Quartile Analysis for Off-Site Reuse Distribution System

Manganese (mg/L)										
Site	Data Points	Mean	Std. Dev.	Min	25%ile	50%ile	75%ile	90%ile	95%ile	Max
NRRRF	0	-	-	-	-	-	-	-	-	-
Walnut LS	40	0.11	0.06	0.04	0.07	0.09	0.14	0.19	0.22	0.26
Reuse Tank	40	0.14	0.20	0.05	0.07	0.08	0.10	0.16	0.67	1.03
Crabtree LS	40	0.19	0.19	0.03	0.08	0.13	0.20	0.32	0.55	1.04
State Street	37	0.11	0.13	0.02	0.05	0.08	0.10	0.16	0.23	0.79
NCSU	1	0.02	-	-	-	-	-	-	-	-

3.8 Nitrification

Nitrification is a two-step process with ammonia being initially oxidized to nitrite and then ultimately nitrate via microbiological processes. Chemical reactions that take place during nitrification are:

$$4NH_4^+ + 3O_2 \longrightarrow 2NO_2^- + 4H^+ + 2H_2O \text{ ....1}$$

$$2NO_2^- + H_2O \longrightarrow 2NO_3^- \text{ ....2}$$

Nitrification can have the adverse impacts of increasing nitrite and nitrate levels, reducing alkalinity, pH, dissolved oxygen, and disinfectant residuals, and promoting bacterial regrowth. **Figure 6** and **Figure 7** present the variation of nitrification monitoring parameters in the treated effluent at NRRRF for the off-site reuse system and at the reuse tank, respectively. No correlation is observed between nitrate-N concentrations with pH and alkalinity at the NRRRF, suggesting that nitrification is not an issue in the treated effluent though it may occur at the reuse tank and system extremities. Comparison of the two charts shows that marginally lower pH values are observed at the reuse tank. During the summer of 2015, a slight decrease in pH was accompanied with a small decrease in the total chlorine residuals and increase in the concentrations of nitrate-N. This indicates nitrification activity in the tank.

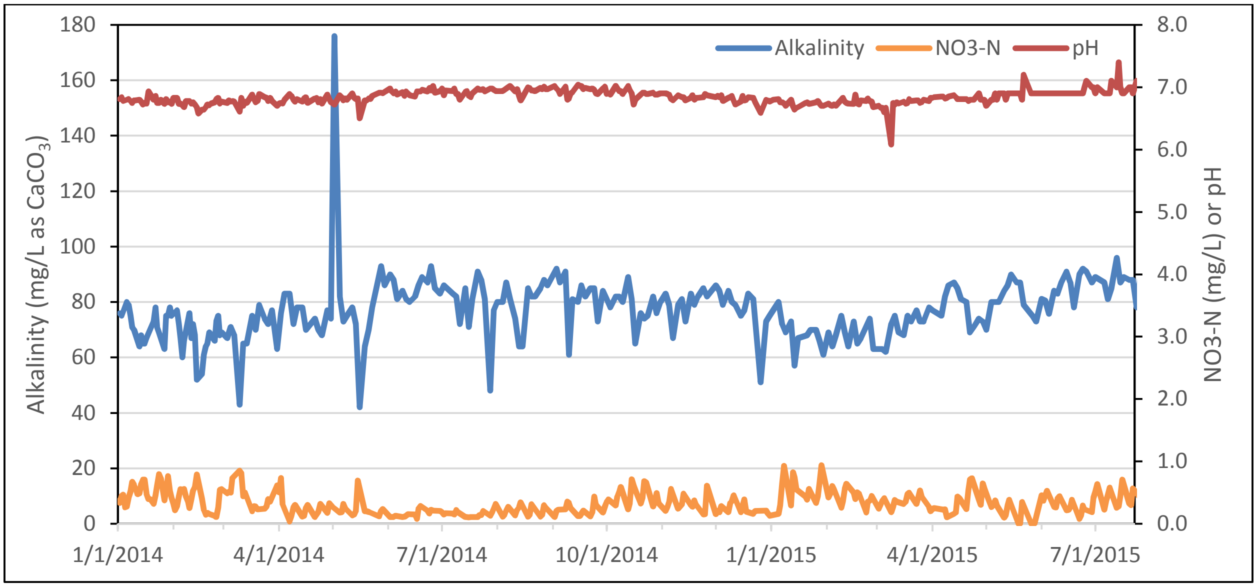


Figure 6. Evaluation of Nitrification Parameters in Treated Effluent at NRRRF for Off-Site Reuse System

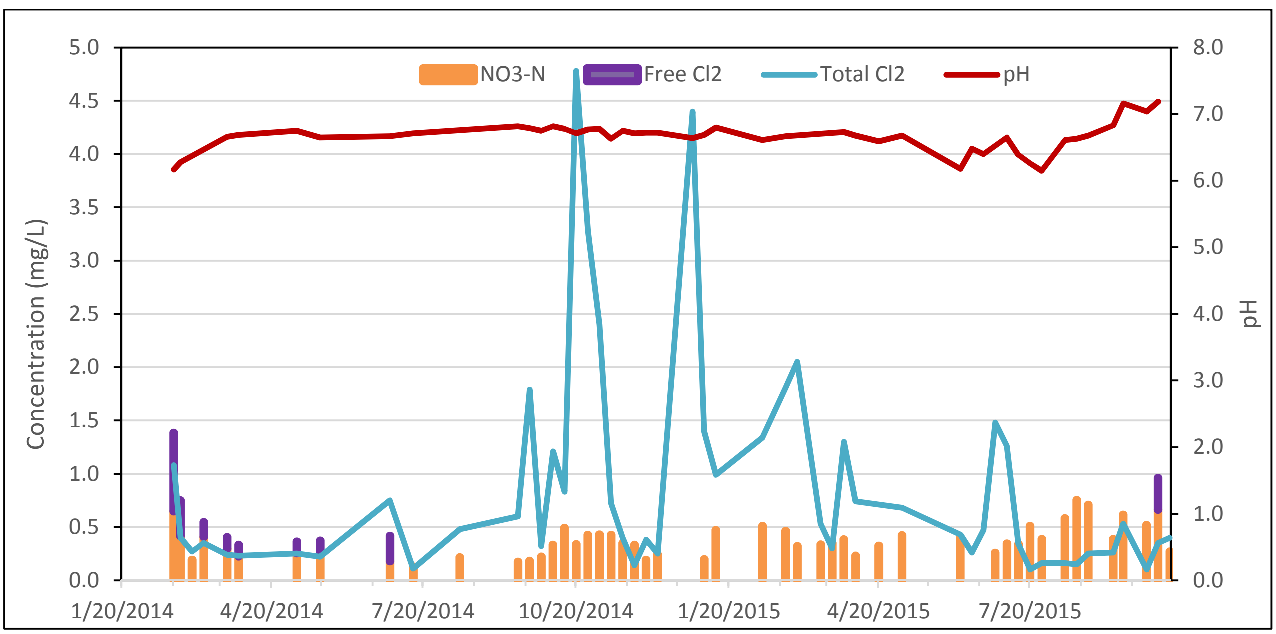


Figure 7. Evaluation of Nitrification Parameters at Reuse Tank

3.9 Microbial Analysis from Reuse Tank Cleaning

CORPUD has contracted with Utility Service Group to clean the Sunnybrook reuse tank. The waste sample from tank cleaning conducted in February 2014 was analyzed to enumerate accumulated biomass and to identify potential mineral induced fouling issues. A copy of the test report is attached under **Appendix B**. The report identified:

- Extremely high bacterial population (approximately 50 million cells/ mL) and likely slime accumulation.
- Excessive presence of sulfur reducing bacteria (SRB). Since these bacteria are killed by exposure to atmospheric oxygen, the environmental niches most frequently occupied by these bacteria are anaerobic, indicating stratification issues in the tank. The SRBs are most notable for the production of hydrogen sulfide as an end product, which has a rotten egg smell.
- Moderate number of protozoans which can be parasitic/ pathogenic, e.g., *Giardia*/ *Cryptosporidium* are some of the protozoans that fall under this category. However, the report did not identify the protozoan type.
- Small number of sulfur oxidizing bacteria typically found in activated sludge (*Thiothrix*), potentially a carryover from the activated sludge secondary treatment at the NRRRF.
- High concentrations of iron and manganese deposits on tank wall.

Due to extended detention times and low chlorine residuals in the tank influent, bio-fouling seems to be a major issue. The longer the detention time in the tank, the greater the potential for the decay of residual disinfectant and microbial regrowth. Section 4 presents results from the water age modeling, confirming that the current detention times in the tank are excessive from a water quality perspective.

3.10 Cooling Tower Water Quality Analysis

A study was recently conducted to evaluate the use of CORPUD's reclaimed water for cooling water makeup, specifically at WakeMed. A copy of the June 2014 report by Arthur Freedman Associates, Inc. is included in **Appendix C**. The report generally concluded that CORPUD's reclaimed water is a good quality, medium hardness water for use in cooling towers. However, tricalcium phosphate scaling will be a serious problem at pH levels above 8 and 5 cycles of concentration or higher. WakeMed recently installed a sulfuric acid feed system to control reclaimed water pH and minimize calcium carbonate scaling in the cooling towers.

3.11 Water Quality Data Summary

Review of the historical water quality data for the off-site reuse distribution system indicates the following:

- The pH in the reuse system samples generally varied from 6.1 mg/L to 7.4 mg/L, and the alkalinity ranged between 42 and 176 mg/L with increasing alkalinity between the NRRRF and system extremities.
- In general, turbidity increased at the lift station sampling points, potentially related to flow changes disturbing sediments or due to accumulation of sediments and biogrowth.
- The average ammonia-N levels in the treated effluent are relatively low, indicating the reliability of operations at the facility.
- Chlorine residuals fall sharply in the reuse distribution system.
- It is unlikely that the depletion of chlorine residuals is primarily due to reaction with ammonia-N. The rapid loss of chlorine residuals could potentially be the result of high reactivity of free chlorine, poor mixing, process not having reached steady state with reactions between chlorine and organic carbon/nitrogen and other chlorine demand, hypo decomposition in the storage tanks, or high chlorine consumption of the reuse water.
- No significant variation was observed in the average nutrient concentrations at sampling locations in the reuse distribution system.
- No significant variation in the average iron and manganese levels in the reuse distribution system are observed, however the maximum concentrations at the Walnut LS and at the reuse tank were high (above 1.0 mg/L).
- Data collected during the summer of 2015 indicates nitrification activity in the reuse tank.
- Due to extended detention times and low chlorine residuals in the reuse tank influent, bio-fouling within the reuse tank seems to be a major issue.

4.0 Water Age Modeling

Time-of-travel simulations were performed using the Innovyze InfoWater hydraulic model of the reuse system to assess water age and storage tank turnover in the distribution system. Modeling of water age or travel time is a cursory analysis to flag potential water quality issues. Water age is a primary factor that influences a system's ability to maintain disinfection residuals. As water age increases, disinfection residual tends to decrease. Similarly, areas of high water age may also indicate an increased likelihood for nitrification, microbial regrowth, or other water quality issues.

Model simulations were run for summer average day demand and winter average day demand scenarios for the existing customers and with future Centennial Campus demands and Lonnie Poole Golf Course demands. Typical seasonal operations of the reuse system were simulated in the model. The full reuse tank volume is not used during off-peak demand periods. Per discussions with CORPUD staff, the high service pumps were controlled to cycle the Sunnybrook reuse tank between approximately 30 to 55 percent full for winter demand scenarios. For the summer demand scenario, the high service pumps were controlled to cycle the reuse tank between approximately 70 to 100 percent full. The water age simulations were run for a duration of 1,000 hours at a 1-hour hydraulic time step to ensure full turnover of all tanks. The average water age at each model node was determined using the final 24 hours of the model simulation. Average water age represents the travel time from the NRRRF through the system.

In addition to water age simulations, the source tracing function of the model was used to determine the extent of influence of water from the reuse tank within the distribution system. The following paragraphs describe the model results for existing customers, existing customers plus Centennial Campus, and existing customers plus Centennial Campus and Lonnie Poole Golf Course.

4.1 Existing Customer Demand Scenarios

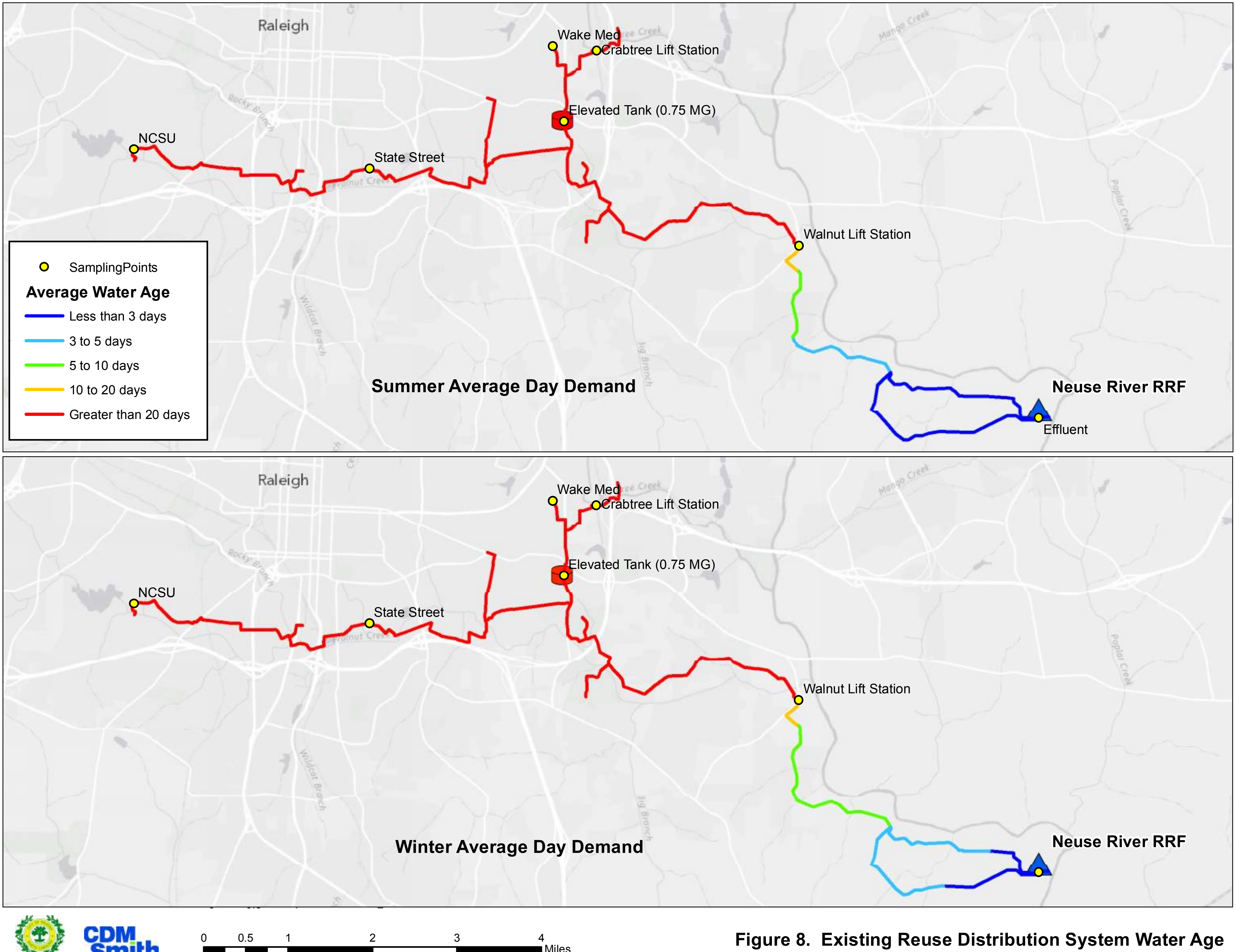
Figure 8 shows the modeled pipes color-coded by average water age for the winter and summer scenarios with existing customer demands (see Table 1). For both scenarios the water age is very high (greater than 20 days) in most of the system due to the low demands relative to the size of the reuse tank and lack of demand on the system west of the Raleigh Country Club. Water from the reuse tank is meeting all of the system demands downstream from the Walnut lift station. Loss of disinfectant residual and deterioration of water quality are not surprising with such high water age. The model shows that the water age is significantly lower if the reuse tank is removed from service in the winter, however, the reuse pumps cannot operate effectively for an extended period of time with the tank out of service.

4.2 Centennial Campus Demand Scenarios

Figure 9 shows the modeled pipes color-coded by average water age for the winter and summer scenarios with existing customer demands plus the NCSU Centennial Campus demand (see Table 1). The winter scenario is similar to existing, with excessive water age (greater than 20 days) in the majority of the system and the reuse tank. However, the summer average demand is increased significantly at the end of the distribution system with the addition of Centennial Campus, which pulls water from the reuse tank and reduces the overall system water age. With Centennial Campus summer demands, the average water age in the distribution system upstream of the tank is less than 5 days. Average water age downstream of the tank is less than 10 days. The average age in the reuse tank, assuming complete mixing, is just over 10 days. Without complete mixing, the tank water age could be significantly higher is some zones of the tank. Water from the reuse tank is meeting the majority of the demands north of the tank and approximately 25 percent of the demand to the west of the tank location. Therefore, the addition of Centennial Campus should help lessen water quality issues in the summer.

4.3 Centennial Campus and Lonnie Poole Golf Course Demand Scenarios

Figure 10 shows the modeled pipes color-coded by average water age for the winter and summer scenarios with existing customer demands plus the NCSU Centennial Campus and Lonnie Poole Golf Course demands (see Table 1). Since the golf course demand for irrigation is primarily in the summer months, the winter scenario is similar to that with just Centennial Campus demands (Figure 9). Summer average water age is further reduced in the distribution system with the



CDM Smith

Figure 8. Existing Reuse Distribution System Water Age

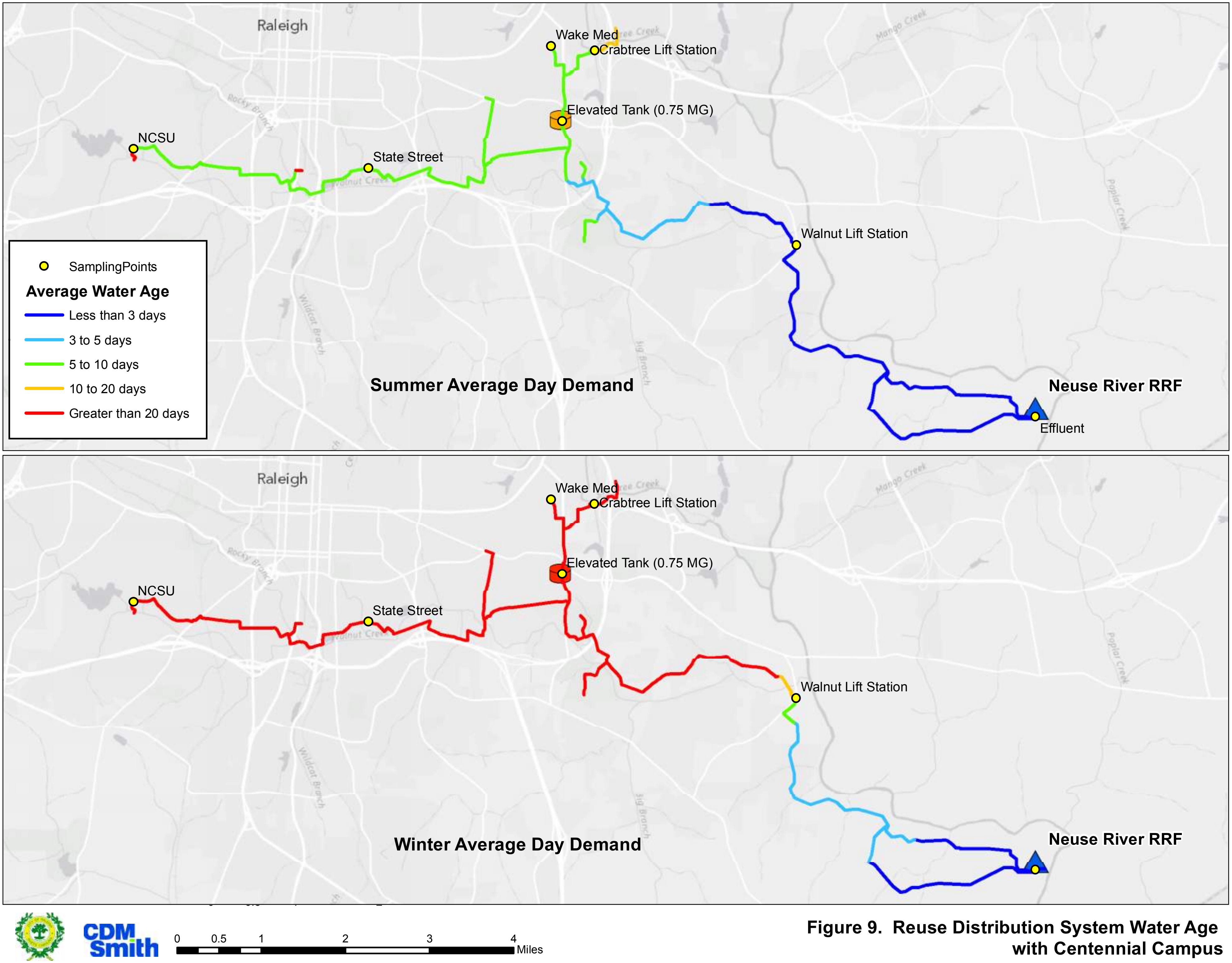


Figure 9. Reuse Distribution System Water Age with Centennial Campus

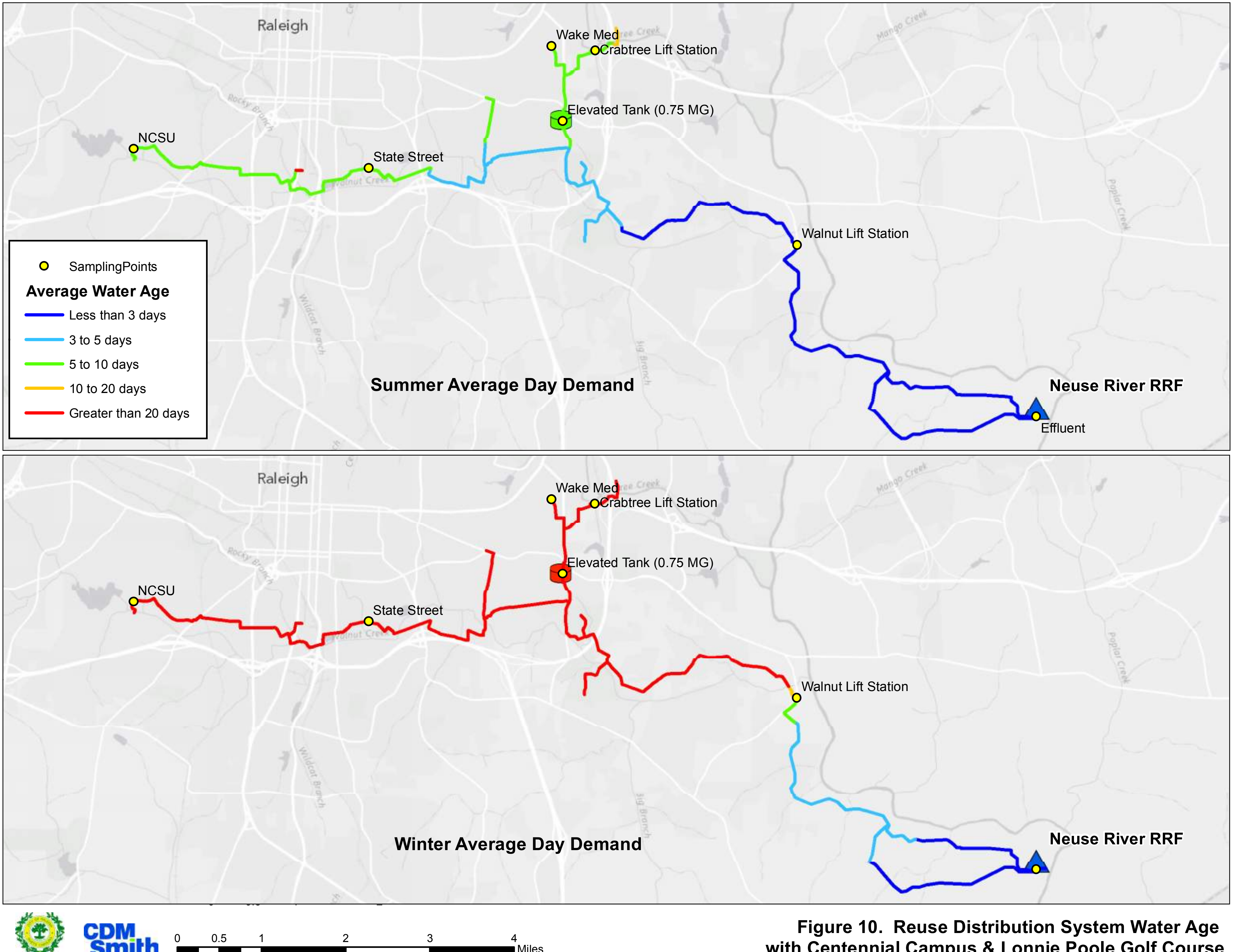


Figure 10. Reuse Distribution System Water Age with Centennial Campus & Lonnie Poole Golf Course

additional irrigation demand from the golf course. The average age in the reuse tank, assuming complete mixing, is approximately 8 days.

4.4 Water Age Summary

Results of the water age modeling indicate excessive water age (greater than 20 days) in the reuse tank and most of the reuse distribution system for both existing winter and summer demand scenarios due to the low existing demands relative to the size of the reuse tank and lack of demand on the system west of the Raleigh Country Club.

As demands from Centennial Campus are added to the far end of the reuse distribution system, additional water is used from the reuse tank and the overall system water age is reduced. Water age for the winter scenario with Centennial Campus is still excessive in the majority of the distribution system and reuse tank. However, for summer demands, the average water age in the distribution system upstream of the tank is reduced to less than 5 days and average water age downstream of the tank is reduced to less than 10 days. Therefore, the addition of Centennial Campus should help lessen water quality issues in the summer.

Addition of the Lonnie Poole Golf Course irrigation demand further decreases overall system water age for the summer demand scenario, but does not have an impact on the winter demand scenario.

5.0 Water Quality Improvement Alternatives

After review of the existing hypo feed system configuration, reuse distribution system water quality data, and water age modeling, several alternatives were considered to improve the water age, water quality, and disinfection residual in the reuse distribution system.

5.1 General Considerations

The following are items to consider for improving water quality in the reuse distribution system. Specific improvement alternatives for CORPUD's off-site reuse facilities are presented in Sections 5.2 through 5.7.

Improve Process Monitoring and Determine Efficiency of Mixing at Existing Hypo Feed Location

As discussed in Section 2, the existing hypo facilities feed multiple injection points for the on-site system, on-site high pressure irrigation system, and off-site reuse system. There is no on-line monitoring for the hypo feed to the off-site wet well or residual analyzer for the off-site reuse system. Improvements to process monitoring and control, including adding a flowmeter on the discharge of hypo metering pump number 5 and residual chlorine analyzer for the off-site reuse system, are recommended to address any discrepancies in the hypo feed rates.

In addition, short-circuiting in the off-site wet-well (where the majority of the off-site hypo dose is currently fed) may lead to insufficient mixing and chlorine contact time. Tracer testing or CFD modeling is recommended to confirm the efficiency of chlorine mixing in the wet well.

Lower Oxidant Demand

Disinfection cannot proceed until the system oxidant demand is met. It is necessary to satisfy the chlorine demand of the water in order to have free available chlorine for disinfection. Although UV disinfection is used for treated effluent at the NRRRF, UV disinfection does not satisfy the oxidant demand. Options to lower the oxidant demand before final disinfection include:

- Optimize organics removal in the treated effluent using granular activated carbon (GAC) bio-filters with or without ozone, reverse osmosis (RO), or partial RO. Ozone being a strong oxidant oxidizes the organics to biodegradable dissolved organic carbon, which is broken down by the biologically active GAC filters. Chemical oxygen reductions of 20 to 30 percent have been observed with 25 minutes of contact time using GAC bio-filters without ozone. The percent reduction increases when GAC bio-filters are used with ozone.
- Practice breakpoint chlorination followed by chlorination/ chloramination. At breakpoint chlorination, inorganics (iron, manganese, free ammonia) and organics are oxidized and a long lasting free chlorine residual begins to persist. Breakpoint chlorination will also prevent ammonia peaks from entering the distribution system, in the event of an upstream operational upset.

Improve Biological Stability of Treated Effluent

Improving "biological stability" of treated effluent prior to distribution will assist in controlling microbial growth in the reuse distribution system. This can be accomplished in several ways:

- Removing additional nutrients (nitrogen, phosphorous, organic carbon) from the water prior to distribution. The treated effluent at the NRRRF has low average free ammonia levels (0.17±0.06 mg/L as N). It is recommended that CORPUD continue optimizing operations to achieve low free ammonia levels at all times. Adding a tertiary filtration step upstream of the wet well for the off-site system could help in improving phosphorus removal. A pilot testing could be conducted to evaluate the performance of cloth media filtration. The cost for piloting will be approximately $25,000 to $30,000. Details for the pilot unit are attached under **Appendix D**.
- Maintaining a disinfectant residual in the treated effluent.
- Combining additional filtration and disinfectant residual maintenance.
- Adding other growth inhibitors such as chlorite.

Increase Chlorine Residuals in Treated Effluent

Target chlorine residuals for the distribution system sample sites to be between 2 mg/L and 4 mg/L. This can be achieved by increasing the hypo dose at the NRRRF to carry higher free chlorine residuals to the reuse tank and if necessary add booster disinfection at the reuse tank as discussed in Section 5.7.

To practice breakpoint chlorination at the NRRRF and carry a free chlorine residual to the reuse tank, hypo feed at the NRRRF should account for the following:

- Weight ratios of 8:1 for chlorine to TKN. Bench-scale tests should be conducted to determine the chlorine demand and breakpoint chlorine dosages. The effect of seasonal variation on disinfectant demand should also be evaluated. Since the bench tests cannot duplicate distribution system conditions, use a safety factor of at least 2 for determining chlorine doses.
- Dissolved organic carbon (DOC) in the NRRRF effluent. Considering no DOC data is available for the treated effluent at NRRRF, CORPUD should monitor DOC in the effluent from NRRRF.
- Loss of free chlorine residuals in transit between NRRRF and the reuse tank. Per Table 7, an average of 1.5 mg/L free chlorine is lost between the Walnut LS and the reuse tank. Since no free chlorine data is available in the effluent for NRRRF, loss of free chlorine residuals in transit from NRRRF to the Walnut LS cannot be calculated. Therefore free chlorine residuals should be monitored in the effluent from NRRRF. In addition, conduct bench-scale tests to determine the disinfection decay curves at alternate temperatures for the treated effluent at the NRRRF.
- Target free chlorine residual of 1 mg/L at a minimum in the reuse tank influent.

Improve System Hydraulics

Adding recirculation and mixing system in the reuse tank will limit short-circuiting and assist in improving water quality. Retrofitting the reuse tank with separate inlet and outlet will also improve the general water quality. Installation of a mixing system in the Sunnybrook reuse tank is a possible option to eliminate thermal stratification. If system hydraulics allow, increase the drawdown level of the tank. Additionally, looping of dead ends and adding auto flushers in areas of low flow and high residence time will lower overall system residence time.

Limit Biological Growth in Distribution System

Microorganisms can grow either in the water column or as biofilm on pipe surfaces or tank walls. The aggregation of cells in the biofilms increases the resistance to disinfection. Therefore, it is important to limit biological growth in the distribution systems to improve water quality. Options include:

- Add booster disinfection in the distribution system to improve disinfectant residuals.
- Perform chlorine burn of the system to clean the existing biofilm. In the beginning, consider performing chlorine burns bi-annually. With regular burnouts, system demand is expected to decrease over time and frequency can then be lowered to once every year. Chlorine burn should be performed using high chlorine doses at the NRRRF so that consistent free chlorine residuals of 0.5 mg/L at a minimum are observed at system extremities.
- Provide corrosion protection of pipes in the distribution system since corrosion leads to tubercles and other deposits that can harbor microbes.

5.2 Alternative 1 – Chlorine Feed/ Monitoring Improvements

TKN in the reuse water exerts a major chlorine demand, not just free ammonia-N. Therefore, considering the average historical TKN in the NRRRF effluent of 0.99±0.26 mg/L and the weight ratios for chlorine to TKN of 8 to 1, at least 8.0 mg/L of hypo is needed to breakpoint (oxidize or overcome) the chlorine demand of the TKN in the reuse water in order to produce a free chlorine residual. The actual chlorine demand is probably higher due to the demand exerted by organic carbon. Based on this, the hypo doses as calculated in Table 2 are low. So, the recent hypo dose of 13 to 15 mg/L for the off-site reuse system, as indicated by the CORPUD staff, seems more likely.

To provide direct confirmation of hypo feed rates to the off-site system, it is recommended that a flowmeter be added on the discharge of hypo metering pump number 5. Further, total chlorine and free chlorine residual analyzers for the off-site system should be installed to provide direct confirmation of the chlorine residual leaving the NRRRF site. This additional monitoring will assist with making process and chemical feed adjustments, as necessary, to confirm an adequate chlorine residual leaving the NRRRF site and quantify residual loss downstream in the reuse distribution system.

In addition, tracer testing or CFD modeling is recommended to confirm the efficiency of hypo mixing and detention time in the off-site wet well. If the testing shows short circuiting in the wet well, a mixing system, such as a Chlor-A-Vac or similar mixing device should be added to improve mixing of chemicals in the wet well. Alternately, CORPUD should consider relocating the hypo feed point to the 36-inch reuse influent line between the junction box and the wet well, as described in Alternative 4.

5.3 Alternative 2 – Change Disinfectant Type

Chlorine disinfection is the most commonly used disinfection method. Free chlorine and combined chlorine are the two most common forms of chlorine disinfection. The total chlorine residual includes monochloramine, dichloroamine, and trichloroamine. When adding free chlorine to ammonia containing water, the amount and composition of the chlorine residual depends on the chlorine-to-ammonia-N ratio, which increases as more chlorine is added.

Table 14 presents a comparison of free and combined chlorine as disinfectants in terms of potential for creation of chemical byproducts, residual disinfectant stability, capital and operational cost, upstream treatment requirements, and operational considerations.

Table 14. Comparison of Free Chlorine and Combined Chlorine for Disinfection

Parameters	Disinfectant Type	
	Free Chlorine	Combined Chlorine
Residual Stability	Low	More stable; provides better protection against regrowth in the system
Chemical Byproducts	THMs, HAAs; could pose problem for indirect or direct potable water reuse	Lower THMs, HAAs
Capital and Operating Costs	Low	
Treatment Requirement	No change in current operations	Ammonia storage and feed required
Operational Considerations		More effective in controlling biofilms
		Increases potential for nitrification due to presence of free ammonia
		Annual or bi-annual chlorine burn is recommended to address regrowth issues

In addition to free chlorine and combined chlorine, alternate disinfectant types include chlorine dioxide, ozone, and UV. Chlorine dioxide can meet some of the oxidant demand and help inhibit regrowth, however, it forms chlorite and chlorate ions as byproducts. UV disinfection is already practiced at the NRRRF. Because ozone and UV do not provide a residual in the reuse distribution system, chlorine needs to be added downstream of disinfection facility to provide supplemental disinfection.

Alternative 2 includes a switch from free chlorine to combined chlorine disinfection for CORPUD's off-site reuse system at the NRRRF. This can be achieved with or without resorting to breakpoint chlorination prior to the switch. Alternative 2 discusses the switch to combined chlorine without breakpoint chlorination. The option to switch to combined chlorine with breakpoint chlorination is discussed in Section 5.4. The design reclaimed water flow rates for the combined chlorine disinfection for the off-site system at the NRRRF are presented in **Table 15**.

Table 15. Design Reclaimed Water Flow Rate Ranges for Off-Site System at NRRRF

	Design Reclaimed Water Flow Rates (mgd)		
	Min[1]	Average[2]	Max[3]
Existing System	0.35	0.87	1.96
With Centennial Campus	0.37	1.19	3.41
With Centennial Campus and Lonnie Poole Golf Course	0.40	1.22	3.45

[1] Winter average demand (November to April); flows at tank averaged over 24-hour period
[2] Summer average demand (May to October); flows at tank averaged over 24-hour period
[3] Peak hour flows

Combined chlorine, also referred to as chloramines, is free chlorine combined with ammonia or other nitrogen containing organic substances. When using combined chlorine, a 19 percent ammonium hydroxide solution will be added to form monochloramines. As an alternate to ammonium hydroxide, ammonium sulfate (10 percent) can be used in dry or liquid form. Ammonium sulfate eliminates dealing with odor issues and has been used for small systems. However, preliminary sizing is based on using ammonium hydroxide solution.

For drinking water applications using chloramines, a chlorine to ammonia-N ratio of 4:1 is used. In reclaimed water, due to the presence of residual organic nitrogen, which will exert chlorine demand and form organic chloramines, a ratio of 4.5 to 1 is preferred. The hypo dose is driven by the TKN concentration and the DOC in the treated effluent from NRRRF. The average TKN concentration of 0.99 ± 0.26 mg/L was used and DOC of 2 mg/L to 4 mg/L was assumed for sizing hypo storage and feed facilities. Assuming the required monochloramine residual of 4 mg/L to 6 mg/L, the ammonia-N concentrations will require between 5.3 mg/L to 9.6 mg/L free chlorine, given the 4.5:1 chlorine to ammonia dosing requirements. **Table 16** details the range for chemicals that the metering pumps should have for reuse flow rates as presented in Table 15. A 12.5 percent hypo solution deteriorates rapidly at temperatures above 70^{o}F so long term storage at this strength is not recommended. Shelf life can be extended to several months by diluting to 6 percent. Hence it is recommended that bulk chlorine supplied in the form of 12.5 percent hypo solution should be diluted to approximately 6 percent.

Table 16. Design Chemical Doses for Switch to Combined Chlorine Disinfection for Off-Site Reuse System at NRRRF (Chlorine to Ammonia Ratio of 4.5 to 1, Without Breakpoint Chlorination)

Chemical	Solution Strength (%)	Dosages (mg/L)		
		Min	Average	Max
Hypo	6	5.3	7.5	9.6
Ammonium Hydroxide	19	0.9	1.1	1.3

Table 17 presents the chemical flow rates calculated based on expected reclaimed water flow rates and chemical doses for the off-site system. Considering the existing hypo metering pumps are 61.8 gph each, no upgrades to the metering pumps is required.

Table 17. Design Chemical Flow Rates for Switch to Combined Chlorine Disinfection for Off-Site System at NRRRF (Chlorine to Ammonia Ratio of 4.5 to 1, Without Breakpoint Chlorination))

	Chemical Flow Rates (gph)		
	Min	Average	Max
Hypo (6% solution)			
Existing System	1.2	4.0	11.8
With Centennial Campus	1.2	5.5	20.5
With Centennial Campus and Lonnie Poole Golf Course	1.3	5.7	20.7
Ammonium Hydroxide (19% solution)			
Existing System	0.1	0.2	0.6
With Centennial Campus	0.1	0.3	1.1
With Centennial Campus and Lonnie Poole Golf Course	0.1	0.3	1.1

Table 18 presents the minimum usable volumes for 30 days of storage at average flow and dose that each storage tank will have for chemicals. When Centennial Campus and Lonnie Pool Golf Couse are connected to the reuse system, monthly required storage for hypo for the off-site system will be approximately 4,100 gallons. Considering the hypo consumption for the off-site system accounts for most of the hypo usage at the NRRRF, with (2)-10,000 gallon existing hypo tanks, no additional storage volume is recommended. Ammonium hydroxide can be supplied in 300 gallon totes or stored on-site using mini bulk tanks with secondary containment and chemical metering pumps. When using 19 percent solution, a pressurized tank would not be required and there are mini bulk loading companies that can provide a minimum delivery of 350 gallons. Considering approximately one-300 gallon tote will be required per month to meet existing, Centennial Campus and Lonnie Pool Golf Course demands during summer, totes may be considered for on-site storage.

Table 18. Bulk Storage Tank Volumes Required for Switch to Combined Chlorine for Disinfection for Off-Site System at NRRRF (Without Breakpoint Chlorination)

	Chemical	Tank Material	30 Day Storage Volume (gal)[1,2]
Sodium Hypochlorite (6% solution)			
Existing System	Liquid	Fiberglass	2,900
With Centennial Campus	Liquid	Fiberglass	4,000
With Centennial Campus and Lonnie Poole Golf Course	Liquid	Fiberglass	4,100
Ammonium Hydroxide (19% solution)			
Existing System	Liquid	Steel Tank or Totes	160
With Centennial Campus	Liquid	Steel Tank or Totes	230
With Centennial Campus and Lonnie Poole Golf Course	Liquid	Steel Tank or Totes	230

[1] At average flow and dose
[2] Rounded off to the nearest hundred for hypo and to the nearest ten for ammonium hydroxide

Space Requirements and Other Considerations

A building size of approximately 12-feet x 10-feet is proposed for housing the ammonium hydroxide feed and storage. The building will house totes for ammonium hydroxide, metering pumps, piping, and appurtenances.

Since mixing and contact time are important factors for sufficient disinfection with combined chlorine, the Alternative 4 relocation of chlorine feed (discussed in Section 5.5) should also be implemented with the switch to combined chlorine.

5.4 Alternative 3 – Practice Breakpoint Chlorination and Switch to Combined Chlorine

As discussed in Section 5.1, oxidation of organics, inorganics and nitrogen compounds occurs at breakpoint chlorination and persistent free chlorine residual is observed beyond breakpoint. This section presents the sizing of hypo storage and feed facility if breakpoint chlorination is practiced and the switch to combined chlorine is made at the NRRRF. This option will not affect the sizing of ammonium hydroxide feed and storage from Alternative 2.

Assuming a monochloramine residual of 4 mg/L to 6 mg/L, a ratio of 8:1 for chlorine to TKN, an average TKN concentration of 0.99±0.26 mg/L and assuming DOC of 2 mg/L to 4 mg/L in the treated effluent from NRRRF, **Table 19** details the range for hypo that the metering pumps should have for reclaimed water flow rates as presented in Table 15. The ammonium hydroxide design doses are the same as those listed in Table 16 for Alternative 2. Bench-testing should be performed to determine the specific chlorine to TKN ratio to achieve breakpoint chlorination for the CORPUD reuse water and DOC should be monitored in the effluent from NRRRF.

Table 19. Disinfectant Dosages for Breakpoint Chlorination Disinfection at NRRRF

Chemical	Solution Strength (%)	Dosages (mg/L)		
		Min	Average	Max
Hypo	6	7.8	10.9	14.0

Table 20 presents the hypo flow rates calculated based on reclaimed water flow rates and chemical doses presented in Tables 15 and 19, respectively. Considering the existing hypo metering pumps are 61.8 gph each, no upgrades to the metering pumps are required for the existing system. The ammonium hydroxide design chemical flow rates are the same as those listed in Table 17 for Alternative 2.

Table 20. Design Hypo Flow Rates for Breakpoint Chlorination Disinfection at NRRRF

	6% Hypo Flow Rates (gph)		
	Min	Average	Max
Existing System	1.7	5.9	17.1
With Centennial Campus	1.8	8.1	29.8
With Centennial Campus and Lonnie Poole Golf Course	2.0	8.3	30.1

Table 21 presents the minimum usable volumes for 30 days of storage at average flow and dose for hypo for practicing breakpoint chlorination for the off-site system at NRRRF. When Centennial Campus and Lonnie Pool Golf Couse are connected to the reuse system, monthly required storage for hypo for the off-site system will be approximately 6,000 gallons. Considering the hypo consumption for the off-site system accounts for bulk of the hypo usage at the NRRRF, with (2)-10,000 gallon existing hypo tanks, no additional hypo storage volume is recommended. The recommendations for ammonium hydroxide storage are the same as those listed in Table 18 for Alternative 2.

Table 21. 30-Day Storage for Bulk Storage Tank Volumes for Hypo for Breakpoint Chlorination for Off-Site Reuse System at NRRRF

	Chemical	Tank Material	30 Day Storage Volume (gal)[1,2,3]
Existing System	Liquid	Fiberglass	4,300
With Centennial Campus	Liquid	Fiberglass	5,800
With Centennial Campus and Lonnie Poole Golf Course	Liquid	Fiberglass	6,000

[1] At average flow and dose
[2] For 6 percent hypo
[3] Rounded off to the nearest hundred

Space Requirements and Other Considerations

Since existing hypo bulk tanks and metering pumps can meet the increased storage volume and pumping flow rates, respectively, no additional space needs allotted beyond that given for ammonium hydroxide storage as listed under Alternative 2.

Since mixing and contact time are important factors for sufficient disinfection with combined chlorine, the Alternative 4 relocation of chlorine feed (discussed in Section 5.5) should also be implemented with the switch to combined chlorine and practice of breakpoint chlorination.

5.5 Alternative 4 - Relocation of Chlorine Feed

As discussed in Section 2.1, chlorine is fed at the off-site wet well and at the downstream hypochlorite injection vault 1. Relocation of the hypo feed points at both locations is proposed as discussed below.

Off-Site Wet Well

The potential for short circuiting in the off-site wet well, as discussed in Section 2.2, should be investigated and confirmed with tracer testing. If short circuiting is occurring, relocating the hypo feed point from the off-site wet well is recommended. A ground storage tank at the NRRRF was considered for this purpose. However, preliminary model runs with estimated future system demands for the Centennial Campus and Lonnie Poole Golf Course indicate that maximum day system operations can be met with two off-site reuse pumps running and additional storage should not be required at the NRRRF for reclaimed water supply. Addition of a ground storage tank would contribute to system detention time and water age with minimal benefit. Therefore addition of a ground storage tank upstream of the off-site reuse pumping station to improve the disinfectant mixing and contact time is not recommended.

Instead of a ground storage tank, it is proposed that hypo should be fed in the 36-inch reuse influent line between the junction box and the off-site wet well. If the switch to combined chlorine is made, ammonium hydroxide will also be added to the 36-inch reuse influent pipe. When hypo is added to reclaimed water, it has the option to react with free ammonia, organic N, and DOC, so some of it will be consumed as a non-monochloramine residual. Therefore, the suggested approach would be to add ammonium hydroxide first so that when hypo is added, formation of monochloramine would be favored. Bench-scale tests should be conducted with 1.33 mg/L ammonia-N and varying doses of hypo (6 mg/L to 10 mg/L) and residual free ammonia. Free and combined chlorine residuals should be monitored at the end of the test.

Manholes will be added on the 36-inch reuse influent line to feed and mix the chemicals. A jet chlorination system (Chlor-A-Vac or similar) could be considered for mixing in the manholes. A flowmeter will be installed upstream of the hypo feed point if using free chlorine or upstream the ammonium hydroxide feed point, if using combined chlorine for flow pacing the chemical feed. On-line analyzers for free ammonia, free chlorine and total chlorine will be added for process monitoring and control. A check valve will be added upstream the hypo feed point to prevent the chlorinated water from back flowing into the junction box when the off-site reuse pumps are not operating.

Hypochlorite Injection Vault 1

The CORPUD staff has reported the hypo feed pipe to the hypochlorite injection vault 1 fails frequently and suspect the high backpressures (100 psi to 120 psi) to be the cause. Pipe failure is observed mainly between the hypochlorite metering vault and the hypochlorite injection vault 1.

The hypo metering pump discharge pipe in the hypo facility and in the vaults is polyvinyl chloride (PVC) and the pipe transitions to high density polyethylene (HDPE) in the yard. The existing drawings show that the transition from PVC to HDPE is made using a flanged connection. HDPE pipe is available in a variety of wall thicknesses. In general, schedule 80, HDPE pipe is recommended for use with hypo solution. The frequent pipe breaks could be attributed to:

- Pressure exceeding the rating of the pipe, either hydraulically from the pumps, or by isolation between closed valves or due to hypo decomposition to form oxygen. Asahi sells HDPE pipe with a SDR11 rating that has a maximum pressure rating of 150 psi. Other vendors have different SDR ratings for higher pressures. The presence of heavy metals and suspended solids in the bulk hypo can affect the rate of decomposition of hypo to oxygen. So confirming the quality of the delivered hypo is recommended.
- Failure of the HDPE pipe joints due to chemical attack on the resin, if used.
- Failure of the pipe joints where the pipe transitions from PVC to HDPE. Solvent joint PVC pipe is not recommended for pressures exceeding 100 psi.
- Improper installation.

Relocation of the chlorine feed to a single point upstream of the wet-well for the off-site reuse system will eliminate the issues with feeding chlorine in the injection vault 1 downstream of the off-site reuse pumps.

5.6 Alternative 5 - Reuse Tank Mixing

Low turnover rate and high water age in the Sunnybrook reuse tank allows thermal stratification, resulting in loss of chlorine residuals, bacteria regrowth, and biofilm growth. Options to eliminate such problems and improve water quality include:

- Separate inlet and outlet pipes.
- Add recirculation pumps to mix the contents of the tank. Since this is a composite tank, the pumps can be located in the enclosed area under the tank bowl. Alternatively, the pumps can be located outside the tank. Under both options, pumps can be readily accessed for inspection and maintenance.
- Add active mixing systems like submersible mixers and solar powered mixers.

Mixing can slow the loss of disinfectant residuals in a tank by mitigating dead zones and thermal stratification. Adequate chlorine residuals in the tank are still needed. In addition, water quality also depends on volume turnover. Without volume turnover, continuous mixing only results in mixing continually aging water. Therefore booster disinfection as discussed in the following paragraphs is recommended. An example system for tank mixing and chlorine residual monitoring is attached under **Appendix E**.

5.7 Alternative 6 - Booster Disinfection in the Distribution System

Non-potable reuse systems such as CORPUD's, where a signification portion of the demand is due to irrigation, face a dilemma of more production than needed in winter months when the irrigation demand is at its lowest. Decrease in reclaimed water demand creates a challenge of maintaining water quality in the system. Addition of booster disinfection station will provide appropriate chemical storage and injection facilities to boost disinfectant concentrations to optimum levels in the distribution system.

Location

Injection of the disinfectant at optimally located booster stations, in addition to the NRRRF, may reduce the total disinfectant dose while maintaining residuals throughout the system. In general, booster disinfection stations should be located in areas of high water age and low disinfectant residuals. As shown in Figure 5, historical average chlorine residuals in the reuse tank have been low. **Figure 11** shows the daily variation of disinfectant residuals for the period January 2014 to October 2015. The chart shows no free chlorine residuals existed for majority of the data period. Even when residuals were detected, they were lower than 0.2 mg/L on an average. The total chlorine residuals were slightly higher, however, the residuals dropped when the temperature increased during the summer months.

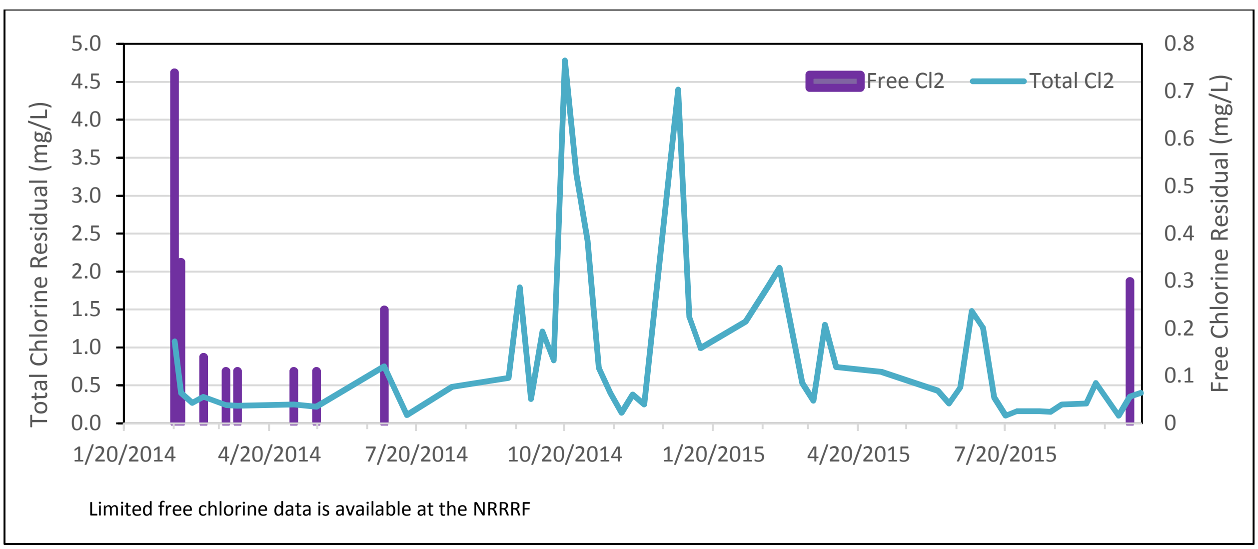


Figure 11: Variation of Disinfectant Residuals at Reuse Tank

Per Figure 9, during the summer average day demand scenario when the Centennial Campus is on-line, the average water age in the reuse tank is approximately 10 days and a portion of the system demand at WakeMed, Crabtree lift station, Raleigh Country Club, and Centennial Campus are met by the reuse tank. Boosting chlorine at the reuse tank will allow treating a large volume of reclaimed water in one place and if combined with tank mixing will provide blending of the chlorine residuals. Therefore, the optimum location of the booster disinfection facility is at the reuse tank. The new booster disinfection facility will house the chemical storage and feed equipment required to boost the disinfectant concentration by adding free chlorine or forming monochloramines. Each option is discussed in the following paragraphs.

Design Criteria

The design flow rates for the booster disinfection facility are presented in **Table 22**.

Table 22. Design Reclaimed Water Flow Rate Ranges for Booster Disinfection Facility at the Reuse Tank

	Design Reclaimed Water Flow Rates (mgd)		
	Min[1]	Average[2]	Max[3]
Existing System	0.23	0.45	1.89
With Centennial Campus	0.28	0.46	1.96
With Centennial Campus and Lonnie Poole Golf Course	0.29	0.48	2.47

[1] Winter average demand (November to April); flows at tank averaged over 24-hour period

[2] Summer average demand (May to October); flows at tank averaged over 24-hour period

[3] Peak hour flows

The sizing of booster disinfection facility will depend on the chlorine demand of the reclaimed water and the system demand. The system demand depends on how much organic matter is in the piping/ tank that will consume chlorine. The tank cleaning report (Appendix B) indicates extensive biofilm growth in the tank. However, the chlorine demand should decrease over time provided regular tank cleaning and annual or bi-annual chlorine burn of the system is practiced. Per CORPUD staff, chlorine doses as high as 13 mg/L to 15 mg/L at the NRRRF have not resulted in measurable free chlorine residuals at the reuse tank. CORPUD conducted chlorine burn of the off-site reuse distribution system for the first time in October 2015 since start-up by dosing 30 mg/L chlorine at the NRRRF. The chlorine burn lasted for 6 hours. CORPUD observed total chlorine residuals of 2.0 mg/L at the reuse tank and 0.6 mg/L at the NCSU location. Therefore it is imperative that chlorine demand for the influent water is established by bench testing.

The booster disinfection using free chlorine is sized for breakpoint chlorination as the worst case scenario using the average historical parameters. Following assumptions are used for sizing hypo storage and feed facility:

- No breakpoint chlorination is practiced at NRRRF. Therefore residual TKN and DOC will be present in the influent to the reuse tank;
- DOC between 0.5 mg/L and 1 mg/L;
- Minimum 1 mg/L free chlorine residual in the influent to the reuse tank;
- Target free chlorine residuals of 2 mg/L to 4 mg/Lin the tank effluent;
- Weight ratios of 8:1 for chlorine to TKN for breakpoint chlorination
- 6 percent concentration for hypo bulk solution

For booster disinfection using combined chlorine, sizing of ammonium hydroxide feed and storage is based on the following assumptions:

- Free chlorine or combined chlorine residuals are used at the NRRRF;
- No breakpoint chlorination is practiced when using free chlorine or prior to the switch to combined chlorine at the NRRRF;
- Residual DOC in the influent to the reuse tank is 0.5 mg/L to 1 mg/L;
- Minimum 1 mg/L combined chlorine residual in the influent to the reuse tank;
- Free ammonia-N concentration of 0.12 mg/L in the influent to the reuse tank;
- Ratio of 4.5 to 1 for chlorine to ammonia-N ratio;
- Target monochloramine residual of 3 mg/L to 5 mg/L in the tank effluent.

Free chlorine residuals in the influent to the reuse tank should be monitored to determine the amount of additional hypo to be added to meet the target free chlorine residuals in the tank effluent. If switch to combined chlorine residual is made at the NRRRF and combined chlorine residuals are carried to the reuse tank, booster doses at the reuse tank along with free/ total chlorine residuals and free ammonia residuals should be monitored and carefully managed. Assuming breakpoint chlorination is not practiced at the NRRRF, additional hypo feed would be required to compensate for the loss of residuals in transit to the reuse tank and to account for the residual TKN and DOC.

For preliminary sizing, **Table 23** details the range for the chemicals that the metering pumps should have for flow rates as presented in Table 22. Considering the improved shelf life of 6 percent hypo solution, bulk chlorine will be supplied in the form of 12.5 percent hypo solution and diluted to approximately 6 percent. If using chloramines, a 19 percent ammonium hydroxide solution will be added to form monochloramines. The historical average TKN concentration of 1.06±0.32 mg/L in the influent to the reuse tank is used for sizing.

Table 23. Design Chemical Doses for Booster Disinfection Facility

Chemical	Solution Strength (%)	Dosages (mg/L)		
		Min	Average	Max
Hypo - Free Chlorine for Breakpoint Chlorination	6	10.0	12.3	14.5
Hypo - Combined Chlorine Booster Disinfection	6	4.8	7.5	10.2
Ammonium Hydroxide	19	0.2	0.4	0.6

Each chemical will require storage tanks with secondary containment and chemical metering pumps. If using combined chlorine, equipment associated with each chemical will be stored in isolated rooms in the new booster disinfection facility. Individual pumps will accurately meter the feed of each chemical to the discharge of booster pump station. An alternative is to house the metering pumps at the base of the Sunnybrook reuse tank. **Table 24** presents the chemical flow rates calculated based on expected reclaimed water flow rates and chemical dosages.

Table 24. Design Chemical Flow Rates for Combined Chlorine Disinfection

	Chemical Flow Rates (gph)		
	Min	Average	Max
Hypo (6% solution) – Free Chlorine for Breakpoint Chlorination			
Existing System	1.4	3.4	17.1
With Centennial Campus	1.7	3.5	17.8
With Centennial Campus and Lonnie Poole Golf Course	1.8	3.7	22.4
Hypo (6% solution) – Combined Chlorine Booster Disinfection			
Existing System	0.7	2.1	12.0
With Centennial Campus	0.8	2.2	12.5
With Centennial Campus and Lonnie Poole Golf Course	0.9	2.3	15.7
Ammonium Hydroxide (19% solution)			
Existing System	0.02	0.1	0.3
With Centennial Campus	0.02	0.1	0.5
With Centennial Campus and Lonnie Poole Golf Course	0.02	0.1	0.5

Table 25 presents the minimum usable volumes for 30 days of storage at average flow and dose that each storage tank will have for chemicals. A full load of bulk hypo delivery is 4,500 gallons. Since required volume for 30 days of storage is approximately 3,000 gallons and hypo degrades over time, options for bulk hypo delivery include:

- Buying 300 gallon totes with bulk hypo concentration of 12.5 percent. The bulk hypo will be diluted to approximately 6 percent and pumped to the storage tanks. Maximum five-300 gallon totes will be required per month with Centennial Campus and Lonnie Poole Golf Course on-line.
- Splitting bulk delivery between the booster disinfection facility and the NRRRF.

Ammonium hydroxide can be stored on-site in 300 gallon totes. One-300 gallon tote will last for approximately three months when Centennial Campus and Lonnie Pool Golf Course are connected to the reuse system.

Table 25. Bulk Storage Tank Volumes

	Chemical	Tank Material	30 Day Storage Volume (gal)[1,2]
Hypo Tanks 1, 2 – Free Chlorine Booster Disinfection	Liquid	Fiberglass	2,600
Hypo Tanks 1,2 – Combined Chlorine Booster Disinfection	Liquid	Fiberglass	1,600
Ammonium Hydroxide	Liquid	Steel Tank or Totes	90

[1] At average flow and dose

[2] Rounded off to the nearest hundred for hypo and to the nearest 10 for ammonium hydroxide

Space Requirements and Other Considerations

A building size of approximately 27-feet x 18-feet is proposed for hypo feed and storage. The building will house two-8 feet diameter bulk tanks for hypo, metering pumps, piping, and appurtenances. The space will require heating and ventilation. The scope of facilities will also include chemical feeding station, total and free chlorine residual analyzers, rotameters (circulating flow and chemical feed rotameters), pulsation dampeners, electric valves, backpressure valves, and blending chambers. The chemical injection feed will be designed so that chemical flow can go in either direction such as in the inlet/ outlet pipe to the reuse tank. Since the tank has a common inlet/ outlet pipe, flow switches will be provided to detect the water pipe flow in either direction and to reverse the flow of circulated sampling/ injection water by actuating motorized three-way valves.

If using chloramines, the building size will increase to approximately 43 feet x 18 feet to house the ammonia storage and feed equipment.

6.0 Opinion of Probable Construction Cost

A preliminary estimate of the opinion of probable cost of construction (OPCC) for the alternatives discussed in Section 5 was prepared based on process configuration and equipment sizing described above.

The construction cost estimates prepared for this memorandum are at the American Association of Cost Engineers (AACE) "Study Estimate" level (Category 2), which has an accuracy of +30% to -20%. The estimates were prepared using previous estimates for similar projects, historical data from comparable work, and equipment costs obtained from vendors.

The OPCC is presented in **Table 26.** Costs are shown in 2015 dollars and include a 25 percent construction contingency. Note that this opinion does not account for chemical purchase costs or operations and maintenance costs. The equipment sizing and costs should be confirmed as more accurate information becomes available for the NCSU Centennial Campus and Lonnie Poole Golf Course reuse demands. Equipment sizing and costs should also be reviewed for Alternative 2 (switch to chloramines), Alternative 3 (breakpoint chlorination), and Alternative 6 (booster disinfection) after bench testing is preformed to determine the specific chlorine demand for the CORPUD reuse water.

7.0 Summary and Recommendations

Review of CORPUD's off-site reuse distribution system water quality data and results of the water age modeling indicate long detention times in the reuse tank and distribution system and rapid loss of chlorine residual in the distribution system leading to biological growth and degradation of water quality.

- **Alternative 1**: Add process monitoring including a flowmeter on the discharge of hypo metering pump number 5 and total and free chlorine residual analyzers for the off-site system to provide direct confirmation of the hypo feed to the off-site wet well and chlorine residual leaving the NRRRF site. Perform tracer testing or CFD modeling to confirm the efficiency of hypo mixing and detention time in the off-site wet well. If mixing is insufficient, add a Chlor-A-Vac or similar mixing device to improve mixing of the chemicals in the wet well or consider the improvements to relocate the chlorine feed in Alternative 4. Construction cost for Alternative 1 improvements is estimated at $120,000. Costs do not include tracer testing or CFD modeling.
- **Alternative 2**: Use combined chlorine as a disinfectant instead of free chlorine to provide a more stable residual in the reuse distribution system without practicing breakpoint chlorination. The combined chlorine may persist sufficiently in the reuse system even without overcoming the oxidant demand since monochloramine is a much weaker oxidant. Required hypo doses will be lower (5.3 mg/L to 9.6 mg/L) compared to Alternative 3 (7.8 mg/L to 14 mg/L) when combined chlorine is produced in the breakpoint chlorinated water. Bench testing should be conducted to determine how stable the residual would be without

Table 26. Alternatives Improvements for Off-Site Reuse System – Opinion of Probable Construction Costs

Alt	Description	Construction Costs1	
		Free Chlorine	Combined Chlorine
1	**Chlorine Feed/Monitoring Improvements**		
	On-Line Chlorine Analyzers & Flowmeter	$ 80,000	$ -
	Mixing in Wet Well	$ 15,000	$ -
	Subtotal	$ 95,000	$ -
	Alternative 1 Total (including 25% Construction Contingency)	**$ 120,000**	**$ -**
2	**Switch to Combined Chlorine for Disinfection at NRRRF**		
	Brick Building for Ammonia Storage[2]	$ -	$ 85,000
	(2)-5 gph Metering Pumps	$ -	$ 9,000
	Subtotal	$ -	$ 94,000
	Alternative 2 Total (including 25% Construction Contingency)	**$ -**	**$ 120,000**
3	**Switch to Combined Chlorine for Dininfection at NRRRF (Sized to Allow Breakpoint Chlorination)[3]**		
	Brick Building for Ammonia Storage[2]	$ -	$ 85,000
	(2)-5 gph Metering Pumps	$ -	$ 9,000
	Subtotal	$ -	$ 94,000
	Alternative 3 Total (including 25% Construction Contingency)	**$ -**	**$ 120,000**
4	**Relocation of Chlorine Feed**		
	Schedule 80, 1-1/4" HDPE Pipe[4]	$ 19,000	$ 48,000
	5' dia MHs & Mixer (for chemical dosing/mixing)[5]	$ 26,000	$ 52,000
	36" Check Valve	$ 90,000	$ 90,000
	On-Line Chlorine/Ammonia Analyzers & Flowmeter	$ 117,000	$ 117,000
	Subtotal	$ 252,000	$ 307,000
	Alternative 4 Total (including 25% Construction Contingency)	**$ 320,000**	**$ 380,000**
5	**Add Mixing in Reuse Tank**		
	Separate Inlet and Outlet Pipes in Reuse Tank	$ 65,000	$ 65,000
	Add Recirculation Pumps **OR** Tank Mixing System[6]	$ 58,000	$ 58,000
	Subtotal	$ 123,000	$ 123,000
	Alternative 5 Total (including 25% Construction Contingency)	**$ 150,000**	**$ 150,000**
6	**Add Booster Disinfection Facility at the Reuse Tank**		
	Brick Building[7]	$ 346,000	$ 551,000
	(2)-3,000 gallon Hypo Tanks	$ 35,000	$ 35,000
	Skid-Mounted Metering Pumps[8]	$ 19,000	$ 38,000
	On-Line Chlorine/Ammonia Analyzers & Flowmeter	$ 117,000	$ 117,000
	Subtotal	$ 517,000	$ 741,000
	Alternative 6 Total (including 25% Construction Contingency)	**$ 650,000**	**$ 930,000**

Notes:

1) Construction costs include contractor overhead, profit, sales tax, bonds, insurance, and allowance for electrical, instrumentation, and sitework. Engineering costs are not included. Costs are given in 2015 dollars.

2) Assumes 12' x 10' climate controlled brick building on NRRRF site.

3) Does not require any additional facilities beyond Alternative 2.

4) Includes a parallel pipe run for redundancy.

5) Assumes 2 MHs for free chlorine option and 4 MHs for combined chlorine option.

6) Cost for tank mixing system based on vendor information for PAX mixing.

7) Assumes 27' x 18' climate controlled brick building on reuse tank site for free chlorine option and 43 x 18' climate controlled brick building on reuse tank site for combined chlorine option.

8) Assumes (2)-25 gph hypo metering pumps for free chlorine option and additional (2)-1 gph ammonia metering pumps for combined chlorine option.

first going to breakpoint. When switching to combined chlorine, perform periodic free chlorination for long-term control of biofilms. Limit the concentration of free ammonia in the system to less than 0.1 mg/L to eliminate nitrification issues. Construction cost for Alternative 2 improvements is estimated at $120,000. Alternative 2 should be implemented in combination with improvements to the disinfection feed in Alternative 4.

- **Alternative 3**: Use combined chlorine as a disinfectant instead of free chlorine and practice breakpoint chlorination to lower the oxidant demand before final disinfection using combined chlorine. Breakpoint chlorination will also prevent ammonia peaks from entering the distribution system, in the event of an upstream operational upset. Based on the estimated chemical doses, no additional facilities beyond those recommended in Alternative 2 are needed for breakpoint chlorination (although chemical costs are higher). Therefore, construction cost for Alternative 3 improvements are the same as Alternative 2 ($120,000). Alternative 3 should be implemented in combination with improvements to the disinfection feed in Alternative 4. Bench-scale tests should be conducted to determine the breakpoint chlorine doses and disinfection decay curves at alternate temperatures for the treated effluent at the NRRRF. Effect of seasonal variation on disinfectant demand should also be evaluated. Further, monitoring of free chlorine residuals in the effluent from NRRRF should be conducted.

- **Alternative 4**: Relocate the disinfection feeds from the injection vault 1 and off-site wet well to a single feed point in the 36-inch reuse influent line between the junction box and the off-site wet well to address short circuiting and operational concerns. Add manholes on the 36-inch reuse influent line to feed, mix and monitor the disinfectant residuals. Monitoring for influent flow, free/ total chlorine and free ammonia should be conducted for process monitoring and control. Construction cost for Alternative 5 improvements in estimated at $320,000 for free chlorine and $380,000 if switching to combined chlorine.

- **Alternative 5**: Install a mixing system in the Sunnybrook reuse tank to eliminate thermal stratification. Mixing may include creating separate inlet and outlet pipes, adding recirculation pumps, or adding active mixing systems. Routine tank cleaning should be performed when improvements are installed. Assuming that the inlet/outlet pipes are separated and either recirculation pumps or a mixing system is added to the tank, the construction cost for Alternative 4 improvements is estimated at $150,000 (excluding cost of routine tank cleaning).

- **Alternative 6**: Add booster disinfection in the reuse distribution system at the Sunnybrook reuse tank. Construction cost for Alternative 6 improvements is estimated at $650,000 for free chlorine and $930,000 for combined chlorine.

In addition to the facility improvement alternatives above, the following operational improvements are recommended for the reuse system:

- Increase hypo dose at the NRRRF with target chlorine residuals between 2 mg/L and 4 mg/L for the distribution system sample sites. Conduct bench-scale tests to determine the chlorine demand, breakpoint chlorine doses and disinfection decay curves at alternate temperatures for the treated effluent at the NRRRF. The effect of seasonal variation on disinfectant demand should also be evaluated. Since the bench tests cannot duplicate system conditions, use a safety factor of at least 2 for determining chlorine dosages. In addition, monitoring for DOC and free chlorine residuals in the effluent from the NRRRF should be conducted.
- 10 to 15 percent sodium hypo solution deteriorates rapidly especially at higher temperatures and extended storage at this strength is not recommended. Consider diluting the bulk hypo to 6 percent to increase the shelf life of the chemical. Check strength of bulk hypo solution in the storage tanks at least once a week to confirm that representative hypo concentration is being used in chemical dose calculations.
- Control sediment accumulation in distribution system pipelines by conducting routine high velocity flushing. Where system limitations do not allow high velocity flushing, consider ice pigging to dislodge the biofilms on pipe walls.
- Perform annual cleaning and disinfection of the Sunnybrook reuse tank to prevent sediment buildup and microbial growth.

Appendix B

Evaluation of Reuse Water for Bioenergy Recovery at the Neuse River Resource Recovery Facility Technical Memorandum

CDM Smith

DRAFT Memorandum

To: *City of Raleigh Public Utilities Department*

From: *CDM Smith*

Date: *February 10, 2016*

Subject: *Evaluation of Reuse Water for Bioenergy Recovery at the Neuse River Resource Recovery Facility*

The City of Raleigh Public Utilities Department (CORPUD) provides reuse water generated at the Neuse River Resource Recovery Facility (NRRRF) for non-potable uses on the NRRRF site and for distribution to reuse water customers in southeast Raleigh. CORPUD is currently evaluating new facilities at the NRRRF as part of a bioenergy recovery program. These new facilities will have a demand for non-potable water, most significantly as makeup water in the heat exchanger (HEX) for cooling of sludge from the thermal hydrolysis pretreatment (THP) process. This memorandum discusses options and recommendations for using the existing reuse system at the NRRRF to meet the non-potable demands of the bioenergy recovery program.

NRRRF Reuse System

The reuse facilities at the NRRRF pump reuse water through three separate systems: 1) on-site reuse system for plant and other on-site uses, 2) high pressure irrigation system for irrigation of the agricultural fields near the NRRRF and 3) off-site distribution system to provide reuse water for public utility facilities, parks and recreational fields, golf courses, and commercial/industrial uses. Reuse water for all three systems is drawn from the ultraviolet (UV) disinfection effluent pipeline. A sodium hypochlorite feed system is used to provide residual chlorine in the distribution system. Additional details of each system are discussed in the following paragraphs.

On-Site Reuse System

The on-site reuse system includes four vertical turbine can-type pumps with varying design capacities (see Table 1). The largest of these pumps (Pump #4) can swing between the on-site system and high pressure irrigation system. The operating pressure for the on-site system is set at 90 pounds per square inch (psi). Hypochlorite is fed in an injection vault downstream of the pumps. A minimum chlorine residual is provided to inhibit biological growth in the pipelines.

This system supplies reuse water for on-site uses at the headworks/pretreatment facility, secondary clarifiers, centrifuge building, dewatering building, sludge thickening building, and miscellaneous washdown areas.

Table 1. Reuse Pumping Facilities at the NRRRF

Pumping Facility	Pump	Design Capacity per Pump (gpm)	Variable Frequency Drive
On-Site	Pump #1	250[1]	No[1]
	Pump #2	500	No
	Pump #3	1,000	Yes
	Pump #4[2]	2,000	Yes
High Pressure Irrigation	Pump #5 & 6	3,000	Yes
Off-Site	Pump #2, 3, & 4	1,100	No

1) Pump #1 is planned to be replaced with a 500 gpm pump with VFD.
2) Pump #4 can swing between the on-site and high pressure irrigation systems.

High Pressure Irrigation System

The high pressure irrigation system has two dedicated vertical turbine can-type pumps with a design capacity of 3,000 gallons per minute (gpm) per pump (see Table 1). Pump #4 from the on-site system can also be used for high pressure irrigation. The operating pressure for the high pressure irrigation system is set to 120 psi. Hypochlorite is fed in an injection vault downstream of the pumps. A minimum chlorine residual is provided to inhibit growth in the pipelines. This system supplies reuse water for the water cannons at the flow equalization basin and irrigation of agricultural fields surrounding the NRRRF.

Off-Site System

The pump station for the off-site reuse system is located in a dedicated building and consists of three 1,100 gpm constant speed vertical turbine pumps with space for two additional pumps (see Table 1). The discharge pressure for the off-site reuse system is approximately 120 psi. Hypochlorite is added in the pump station wet well and in an injection vault downstream of the pumps. Although total hypochlorite doses have been in the range of 13 to 15 mg/L, CORPUD has experienced difficulty in maintaining disinfectant residual in the off-site reuse distribution system. The existing hypochlorite feed system and evaluation of reuse water quality are described in detail in the December 7, 2014 Reuse System Water Quality Technical Memorandum by CDM Smith.

The off-site reuse system supplies the bulk reuse truck filling station on the NRRRF site, the NRRRF administration building, and the southeast Raleigh distribution system which provides reuse water to city, municipal, commercial, and industrial customers. Existing operations of the off-site pump station typically involve only one pump running at a time, based on levels in the elevated storage tank on Sunnybrook Road. There is an interconnection between the off-site and on-site reuse system near the administration building that would allow the on-site system to be served via the off-site pumps in case of emergency.

Reuse Demands

Existing Demands

Table 2 lists the existing demands on each of the reuse systems, including the reuse demands associated with the Phase 3 and Phase 4 expansion to 75 mgd at the NRRRF.

Table 2. Existing Reuse Demands (Including NRRRF 75 mgd Expansion Phase 3 & Phase 4)

Reuse System	Location	Demand (gpm)		
		Minimum	Average	Maximum
On-Site[1]	Headworks/Pretreatment Facilities	110	596	1,009
	Secondary Clarifier Spray Nozzles	60	360	360
	Centrifuge Building	0	0	100
	Final Dewatering Building	0	420	420
	Thickening Building	132	205	205
	Miscellaneous Washdown	0	0	30
	Primary Clarifiers (Phase 3)	0	15	15
	RAS & WAS Pump Stations (Phase 4)	7	7	7
	Carbon Storage & Feed Facility (Phase 4)	0	35	35
	On-Site Total	**309**	**1,638**	**2,181**
High Pressure Irrigation	Equalization Basin Water Cannons[2]	0	0	1,500
	Irrigation[3]	0	0	3,000
	High Pressure Irrigation Total	**0**	**0**	**4,500**
Off-Site[4]	NRRRF Administration Building	13	250	--
	Bulk Reuse Station[5]	0	0	--
	Distribution System Customers[6]	227	613	--
	Off-Site Total	**240**	**863**	**2,200**

1) Minimum, average, and maximum on-site demands are per spreadsheet provided by Black & Veatch on December 22, 2015.
2) Equalization basin water cannon maximum demand assuming 750 gpm each with no more than 2 cannons operated at a time. Used quarterly to clean the equalization basin.
3) Maximum irrigation demand assuming one pump running at full speed.
4) For the off-site system, the minimum demand is equal to the winter average (average flow in November through April), the average demand is equal to the summer average (average flow in May through October), and the maximum demand is based on maximum pumping (two pumps running) at the off-site pump station. Elevated storage is available in the off-site reuse distribution system to meet peak hourly demands.
5) Demand at the bulk reuse station is sporadic and generally accounts for less than one percent of the off-site system demand.
6) Distribution system demands include estimated demands for North Carolina State University Centennial Campus and the Lonnie Poole Golf Course, which are expected to be in-service by early 2016.

Future Off-Site Demands

An update to the Reuse System Master Plan is currently underway for the NRRRF off-site reuse distribution system. The master plan identifies potential areas for future extension of the system to serve additional customers. Preliminary work has identified approximately 2.5 to 3.0 mgd of future maximum day reuse demands for the off-site distribution system. Modeling work is ongoing to determine the feasibility and required infrastructure to supply reuse water from the NRRRF to meet these demands.

Assuming an additional future off-site system maximum day demand of 2.5 mgd (1,700 gpm), the off-site pump station would need to be expanded to approximately 3,900 gpm firm capacity, which is an approximately 80 percent increase in the existing firm capacity. Therefore, the additional two pump slots will potentially be needed in the future for off-site distribution.

Bioenergy Recovery Demands

Estimates of additional reuse demands related to the bioenergy recovery program are summarized in Table 3 for the facility size at startup and ultimate buildout. The largest single demand is for makeup water in the HEX for cooling of sludge from the THP process. This use is anticipated to be continuous (24 hours per day) and range from 350 to 2,500 gpm initially (350 to 3,300 gpm at buildout) based on loading, seasonal, and other factors. This demand alone will approximately double the on-site reuse at the NRRRF.

Table 3. Additional Bioenergy Recovery Reuse Demands[1]

Location	Initially Installed Equipment Demand (gpm)			Ultimate Buildout Demand (gpm)		Minimum Pressure (psi)
	Minimum	Average	Maximum	Average	Maximum	
Primary Sludge Degritting Tank – Water Cannon	0	500	0	500	0	120
Primary Sludge Degritting Tank – Other	4	104	4	104	4	95
Thickening Building	0	0	102	103	272	95
Pre-Dewatering & Sludge Screening Facility	83	155	273	225	438	95
Sludge Storage	1	1	1	1	1	95
THP – Sludge Cooling HEX	350	1,350	2,500	1,800	3,300	45
THP – Other	12	70	139	116	206	95[2]
Final Dewatering Building	0	50	80	410	440	95
Sidestream Treatment	0	74	74	74	74	95
Gas Use and Storage	20	50	100	150	300	45
New Bioenergy Recovery Total	**470**	**2,354**	**3,273**	**3,483**	**5,035**	**--**

1) Demands based on spreadsheet provided by Black & Veatch on December 22, 2015.
2) THP discharge dilution water minimum pressure is 45 psi.

With the exception of the water cannon for the primary sludge degritting tank, all of the new demands have a pressure requirement of 95 psi or less, which is similar to the current discharge pressure of the on-site reuse system. The water cannons require 120 psi, which is similar to the high pressure irrigation system. CDM Smith's experience with similar systems is that the THP discharge dilution water, THP sludge cooling HEX makeup water, and process gas cooling makeup water have a minimum operating pressure requirement of 45 psi, at which point system will go into idle and stop processing. Hence, these systems typically operate at higher pressures. The DC Water THP system uses non-potable reuse water for cooling demands at pressures that fluctuate between 50 and 120 psi.

The required chlorine residuals for the bioenergy recovery demands are anticipated to be similar to the current on-site reuse system requirement of approximately 1 mg/L to control biological growth in the pipelines. However, the sidestream treatment processes require that chlorine residual is removed in order to maintain the biology. The THP sludge cooling HEX makeup water has a maximum chlorine residual limit of 2 mg/L to prevent corrosion.

Additional considerations for using reuse water for the THP sludge cooling include fouling of the HEX. CDM Smith's experience with similar systems has indicated that even with high quality effluent, fouling can be an issue. Iron and manganese are of concern, particularly since higher levels of iron and manganese have been measured in the reuse distribution system. CORPUD should confirm water quality parameter requirements and any necessary treatment/modifications with the HEX designers.

Reuse Supply Capacity

The new bioenergy facilities will add significantly to the NRRRF reuse demands. In addition, the largest portion of the new reuse demand (HEX makeup water) will be a continuous demand that is critical for the operation of the THP facilities. If the peak reuse demands exceed the minimum hourly wastewater flows at the NRRRF, additional storage facilities or storage management (using the existing equalization basin) will be required to provide a reliable supply of reuse water. Therefore, a simple mass balance calculation was performed to compare reuse water supply and demand. As given in Table 4, the minimum hourly flow is estimated using a minimum day to average annual wastewater flow ratio of 0.85 and a minimum hour to daily ratio of 0.6. These factors were determined using available historical effluent data. Based on a 2015 average annual flow of approximately 45 mgd, the minimum hourly effluent flow is approximately 23 mgd (16,000 gpm). The reuse supply exceeds the maximum demand for the on-site, high pressure irrigation, off-site, and initially installed bioenergy recovery equipment by approximately 24 percent (Table 5).

Assuming an average annual wastewater flow of 56 mgd at completion of the ongoing plant expansion (75 percent of the 75 mgd plant capacity), the minimum hourly effluent flow is approximately 29 mgd (19,900 gpm), which exceeds buildout reuse demands by approximately 22 percent (Table 5). It is recommended that need for reuse system storage be revisited as additional hourly effluent data for the NRRRF is available.

Table 4. NRRRF Reuse Water Supply

Wastewater Flow	Initial	Future Capacity (75 MGD)
Average Annual (AA) Flow (mgd)[1]	45.0	56.0
Minimum Day: AA Ratio[2]	0.85	0.85
Minimum Day Flow (mgd)	38.3	47.6
Min Hour: Average Daily Ratio[3]	0.6	0.6
Minimum Hour Flow (mgd)	23.0	28.6
Minimum Hour Flow (gpm)	**16,000**	**19,900**

1) Initial average annual flow based on July 2014 to June 2015. Future average annual flow based on 75 percent of 75 mgd expanded plant capacity.
2) Ratio based on review of daily effluent data from 2011 through 2013.
3) Ratio based on review of hourly UV effluent data for October 2013.

Table 5. NRRRF Projected Reuse Demand

Maximum Reuse Demand	Initial	Future
On-Site System (gpm)[1]	2,181	2,181
High Pressure Irrigation System (gpm)[1]	4,500	4,500
Off-Site System (gpm)[2]	2,200	3,900
Additional Bioenergy Recovery (gpm)[3]	3,273	5,035
Maximum Total Reuse Demand (gpm)	**12,154**	**15,616**

1. See maximum demands in Table 2. Future on-site demands assumed to remain similar to existing (after Phase 3 & Phase 4 expansion)
2. See maximum demands in Table 2 for existing off-site system. An additional 2.5 mgd (1,700 gpm) is estimated for future off-site demand.
3. See maximum demands in Table 3.

Options for Supplying Bioenergy Recovery Reuse

Due to the number of separated reuse systems currently maintained at the NRRRF and the complexity of the piping and pumping for those systems, CORPUD would like to avoid construction of a new dedicated reuse system for the proposed bioenergy recovery demands. Therefore, the focus of this evaluation is on using either the existing off-site or on-site system to meet the new bioenergy recovery facility demands.

Add New Demands to Off-Site System

The off-site reuse system operating pressure is set at 120 psi based on maintaining pressure in the distribution system and filling the elevated storage tank at Sunnybrook Road. If the new bioenergy recovery demands are added to the off-site reuse system, a new high pressure line would need to be installed to feed those facilities at a pressure of 120 psi, or a pressure reducing valve would need to be installed to reduce the pressure for system processes, if necessary. The existing capacity of the off-site pump station is not adequate to meet the off-site demand plus the bioenergy recovery demands. Therefore, additional pumps would need to be installed. Although the off-site station has two spare pump slots, these may be required in the future for additional off-site demands.

A limiting factor for pumping to the off-site system with the current pump station is the resulting pressures at the low point in the distribution pipeline crossing the creek between the NRRRF and Auburn-Knightdale Road. The elevation at this low point is approximately 20 feet lower than the elevation of the pipe leaving the off-site pump station. Based on hydraulic modeling of the existing system, peak pressures at this point with current demands (without NCSU and Lonnie Poole golf course) and one off-site pump running are approximately 160 psi. Peak pressures with NCSU and Lonnie Poole golf course demands added and two off-site pumps running are projected to be approximately 180 psi. Adding a demand on the NRRRF site for the bioenergy recovery facilities should not impact the downstream distribution pipeline pressures assuming the demand is constant and the pumps are sized appropriately. However, the HEX cooling makeup water demand is anticipated to vary significantly. With the existing constant speed pumps and new larger pumps that would be required to meet maximum bioenergy recovery demands, operations would need to be closely controlled to avoid high pressures in the distribution system.

In addition, chlorine residual management has been an issue for the off-site reuse system. Hypochlorite is fed at both the wet well upstream of the off-site pump station and in an injection well downstream of the pumps. The two feeds combined represent a significant chlorine dose (13 to 15 mg/L). Recommendations have been made to improve chlorine residuals in the off-site distribution system including adding process controls, improving chemical mixing, relocating the hypochlorite feed points, switching to combined chlorine, or practicing breakpoint chlorination. With any of these improvements, the targeted chlorine residual leaving NRRRF may be higher than what is desirable for some of the bioenergy recovery processes, requiring dechlorination to reduce the chlorine residual.

Considering the lower required pressures and chlorine residual for the non-potable bioenergy recovery process use, the limited capacity at the off-site pump station, and the potential difficulties in operating the off-site system with the addition of a variable HEX cooling makeup water demand, adding the bioenergy recovery reuse demand to the off-site system is not recommended.

Add New Demands to On-Site System

The chlorine residual requirements for the new bioenergy recovery facilities are generally the same as the existing on-site reuse system. The on-site system pressures are adequate to meet the needs of the new facilities with the exception of the primary sludge degritting tank water cannons. Using the on-site system for the new demands will minimize waste in pumping energy and not require dechlorination. However, the current on-site system capacity is not adequate for the new demands, and operational flexibility is limited by the lack of VFD’s or pressure maintaining facilities (elevated or hydropneumatic tank). Assuming the reuse demand for the primary sludge degritting tank water cannon is met by the high pressure irrigation system, adding the new bioenergy recovery demands to the on-site system would require increasing the capacity of the pump station to 5,500 gpm initially and 7,200 gpm in the future.

To accommodate this capacity increase, it is recommended that a new on-site pump station be considered to replace the existing on-site pump station. The existing high pressure irrigation pumps would remain as is and a new 5,500 gpm station could be built with adequate space for expansion to meet on-site reuse demands at buildout. Figure 1 shows a potential location for the new on-site pump station.

As discussed previously, the demands for the new bioenergy facilities, particularly the HEX cooling makeup water, may be highly variable. A hydropneumatic tank at the new station could be considered to help maintain system pressures and minimize pump on/off cycles during periods of lower demand. Pumps with VFDs could also help with variable demands.

Opportunities to improve the hypochlorite feed system, particularly chlorine mixing and contact time, should be evaluated in combination with consideration of a new on-site pump station. The December 7, 2014 Reuse System Water Quality Technical Memorandum discusses options for improving the off-site hypochlorite feed. One of these is practicing breakpoint chlorination to improve the stability of chlorine residuals in the distribution system. Construction of a common reuse storage tank/wet well upstream of both the existing off-site and new on-site pump stations could provide benefits for mixing and dosing of hypochlorite to both systems, particularly if breakpoint chlorination is considered. This facility could also provide some amount of storage for reliability of supply due to hourly fluctuations in effluent flow through the plant.

Based on the maximum demands given in Table 2 and 3, the existing 12-inch and 8-inch reuse pipe loop that comprises the on-site system will not provide sufficient capacity for both existing and additional on-site demands. A new on-site reuse pipeline from the new on-site pump station to the east side of the plant, where the new bioenergy facilities are proposed, will likely be necessary as part of the on-site reuse system upgrades. This pipeline can be looped with the existing on-site pipeline to provide redundancy and additional capacity.

Summary

As CORPUD continues to be an industry leader in resource recovery, progress has led to these efforts to find synergy between your reclaimed water program and biosolids management program. This memorandum serves to document many of those advantages and also includes recommendations to ensure your overall management of these resources continues to be successful.

The new bioenergy facilities will add significantly to the NRRRF reuse demands. The largest portion of the new reuse demand (HEX makeup water) will be a continuous demand that is critical for the operation of the THP facilities. None of the existing reuse pumping facilities at the NRRRF have capacity to meet the proposed bioenergy demands without expansion or modifications.

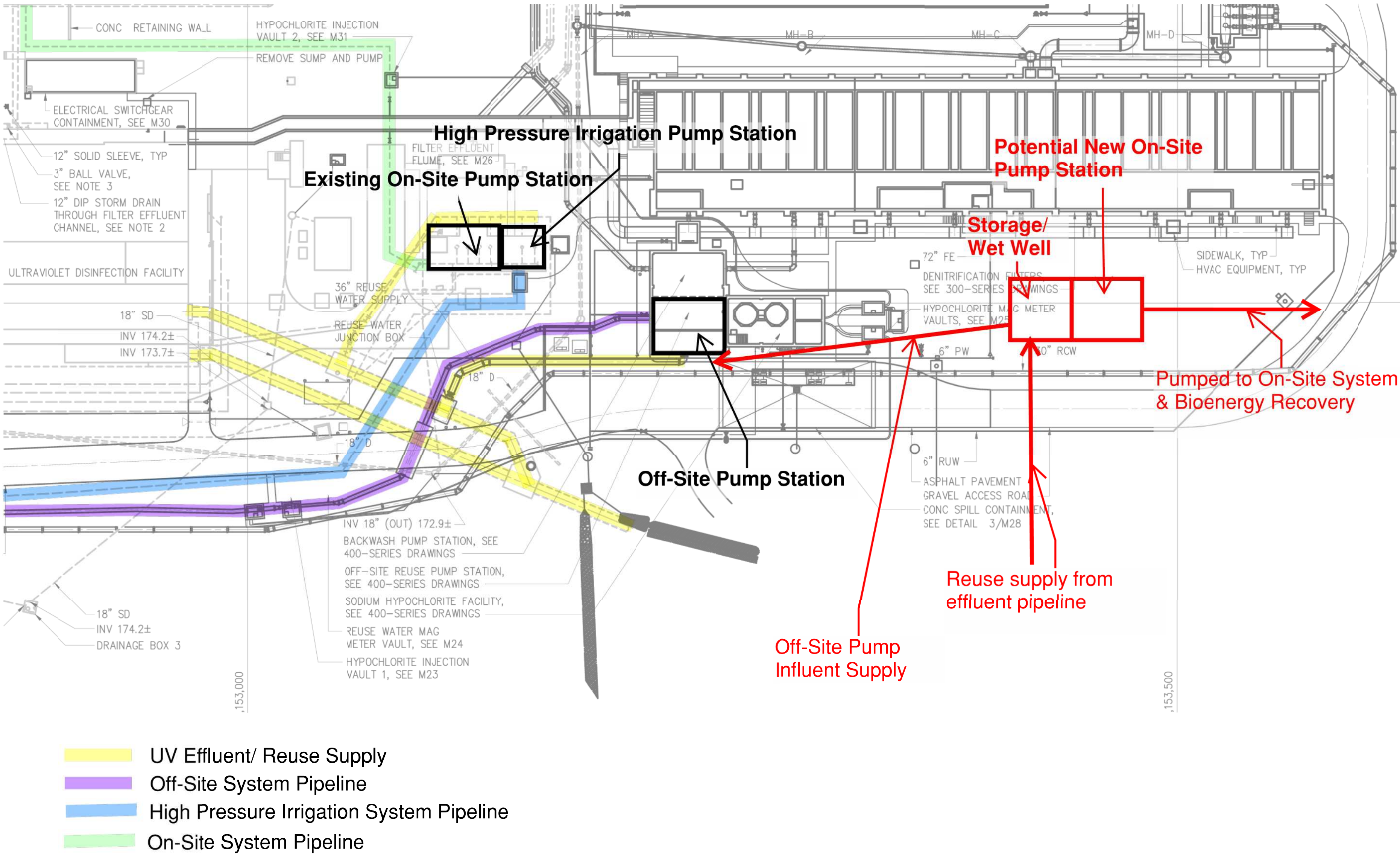


Figure 1. Potential Location for New On-Site Reuse Pump Station

Considering the operating pressures, chlorine residual requirements, and flexibility of operations needed to meet a variable demand for HEX makeup water, it is recommended that the bioenergy reuse demands be added to the on-site reuse system and that a new on-site pump station be considered to replace the existing on-site pump station.

The existing high pressure irrigation pumps could remain as is and a new 5,500 gpm station could be built with adequate space for expansion to meet total future on-site reuse demands. In addition, a hydropneumatic tank or pumps with VFDs should be considered to help maintain system pressures and minimize pump on/off cycles during periods of lower demand. Opportunities to improve the hypochlorite feed system, particularly chlorine mixing and contact time, should also be evaluated in combination with consideration of a new on-site pump station.

Additionally, prior to committing NRRRF reuse water for the bioenergy recovery facility applications, it is recommended that CORPUD confirm the minimum hourly effluent wastewater flows to determine if additional storage is needed to provide reliable supply of reuse water. CORPUD should also confirm water quality requirements for the HEX cooling makeup water.

Appendix C

Model Scenarios for Maintaining Reuse System Operations with Sunnybrook Tank Off-Line

CDM Smith

Smith, Sheryl D

From: Smith, Sheryl D
Sent: Thursday, March 17, 2016 9:33 AM
To: Navarrete, Eileen <Eileen.Navarrete@raleighnc.gov> (Eileen.Navarrete@raleighnc.gov); Dalton, Marla (Marla.Dalton@raleighnc.gov)
Cc: Irby, Kevin; Stroud, Ross
Subject: Reuse Tank Issue
Attachments: Model Summary.pdf

Hi Eileen and Marla,

Hope your empty tank inspection goes well today. Based on our discussions with Marla last week, we've modeled 3 scenarios for maintaining the offsite reuse system with the Sunnybrook tank off-line. Below is a brief description of each scenario and the attached table presents details of modeled flows and pressures.

Scenario 1
This scenario uses the existing offsite reuse pumps with a continuous blowoff to supply the offsite reuse system. Since the demands are much smaller than the capacity of the pumps, the blowoff amount is large (as much as 1,000 gpm) and must be maintained continuously as the pumps will run continuously. The blowoff was modeled at NCSU (100 gpm), State Street (100 gpm), and the rest into the EQ basin at the NRRRF. The blowoffs could be at different locations, although due to the volume, most will probably need to go to the EQ basin. System pressures will fluctuate more than they do currently as the pump flow/head will remain relatively constant while the demands fluctuate over the day. However pressures remain in an acceptable range. May need to confirm if NCSU (or WakeMed or others) have a required pressure range that needs to be maintained.

Scenario 2
This scenario also uses the existing offsite reuse pumps to supply the offsite reuse system, but simulates throttling the valve downstream of the pump to reduce the head to the system and decrease the amount of water needed to blowoff. Based on some assumed CV values and curves for a typical 12-inch butterfly valve, we've modeled a valve closure to about a 10 degree position. At that position, continuous blowoff is still needed, but only about 500 gpm. Again, this could be either a combination of locations in the distribution system or the EQ basin. With this option, pressures at the high point near NCSU vary between 46 and 103 psi. The valve closure may be able to be refined to minimize blowoff even more, but would likely need to consider valve specifics and condition.

Scenario 3
This scenario uses the onsite swing pump #4 to supply both the onsite and offsite reuse system. This scenario assumes that the system valves will allow for supply to both systems simultaneously and that the onsite system could operate at higher pressures than the current 90 psi. The discharge pressure of the pump would need to be closer to the 120 psi set point of the offsite system. In addition, this would complicate the chlorine feed to the offsite system since only the downstream injection point would be available for offsite. However, without the tank in service, the water age would be significantly decreased in the distribution system. As modeled, VFDs for onsite pump #4 would be operating at approximately 80 to 85 percent speed to supply both systems with no blowoff.

With any of these scenarios, pressures would need to be monitored so that blowoffs could be adjusted if there is big spike or dip in demands. A fourth scenario, that may be the best option to avoid significant blowoff volume, is to consider renting smaller pumps temporarily to serve the offsite system. You probably have some contracts with local vendors, but we could certainly check around for pump availability/sizes for you if you'd like. Based on the demands we've assumed in the modeling, you'd be looking at pumps with a range of ~250- 450 gpm for March/April demands and ~600-950 gpm for summer average demands.

Let us know if you have any questions or additional concerns. If you'd like, we can set up a call to go through everything and discuss.

Thanks,
Sheri

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Summary of Reuse System Modeling with Sunnybrook Elevated Tank Out of Service

Modeled Scenario	Description	Demands	Blowoff (1)	High Pressure (2)	Low Pressure (3)	Total Pumped Flow
0	-Existing System with tank in service	March/April average offsite (see note 4)	none	138 - 157 psi	71 - 75 psi	~1,360 gpm to fill tank
1A	-Tank out of service; -Use offsite pumps with continuous blowoff	March/April average offsite (see note 4)	~1,000 gpm continuous	147 - 167 psi	82 - 103 psi	~1,240 - 1,400 gpm continuously
1B		Summer average offsite (see note 5)	~600 gpm continuous	127 - 167 psi	57 - 102 psi	~1,240 - 1,560 gpm continuously
2A	-Tank out of service; -Throttle valve downstream of pump to reduce head (12" butterfly valve closed to ~10 degree position); -Continuous blowoff	March/April average offsite (see note 4)	~600 gpm continuous	122 - 150 psi	52 - 81 psi	~890 - 1,050 gpm continuously
2B		Summer average offsite (see note 5)	~500 gpm continuous	120 - 173 psi	46 - 103 psi	~740 - 1,060 gpm continuously
3A	-Tank out of service; -Use onsite swing pump #4 to supply onsite & offsite demands	March/April average offsite (see note 4) Plus ~750 gpm continuous for onsite	none	129 - 135 psi	60 - 67 psi	Pumps operating at ~80% speed 1,030 - 1,190 gpm continuously
3B		Summer average offsite (see note 5) Puls ~750 gpm continuous for onsite	none	127 - 140 psi	52 - 70 psi	Pumps operating at ~85% speed 1,380 - 1,700 gpm continuously

Notes:

1) Blowoffs were modeled at NCSU (100 gpm max), State Street (115 gpm max), and the EQ basin at the NRRRF. Blowoff location does not have a large impact on the system.
2) Pressures are from the low elevation model node located at the creek crossing at the land bridge near the NRRRF
3) Pressures are from the high elevation model node located near NCSU Centennial Parkway
4) Demands based on March/April 2015, with addition of NCSU physical plant (144,000 gpd), and reduced demand at the NRRRF admin buidling
5) Demands based on average Summer 2015 demand, with addition of NCSU physical plant (180,000 gpd) and NCSU irrigation (140,000 gpd)

DRAFT

Appendix D

Example Pilot Testing Sampling Plan and List of Analytes and Parameters from Gwinnett County

(Source: Gwinnett County Department of Water Resources Pilot Testing Plan, WaterReuse Foundation Project WWRF 15-11)

DPR Testing of Blending Ratios Sampling Plan

Phase:	DPR TESTING OF BLENDING RATIOS (6 mo.)[1]											
Months/Phase:	6											
Parameter	SCFP Raw Water	FWH Effluent	Pilot Influent	Post Ozone	BAF Influent	Filter 1 (Control) Effluent	Filter 4 (GAC) Effluent	WRF 4555 Filter 1 (Control) Effluent	Biofilter Media	Filter 1 (Control) Finished Water	Spent Backwash Water	Samples/ Phase
	RS-SP01	RS-SP02	RS-SP03	RS-SP04	RS-SP14	RS-SP18	RS-SP15	BS-SP18	RS-FM01	RS-SP25	RS-SP19	-
Samples per location	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**-**
Biological Indicators												
Adenosine triphosphate (ATP)									M		M	**12**
Dissolved oxygen consumption, LDO probe[2]					C	C		*				**0**
Heterotrophic plate count (HPC)								*		P		**1**
Molecular biology assays (qPCR, 16S rDNA, TRFLP)												**0**
Giardia and Cryptosporidium (Crypto)	B	B								P		**7**
E. coli	B	B	P							P		**8**
Total coliforms, Fecal coliforms	B	B	P							P		**8**
Coliphage	B	B								P		**7**
Clostridium perfringens	B	B								P		**7**
Enterococcus spp.	B	B								P		**7**
Legionella	B	B								P		**7**
Organic Characteristics												
Total organic carbon (TOC)			3xW	W	3xW	3xW	M	*		W		**303**
Dissolved organic carbon (DOC)			W	W	W	W	M	*		W		**141**
Chemical Oxygen Demand (COD)			W	W	W	W	M	B		W		**144**
Photoelectrochemical oxidant demand (peCOD)			M	M	M	M	M	*		M		**36**
Carboxylic acids					B	B	B	*				**9**
NiCaVis (nitrate, TOC, DOC, COD, UVT, SAC 254)[3]			C	C								**0**
UV 254, Probe						C						**0**
UV transmittance, Grab			W	W	3xW	3xW				M		**222**
Fluorescence Excitation-Emission Matrix (EEM)												**0**
Water Quality												
Turbidity, Probe			C			C	C	*				**0**
Turbidity, Grab			3xW			3xW	M			W	B	**198**
Total dissolved solids (TDS)			B							B		**6**
Total suspended solids (TSS)			B							B	B	**9**
Color, Apparent			M	M	M	M	B			M		**33**
Color, True			B	B	B	B				B		**15**
Ammonia			M		M	M	B			M		**27**
Nitrate (EPA 300.0)			M	M	M	M	B			M		**33**
Nitrite (EPA 300.0)			M		M	M	B			M		**27**
Nitrate (Hach Method 8171)			W			W						**54**
Nitrite (Hach Method 10207)			W			W						**54**
Total Kjeldahl-N			W		W	W	B			W		**111**
Nitrogen, Total			W		W	W	B			W		**111**
Sulfate										M		**6**
Phosphorus, Total			M		M	M	M			B		**27**
Phosphorus, Ortho			M		M	M	M					**24**
T&O (2-methylisoborneol and geosmin)										B		**3**
Temperature			C	W	W							**54**
pH, Probe			C									**0**
pH, Grab			3xW		3xW					B		**165**
Oxidation Reduction Potental (ORP), Probe			C	C								**0**
Alkalinity			B							B		**6**
Hardness, Calcium[4]										B		**3**
Hardness, Total[4]										B		**3**
Foaming Agents										B		**3**
Disinfectants/Disinfection Byproducts												
DBP formation potential (THM-FP)			M	M		M	B					**21**
DBP formation potential (HAA-FP)			M	M		M	B					**21**
Trihalomethanes, Total	B		M	M		M		B		M		**30**
Haloacetic acids (HAA9)	B		M	M		M		B		M		**30**
Bromide			B	B						B		**9**
Bromate			B	B						B		**9**
Chlorite			B							B		**6**
Chloride										B		**3**
Chlorine, Free (as Cl_2)											W	**27**
Chlorine, Total											W	**27**
Hydrogen peroxide												**0**
Dissolved ozone residual, Probe				C								**0**
Dissolved ozone residual, Grab Decay Samples				M								**6**
Trace Organic Constituents												
Sucralose (wastewater tracer)	B		B					B		B		**12**
Nitrosamines (including NDMA)	B		B					B		M		**15**
Nitrogenous disinfection byproducts (including precursors)	B		B					B		M		**15**
Haloquinones	B		B					B		B		**12**
PPCPs	B		B					B		B		**12**
Perfluorinated compounds	B		B					B		B		**12**
Pesticides/herbicides/fungicides	B		B					B		B		**12**
VOCs	B		B					B		B		**12**
1,4-Dioxane	B		B					B		B		**12**
Hormones	B		B					B		B		**12**
Acrylamide	B		B					B		B		**12**
Inorganic Chemicals												
Radium										B		**3**
Metals, SM 3113B and SM 3120B										B		**3**
Metals, EPA 245.1										B		**3**
Cyanide (Free)										B		**3**

Notes: B – once per blend C – continuous M - month W - week 3xW - three times per week P – once per phase * - Sampled as part of WRF 4555

1. Chemical doses include ozone, ferric chloride, polymer, nutrients, and/or H2O2.
2. DO will be monitored from the influent and effluent of one biofilter at a time. The time and date that the DO probes are rotated between filters will be recorded in the pilot plant operator's log. Hach will provide two luminescent DO probes for biofilter monitoring.
3. The YSI NiCaVis online probe will be installed at the pilot plant as noted under each phase. There are two instruments available that will be shared for both the WRF 4555 pilot as well as for WRRF project 15-11.
4. Scaling potential will be calculated using the Langelier Saturation Index calculation

Pilot Complete Analytes and Parameters

Analyte	Analytical Category	Method	Units	MDL	RL	Laboratory
Adenosine triphosphate (ATP)	Biological Indicators	LuminUltra Deposit & Surface Analysis	pg/g	5	-	Gwinnett
Adenosine triphosphate (ATP)	Biological Indicators	LuminUltra Deposit & Surface Analysis	pg/mL	0.1	-	Gwinnett
Clostridium perfringens	Biological Indicators	ASTM D5916-96	MPN/100 mL	-	1	EEA
Coliphage	Biological Indicators	EPA 1602	PFU/100 mL	-	1	EEA
Cryptosporidium (Crypto)	Biological Indicators	EPA 1623	oocysts/10L	-	1 to 10	EEA
Dissolved Oxygen (DO)	Biological Indicators	Hach LDO probe	mg/L	-	0.5	Field
E. coli	Biological Indicators	SM 9223B	CFU/100 mL	-	1	Gwinnett
Enterococcus spp.	Biological Indicators	Idexx	MPN/100 mL	-	1	EEA
Fecal Coliform	Biological Indicators	SM 9222D	CFU/100 mL	-	1	Gwinnett
Giardia	Biological Indicators	EPA 1623	cysts/10L	-	1 to 10	EEA
Heterotrophic Plate Count (HPC)	Biological Indicators	SM 9215B	cfu/mL	-	1	Gwinnett
Legionella	Biological Indicators	CDC	CFU/L	-	10	EEA
Molecular biology assays (qPCR, 16S rDNA, TRFLP)	Biological Indicators	gDNA Extraction & 16s rDNA library construction	N/A	N/A	-	UT Austin
Total Coliform	Biological Indicators	SM 9222D	CFU/100 mL	-	1	Gwinnett
Acetate	Carboxylic Acids	EPA 300.1 mod.	µg/L	5	-	EBMUD
Formate	Carboxylic Acids	EPA 300.1 mod.	µg/L	5	-	EBMUD
Oxalate	Carboxylic Acids	EPA 300.1 mod.	µg/L	5	-	EBMUD
Pyruvate	Carboxylic Acids	EPA 300.1 mod.	µg/L	5	-	EBMUD
Bromate	Disinfectants & Byproducts	EPA 317	µg/L	-	1	EEA
Bromide	Disinfectants & Byproducts	EPA 300.0	mg/L	0.03	-	GT
Chloride	Disinfectants & byproducts	EPA 300.0	mg/L	-	0.2	Gwinnett
Chlorine, Free (as Cl2)	Disinfectants & Byproducts	SM 4500-CL G	µg/L	0.02	-	Field
Chlorine, Total	Disinfectants & Byproducts	Hach 8167	mg/L	0.02	-	Field
Chlorite	Disinfectants & byproducts	EPA 300.0B	mg/L	-	0.01	EEA
Dissolved ozone residual, grab	Disinfectants & Byproducts	Hach Method 8311	mg/L	0.01	-	Field
Dissolved ozone residual, probe	Disinfectants & Byproducts	SM 4500-O3	mg/L	TBD	-	Field
Hydrogen Peroxide	Disinfectants & Byproducts	Chemetrics test kit K-5510	mg/L	0.05	-	Field
Bromoacetic acid (MBAA)	HAAs	EPA 552.3	µg/L	0.01	-	GT
Bromochloroacetic acid (BCAA)	HAAs	EPA 552.3	µg/L	0.01	-	GT
Bromodichloroacetic acid (BDCAA)	HAAs	EPA 552.3	µg/L	0.01	-	GT
Chloroacetic acid (MCAA)	HAAs	EPA 552.3	µg/L	0.05	-	GT
Chlorodibromoacetic acid (CDBAA)	HAAs	EPA 552.3	µg/L	0.02	-	GT
Dibromoacetic acid (DBAA)	HAAs	EPA 552.3	µg/L	0.01	-	GT
Dichloroacetic acid (DCAA)	HAAs	EPA 552.3	µg/L	0.01	-	GT
Tribromoacetic acid (TBAA)	HAAs	EPA 552.3	µg/L	0.05	-	GT
Trichloroacetic acid (TCAA)	HAAs	EPA 552.3	µg/L	0.01	-	GT
2,6-dichloro-1,4-benzoquinone (DCBQ)	Haloquinones	LC-MS-MS	ng/L	1	-	GT
Cyanide, Free	Inorganic Chemicals	Sm4500Cn-F	mg/L	-	0.02	EEA
Fluoride	Inorganic Chemicals	SM 4500-F D	mg/L	0.02	-	Gwinnett
Mercury (inorganic)	Inorganic Chemicals	EPA 245.1	µg/L	0.04	0.2	EEA
Radium 226	Inorganic Chemicals	RA226 GA	pCi/L	-	1[1]	EEA
Radium 228	Inorganic Chemicals	RA228 GA	pCi/L	-	1[1]	EEA
1,1,1-trichloro-2-propanone (TCPN)	Nitrogenous & other DBPs	EPA 551.1	µg/L	0.01	-	GT
1,1,1-trichloroethane (TCE)	Nitrogenous & other DBPs	EPA 551.1	µg/L	0.03	-	GT
1,1-dichloro-2-propanone (DCPN)	Nitrogenous & other DBPs	EPA 551.1	µg/L	0.01	-	GT
1,2-dibromo-3-chloropropane (DBCPN)	Nitrogenous & other DBPs	EPA 551.1	µg/L	0.01	-	GT
1,2-dibromoethane (DBM)	Nitrogenous & other DBPs	EPA 551.1	µg/L	0.02	-	GT
Bromochloroacetonitrile (BCAN)	Nitrogenous & other DBPs	EPA 551.1	µg/L	0.01	-	GT
Bromonitromethane (BNM)	Nitrogenous & other DBPs	EPA 551.1	µg/L	0.03	-	GT
Carbon tetrachloride (CTC)	Nitrogenous & other DBPs	EPA 551.1	µg/L	0.03	-	GT
Chloral hydrate (CH)	Nitrogenous & other DBPs	EPA 551.1	µg/L	0.01	-	GT
Dibromoacetonitrile (DBAN)	Nitrogenous & other DBPs	EPA 551.1	µg/L	0.01	-	GT
Dichloroacetamide (DCAAm)	Nitrogenous & other DBPs	EPA 551.1	µg/L	0.03	-	GT
Dichloroacetonitrile (DCAN)	Nitrogenous & other DBPs	EPA 551.1	µg/L	0.01	-	GT
Tetrachloroethylene (TCEL)	Nitrogenous & other DBPs	EPA 551.1	µg/L	0.01	-	GT
Trichloroacetamide (TCAAm)	Nitrogenous & other DBPs	EPA 551.1	µg/L	0.03	-	GT
Trichloroacetonitrile (TCAN)	Nitrogenous & other DBPs	EPA 551.1	µg/L	0.02	-	GT
Trichloroethylene (TriCEL)	Nitrogenous & other DBPs	EPA 551.1	µg/L	0.01	-	GT
Trichloronitromethane (TCNM)	Nitrogenous & other DBPs	EPA 551.1	µg/L	0.02	-	GT
N-nitrosodiethylamine (NDEA)	Nitrosamines	LC-MS-MS	ng/L	0.5	-	GT
N-Nitrosodimethylamine (NDMA)	Nitrosamines	LC-MS-MS	ng/L	1	-	GT
N-nitrosodi-n-butylamine (NDBA)	Nitrosamines	LC-MS-MS	ng/L	1	-	GT
N-nitrosodi-n-propylamine (NDPA)	Nitrosamines	LC-MS-MS	ng/L	0.5	-	GT
N-nitrosodiphenylamine (NDPhA)	Nitrosamines	LC-MS-MS	ng/L	0.5	-	GT
N-Nitrosomethylaniline (NNMA)	Nitrosamines	LC-MS-MS	ng/L	0.3	-	GT
N-nitrosomethylethylamine (NMEA)	Nitrosamines	LC-MS-MS	ng/L	0.3	-	GT
N-nitrosomorpholine (NMOR)	Nitrosamines	LC-MS-MS	ng/L	0.5	-	GT
N-nitrosopiperidine (NPIP)	Nitrosamines	LC-MS-MS	ng/L	0.3	-	GT
N-nitrosopyrollidine (NPYR)	Nitrosamines	LC-MS-MS	ng/L	0.3	-	GT
Chemical Oxygen Demand (COD), grab	Organic Characteristics	SM 5220D	mg/L	4	12	Gwinnett
Chemical Oxygen Demand (COD), probe (NiCaVis)	Organic Characteristics	YSI 705 IQ sensor	mg/L	0.1	4	Field
Photochemical Oxygen Demand, grab (peCOD)	Organic Characteristics	Mantech peCOD analyzer	mg/L	0.5	-	
Dissolved Organic Carbon (DOC), grab	Organic Characteristics	SM 5310B	mg/L	0.09	0.27	Gwinnett
Dissolved Organic Carbon (DOC), probe (NiCaVis)	Organic Characteristics	YSI 705 IQ sensor	mg/L	0.1	0.1	Field
Fluorescence Excitation-Emission Matrix (EEM)	Organic Characteristics	Fluorescence spectrometer	N/A	N/A	-	Tennessee Tech
Spectral Absorption Coefficient (SAC 254), probe (NiCaVis)	Organic Characteristics	YSI 705 IQ sensor	1/m	0.1	0.1	Field
Total Organic Carbon (TOC), grab	Organic Characteristics	SM 5310B	mg/L	0.09	0.27	Gwinnett
Total Organic Carbon (TOC), probe (NiCaVis)	Organic Characteristics	YSI 705 IQ sensor	mg/L	0.1	0.1	Field
UV254, probe	Organic Characteristics	Sensorex UV-LED transmittance monitor	abs/cm	0.001	-	Field
UV Transmittance, grab	Organic Characteristics	SM 5910	%T	0.1	-	Gwinnett
UV Transmittance, probe (NiCaVis)	Organic Characteristics	YSI 705 IQ sensor	%T	0.1	0.1	Field
Perfluoro butanoic acid (PFBA)	Perfluorinated	MWH PFC (LC-MS-MS)	ng/L	-	10	EEA
Perfluoro octanesulfonic acid (PFOS)	Perfluorinated	MWH PFC (LC-MS-MS)	ng/L	-	5	EEA
Perfluoro octanoic acid (PFOA)	Perfluorinated	MWH PFC (LC-MS-MS)	ng/L	-	5	EEA
Perfluoro-1-butanesulfonic acid	Perfluorinated	MWH PFC (LC-MS-MS)	ng/L	-	5	EEA
Perfluoro-1-hexanesulfonic acid	Perfluorinated	MWH PFC (LC-MS-MS)	ng/L	-	5	EEA
Perfluoro-n-decanoic acid	Perfluorinated	MWH PFC (LC-MS-MS)	ng/L	-	5	EEA
Perfluoro-n-heptanoic acid	Perfluorinated	MWH PFC (LC-MS-MS)	ng/L	-	5	EEA
Perfluoro-n-hexanoic acid	Perfluorinated	MWH PFC (LC-MS-MS)	ng/L	-	5	EEA
Perfluoro-n-nonanoic acid	Perfluorinated	MWH PFC (LC-MS-MS)	ng/L	-	5	EEA
Perfluoropentanoic acid	Perfluorinated	MWH PFC (LC-MS-MS)	ng/L	-	5	EEA
2,3,7,8-TCDD	Pesticides/Herbicides/Fungicides	EPA 1613B	pg/L	-	5	EEA
2,4,5-TP (Silvex)	Pesticides/Herbicides/Fungicides	EPA 515.4	µg/L	-	0.5	EEA
Alachlor	Pesticides/Herbicides/Fungicides	EPA 505	µg/L	-	0.1	EEA
Benzo(a)pyrene (PAHs)	Pesticides/Herbicides/Fungicides	EPA 525.2	µg/L	-	0.02	EEA
Carbofuran	Pesticides/Herbicides/Fungicides	EPA 531.2	µg/L	-	0.5	EEA
Chlordane	Pesticides/Herbicides/Fungicides	EPA 505	µg/L	-	0.1	EEA
Dalapon	Pesticides/Herbicides/Fungicides	EPA 515.4	µg/L	-	1	EEA
Di(2-ethylhexyl) adipate	Pesticides/Herbicides/Fungicides	EPA 525.2	µg/L	-	0.6	EEA
Di(2-ethylhexyl) phthalate	Pesticides/Herbicides/Fungicides	EPA 525.2	µg/L	-	0.6	EEA
Dinoseb	Pesticides/Herbicides/Fungicides	EPA 515.4	µg/L	-	0.2	EEA
Dioxin (2,3,7,8-TCDD)	Pesticides/Herbicides/Fungicides	EPA1613B	pg/L	-	5	EEA

Notes:

-- : Limits not established for this method

TBD = Limits to be determined based on the equipment installed on the pilot

1. Radiochemical detection limits are reported as minimum detectabe activity (MDA)
2. Scaling potential will be calculated using the Langelier Saturation Index calculation.
3. Nitrate results must be corrected to NO3-N after compensating for nitrite interferences (See Sampling SOP)

Pilot Complete Analytes and Parameters

Analyte	Analytical Category	Method	Units	MDL	RL	Laboratory
Diquat	Pesticides/Herbicides/Fungicides	EPA 549.2	µg/L	-	0.4	EEA
Endothall	Pesticides/Herbicides/Fungicides	EPA 548.1	µg/L	-	5	EEA
Endrin	Pesticides/Herbicides/Fungicides	EPA 525.2	µg/L	-	0.1	EEA
Glyphosate	Pesticides/Herbicides/Fungicides	EPA 547	µg/L	-	6	EEA
Heptachlor	Pesticides/Herbicides/Fungicides	EPA 505	µg/L	-	0.01	EEA
Heptachlor epoxide	Pesticides/Herbicides/Fungicides	EPA 505	µg/L	-	0.01	EEA
Hexachlorobenzene	Pesticides/Herbicides/Fungicides	EPA 525.2	µg/L	-	0.1	EEA
Hexachlorocyclopentadiene	Pesticides/Herbicides/Fungicides	EPA 525.2	µg/L	-	0.1	EEA
Lindane	Pesticides/Herbicides/Fungicides	EPA 525.2	µg/L	-	0.1	EEA
Methoxychlor	Pesticides/Herbicides/Fungicides	EPA 525.2	µg/L	-	0.1	EEA
Oxamyl (Vydate)	Pesticides/Herbicides/Fungicides	EPA 531.2	µg/L	-	0.5	EEA
Pentachlorophenol	Pesticides/Herbicides/Fungicides	EPA 515.4	µg/L	-	0.04	EEA
Picloram	Pesticides/Herbicides/Fungicides	EPA 515.4	µg/L	-	0.1	EEA
Polychlorinated biphenyls (PCBs)	Pesticides/Herbicides/Fungicides	EPA 505	µg/L	-	0.1	EEA
Toxaphene	Pesticides/Herbicides/Fungicides	EPA 505	µg/L	-	0.5	EEA
2-Methylisoborneol (2-MIB)	Taste & Odor	SPME/GC-MS	ng/L	0.1	-	GT
Geosmin (GSM)	Taste & Odor	SPME/GC-MS	ng/L	0.5	-	GT
Bromodichloromethane (BDCM)	THMs	EPA 551.1	µg/L	0.02	-	GT
Bromoform (BF)	THMs	EPA 551.1	µg/L	0.1	-	GT
Chloroform (CF)	THMs	EPA 551.1	µg/L	0.01	-	GT
Dibromochloromethane (DBCM)	THMs	EPA 551.1	µg/L	0.01	-	GT
1,4-Dioxane	Trace Organics	EPA 522	µg/L	-	0.7	EEA
1,7-Dimethylxanthine	Trace Organics	LC-MS-MS, + Mode	ng/L	-	10	EEA
17α-Ethynylestradiol (LC-MS-MS)	Trace Organics	LC-MS-MS, - Mode	ng/L	-	5	EEA
17β-Estradiol (LC-MS-MS)	Trace Organics	LC-MS-MS, - Mode	ng/L	-	5	EEA
2,4-D	Trace Organics	LC-MS-MS, - Mode	ng/L	-	5	EEA
4-nonylphenol - semi quantitative	Trace Organics	LC-MS-MS, - Mode	ng/L	-	100	EEA
4-tert-Octylphenol	Trace Organics	LC-MS-MS, - Mode	ng/L	-	10	EEA
Acesulfame-K	Trace Organics	LC-MS-MS, - Mode	ng/L	-	20	EEA
Acetaminophen	Trace Organics	LC-MS-MS, + Mode	ng/L	-	5	EEA
Acrylamide	Trace Organics	MWH PFC (LC-MS-MS)	µg/L	-	0.1	EEA
Albuterol	Trace Organics	LC-MS-MS, + Mode	ng/L	-	5	EEA
Amoxicillin (semi-quantitative)	Trace Organics	LC-MS-MS, + Mode	ng/L	-	20	EEA
Andorostenedione	Trace Organics	LC-MS-MS, + Mode	ng/L	-	5	EEA
Atenolol	Trace Organics	LC-MS-MS, + Mode	ng/L	-	5	EEA
Atrazine (LC-MS-MS)	Trace Organics	LC-MS-MS, + Mode	ng/L	-	5	EEA
Azithromycin	Trace Organics	LC-MS-MS, + Mode	ng/L	-	20	EEA
Bendroflumethiazide	Trace Organics	LC-MS-MS, - Mode	ng/L	-	5	EEA
Bezafibrate	Trace Organics	LC-MS-MS, + Mode	ng/L	-	5	EEA
Bisphenol A (BPA)	Trace Organics	LC-MS-MS, - Mode	ng/L	-	19	EEA
Bromacil (LC-MS-MS)	Trace Organics	LC-MS-MS, + Mode	ng/L	-	5	EEA
Butalbital	Trace Organics	LC-MS-MS, - Mode	ng/L	-	5	EEA
Butylparaben	Trace Organics	LC-MS-MS, - Mode	ng/L	-	5	EEA
Caffeine (LC-MS-MS)	Trace Organics	LC-MS-MS, + Mode	ng/L	-	5	EEA
Carbadox	Trace Organics	LC-MS-MS, + Mode	ng/L	-	5	EEA
Carbamazepine	Trace Organics	LC-MS-MS, + Mode	ng/L	-	5	EEA
Carisoprodol	Trace Organics	LC-MS-MS, + Mode	ng/L	-	5	EEA
Chloramphenicol	Trace Organics	LC-MS-MS, - Mode	ng/L	-	10	EEA
Chloridazon	Trace Organics	LC-MS-MS, + Mode	ng/L	-	5	EEA
Chlorotoluron	Trace Organics	LC-MS-MS, + Mode	ng/L	-	5	EEA
Cimetidine	Trace Organics	LC-MS-MS, + Mode	ng/L	-	5	EEA
Clofibric Acid	Trace Organics	LC-MS-MS, - Mode	ng/L	-	5	EEA
Cotinine	Trace Organics	LC-MS-MS, + Mode	ng/L	-	10	EEA
Cyanazine	Trace Organics	LC-MS-MS, + Mode	ng/L	-	5	EEA
DACT	Trace Organics	LC-MS-MS, + Mode	ng/L	-	5	EEA
DEA	Trace Organics	LC-MS-MS, + Mode	ng/L	-	5	EEA
DEET	Trace Organics	LC-MS-MS, + Mode	ng/L	-	10	EEA
Dehydronifedipine	Trace Organics	LC-MS-MS, + Mode	ng/L	-	5	EEA
DIA	Trace Organics	LC-MS-MS, + Mode	ng/L	-	5	EEA
Diazepam	Trace Organics	LC-MS-MS, + Mode	ng/L	-	5	EEA
Diclofenac	Trace Organics	LC-MS-MS, - Mode	ng/L	-	5	EEA
Dilantin	Trace Organics	LC-MS-MS, + Mode	ng/L	-	20	EEA
Diltiazem	Trace Organics	LC-MS-MS, + Mode	ng/L	-	5	EEA
Diuron	Trace Organics	LC-MS-MS, + Mode	ng/L	-	5	EEA
Erythromycin	Trace Organics	LC-MS-MS, + Mode	ng/L	-	10	EEA
Estrone (LC-MS-MS)	Trace Organics	LC-MS-MS, - Mode	ng/L	-	5	EEA
Ethylparaben	Trace Organics	LC-MS-MS, - Mode	ng/L	-	20	EEA
Flumeqine	Trace Organics	LC-MS-MS, + Mode	ng/L	-	10	EEA
Fluoxetine	Trace Organics	LC-MS-MS, + Mode	ng/L	-	10	EEA
Gemfibrozil	Trace Organics	LC-MS-MS, - Mode	ng/L	-	5	EEA
Ibuprofen	Trace Organics	LC-MS-MS, - Mode	ng/L	-	10	EEA
Iohexal	Trace Organics	LC-MS-MS, - Mode	ng/L	-	10	EEA
Iopromide	Trace Organics	LC-MS-MS, - Mode	ng/L	-	5	EEA
Isobutylparaben	Trace Organics	LC-MS-MS, - Mode	ng/L	-	5	EEA
Isoproturon	Trace Organics	LC-MS-MS, + Mode	ng/L	-	100	EEA
Ketoprofen	Trace Organics	LC-MS-MS, + Mode	ng/L	-	5	EEA
Ketorolac	Trace Organics	LC-MS-MS, + Mode	ng/L	-	5	EEA
Lidocaine	Trace Organics	LC-MS-MS, + Mode	ng/L	-	5	EEA
Lincomycin	Trace Organics	LC-MS-MS, + Mode	ng/L	-	10	EEA
Linuron	Trace Organics	LC-MS-MS, + Mode	ng/L	-	5	EEA
Lipitor (Atorvastatin)	Trace Organics	LC-MS-MS, - Mode	ng/L	-	100	EEA
Lopressor	Trace Organics	LC-MS-MS, + Mode	ng/L	-	29	EEA
Meclofenamic Acid	Trace Organics	LC-MS-MS, + Mode	ng/L	-	5	EEA
Meprobamate	Trace Organics	LC-MS-MS, + Mode	ng/L	-	5	EEA
Metazachlor	Trace Organics	LC-MS-MS, + Mode	ng/L	-	5	EEA
Methylparaben	Trace Organics	LC-MS-MS, - Mode	ng/L	-	20	EEA
Metolachlor	Trace Organics	LC-MS-MS, + Mode	ng/L	-	5	EEA
Naproxen	Trace Organics	LC-MS-MS, - Mode	ng/L	-	10	EEA
Nifedipine	Trace Organics	LC-MS-MS, + Mode	ng/L	-	20	EEA
Norethisterone	Trace Organics	LC-MS-MS, + Mode	ng/L	-	5	EEA
Oxolinic acid	Trace Organics	LC-MS-MS, + Mode	ng/L	-	10	EEA
Pentoxifylline	Trace Organics	LC-MS-MS, + Mode	ng/L	-	5	EEA
Phenazone	Trace Organics	LC-MS-MS, + Mode	ng/L	-	5	EEA
Primidone	Trace Organics	LC-MS-MS, + Mode	ng/L	-	5	EEA
Progesterone	Trace Organics	LC-MS-MS, + Mode	ng/L	-	5	EEA
Propazine	Trace Organics	LC-MS-MS, + Mode	ng/L	-	5	EEA
Propylparaben	Trace Organics	LC-MS-MS, - Mode	ng/L	-	5	EEA
Quinoline	Trace Organics	LC-MS-MS, + Mode	ng/L	-	5	EEA
Salicylic Acid	Trace Organics	LC-MS-MS, - Mode	ng/L	-	100	EEA
Simazine	Trace Organics	LC-MS-MS, + Mode	ng/L	-	5	EEA
Sucralose	Trace Organics	LC-MS-MS, - Mode	ng/L	-	100	EEA
Sulfachloropyridazine	Trace Organics	LC-MS-MS, + Mode	ng/L	-	5	EEA

Notes:
-- : Limits not established for this method
TBD = Limits to be determined based on the equipment installed on the pilot
1. Radiochemical detection limits are reported as minimum detectabe activity (MDA)
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