Town of Cary

Water Distribution System Master Plan Report

Addendum: Water Quality Model and Analysis

April 2010

Prepared by

CH2MHILL

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Appendices

A ADS Environmental Services Report: District Measurement and Analysis Report Town of Cary, North Carolina July 2009

B Bulk Decay Testing Results

C Model Results

D Southern Pressure Zone Model Results

E Water Quality Addendum Review Comments and Responses

Background and Scope of Work

CH2M HILL completed a Water Distribution System Master Plan and Model report for the Town of Cary in June 2009. This project provided the Town with a calibrated hydraulic computer model that can perform extended period simulations (EPS) of existing operating conditions and for the following defined planning periods: 2010, 2015, 2025, and build-out. This project also provided the Town with a list of prioritized water distribution system capital improvement projects (CIPs).

The Town has completed its EPA mandated Stage 2 Initial Distribution System Evaluation (IDSE) study and has identified areas within the water distribution system that on occasion have low chlorine residual and high disinfection by-products such as trihalomethanes (THMs) and Haloacetic Acids (HAAs).

The Town contracted with CH2M HILL to develop a chlorine residual-based water quality model, based on the calibrated hydraulic model, to simulate chlorine residual in the distribution system. This Report Addendum describes the water quality modeling and analysis, and the results of a re-evaluation of the originally proposed capital projects to determine their effects on water quality in the distribution system. This Addendum is subdivided as follows:

- Hydraulic Model Calibration
- Water Quality Model Development
- CIP Evaluation

SECTION 1

Hydraulic Model Calibration

Prior to the water quality model development, additional hydraulic model calibration was conducted based on additional field data, with the intention of refining the EPS model. Field district measurements were conducted to better define the spatial and temporal demand variations in the system. These new diurnal demand patterns were then incorporated into the hydraulic model to improve the EPS calibration.

1.1 District Measurements

District measurements are conducted by isolating an area of a water system and measuring flow in and out of the district through key trunk mains as well as accounting for the flow in and out of elevated storage tanks. Pitometer insertion rod-meters are used to measure flow in the key trunk mains and SCADA tank level data is used to determine flow in and out of the tanks. Calculating the total volume consumed over time provides a diurnal demand curve that can be incorporated into the computer model.

- Seven district measurements were conducted in the Cary water distribution system from June 18-24, 2009 by ADS Environmental Services. Appendix A contains the ADS report which includes a map showing the districts and measurement locations. Diurnal demand curves were developed for the following districts:
- Western Pressure Zone – East District (WPZ ED)
- Western Pressure Zone – West District (WPZ WD)
- Central Pressure Zone – RDU Airport District (CPZ AD)
- Central Pressure Zone – Morrisville District (CPZ MD)
- Central Pressure Zone – South District (CPZ SD)
- Central Pressure Zone – North District (CPZ ND)
- Southern Pressure Zone (SPZ)

1.2 Hydraulic Model Calibration

The EPS calibration was performed using the field data measured on June 23, 2009. The field-measured diurnal demand curves were adjusted by deleting unusual outliers such as spikes that were measured around midnight on that day. Figures 1.1 through 1.4 show the new diurnal curves compared to the curves used in the original model calibration. Questionable constant flat flow data was recorded at meter R2 (shown in Figure 1.5) and it was decided to use the combined diurnal curves of CPZ ND and CPZ SD instead for these two districts. Figure 1.6 shows the updated diurnal curves for the Green Level and Jenks Road master meters (MM) that supply the Town of Apex water system.

FIGURE 1.1
WPZ District Measurement
Hydraulic Model Calibration

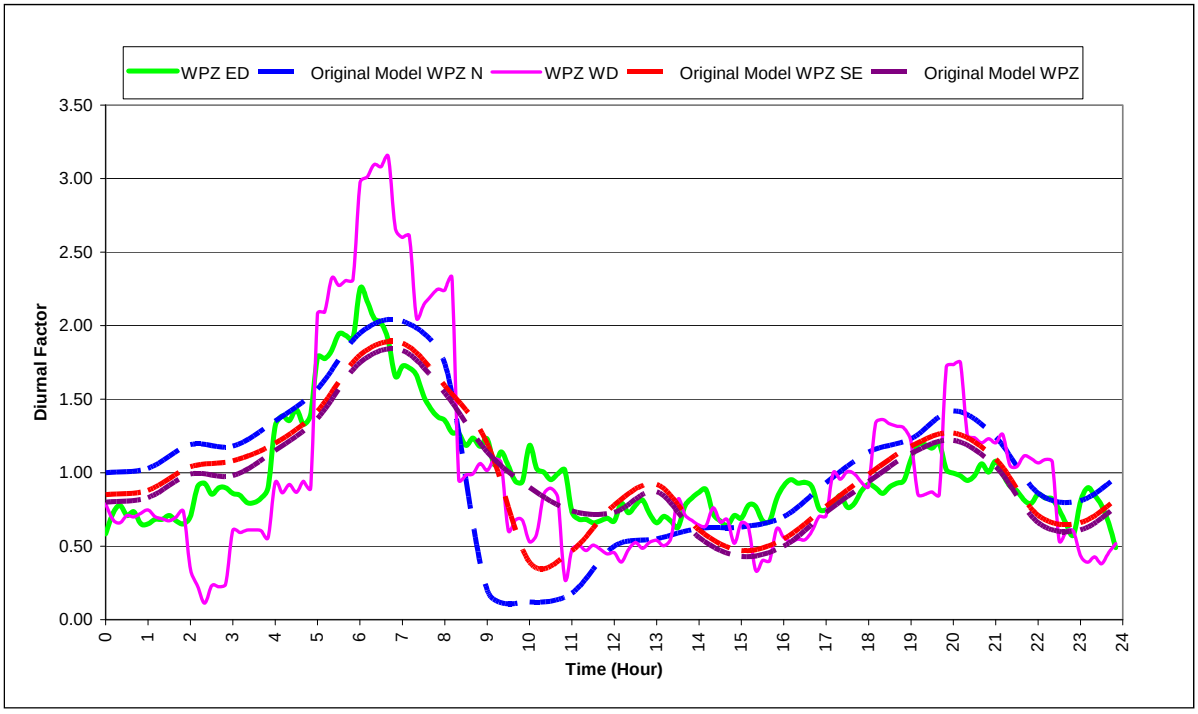


FIGURE 1.2
SPZ District Measurement
Hydraulic Model Calibration

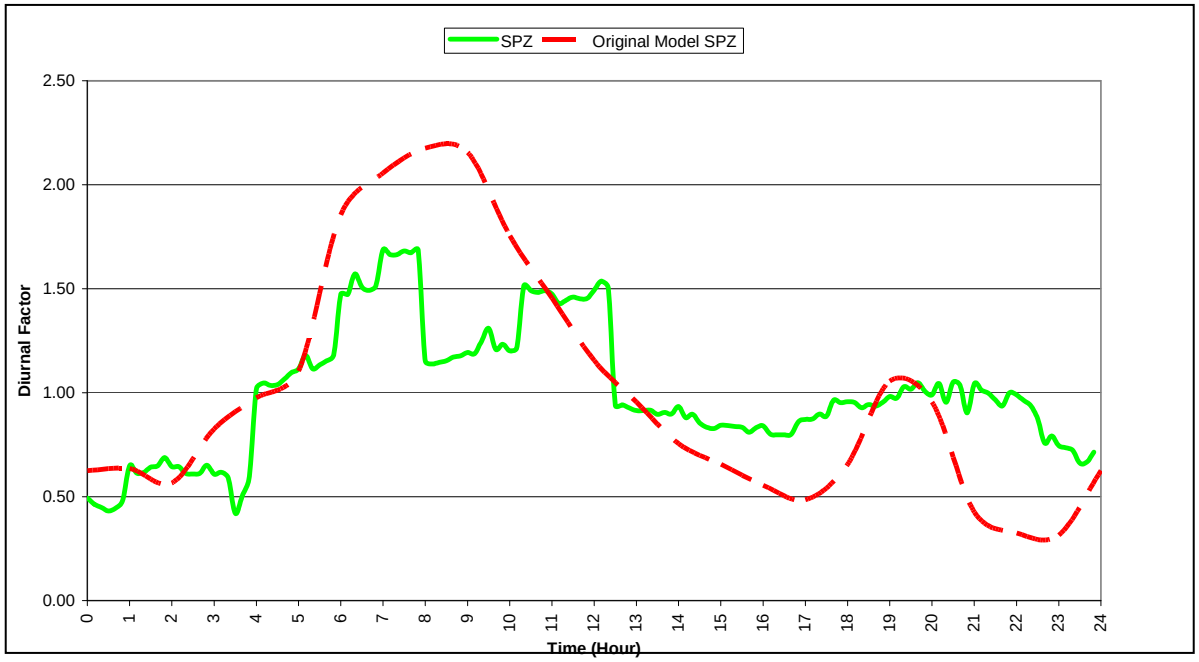


FIGURE 1.3
CPZ Morrisville District Measurement
Hydraulic Model Calibration

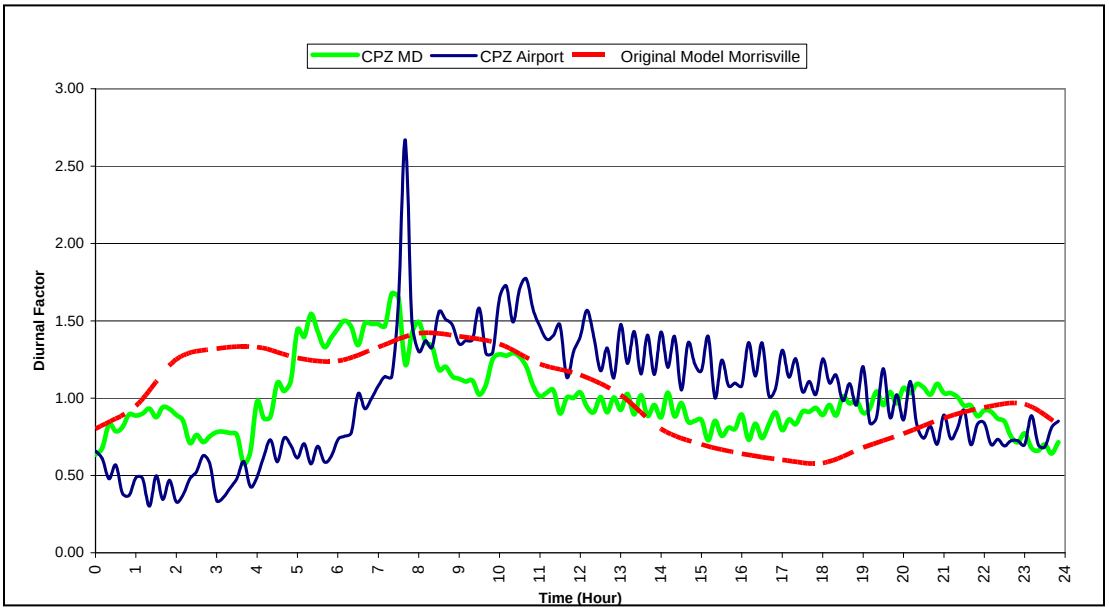


FIGURE 1.4
CPZ District Measurement
Hydraulic Model Calibration

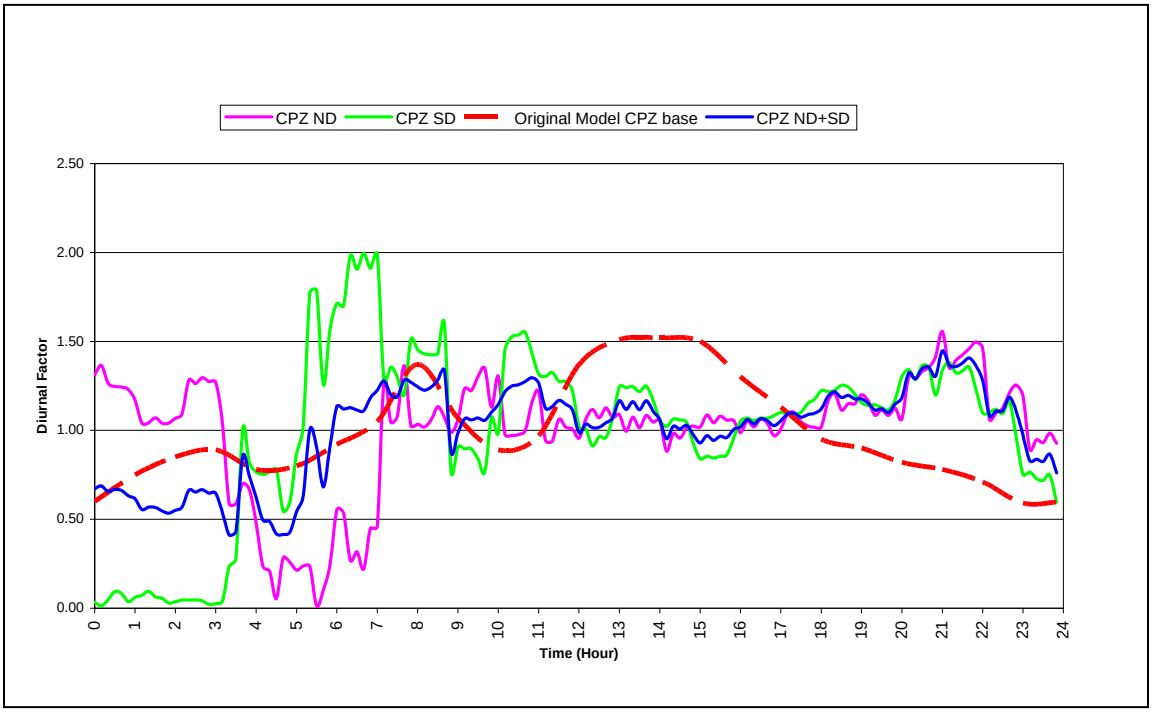


FIGURE 1.5
CPZ District Measurement: Field Data
Hydraulic Model Calibration

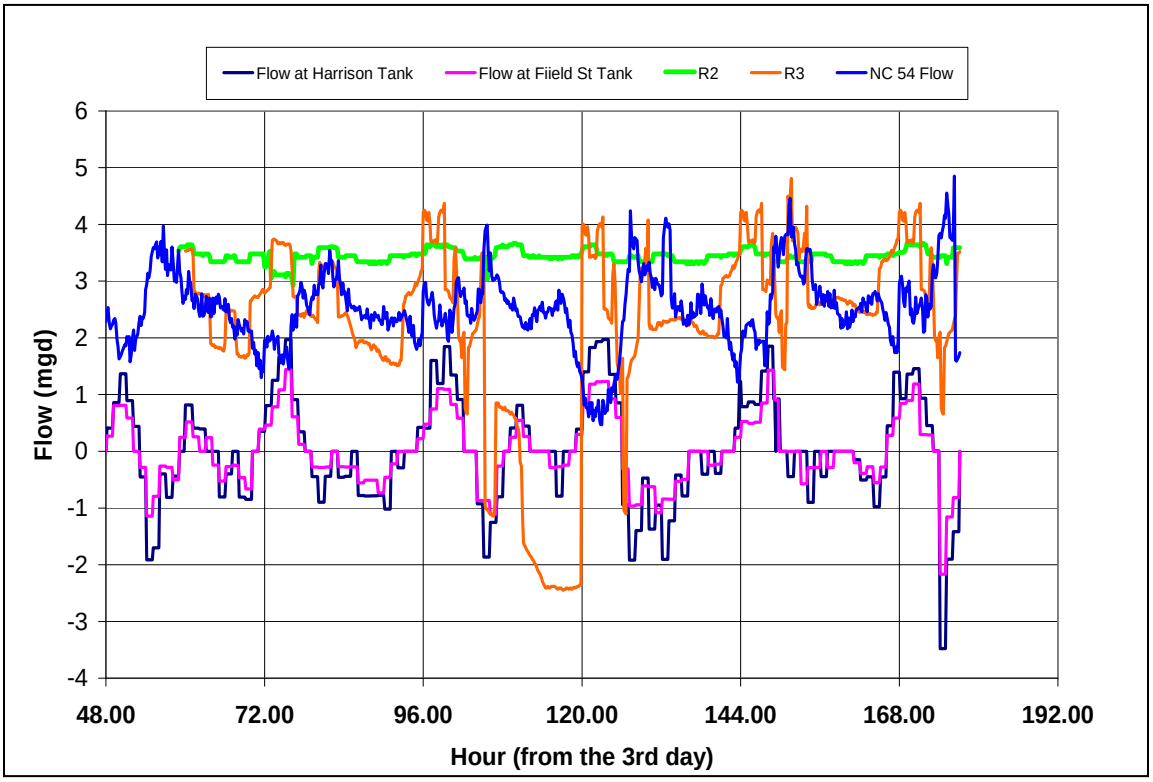
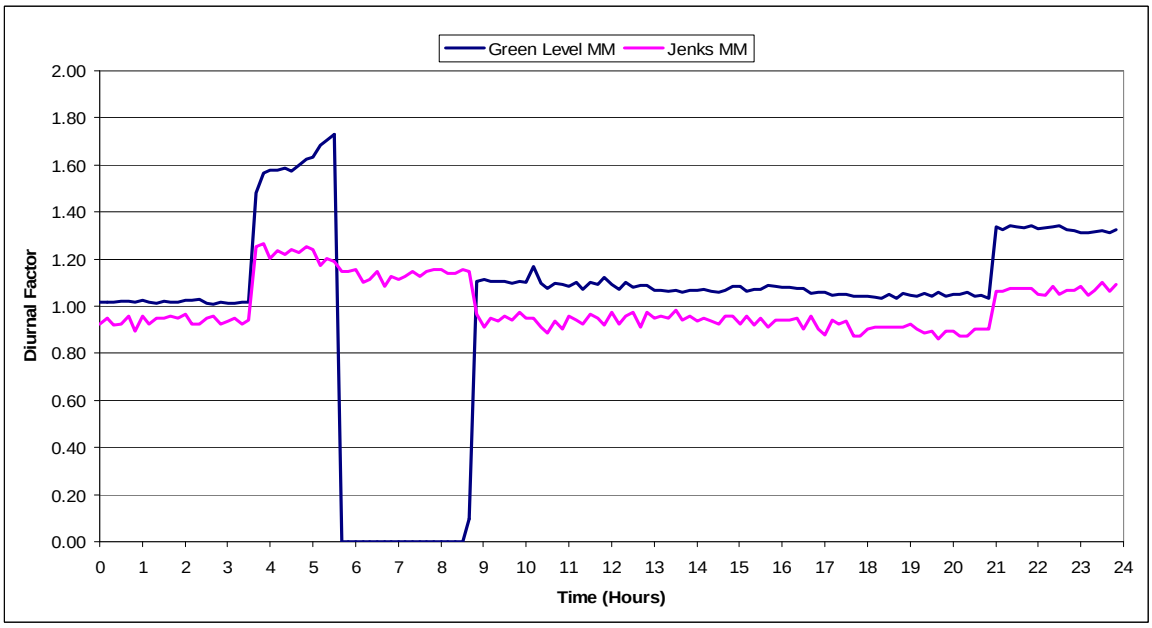


FIGURE 1.6
District Measurement: Green Level Master Meter and Jenks Road Master Meter to Apex
Hydraulic Model Calibration



Using this additional field data, the original hydraulic model was recalibrated for the existing condition average day demand (ADD). The model water demands were first adjusted to reflect the demands measured in the field on the calibration date of June 23, 2009 as shown in Table 1.1. The model controls at the Cary/Apex Water Treatment Plant High Service Pump Station (HSPS) and the Kildaire Farm Road control valve were updated based on the Town's SCADA records to reflect the system operation on the calibration date.

TABLE 1-1
Water Demands Measured on June 23, 2009
Hydraulic Model Calibration

Pressure Zones/Districts	Water Demand Measured on June 23, 2009 (mgd)
WPZ	4.04
CPZ Morrisville / RDU Airport	2.88
CPZ without Morrisville / RDU Airport	6.77
SPZ	2.53
Apex	4.36
Total	**20.58**

Town staff had noted modifications needed to the model to reflect actual operating conditions at two locations and the model was updated to include these two network changes as follows:

- Disconnected the 8-inch line at Church Street from the 16-inch line from Town Hall Drive. The result is that the Old Town area is only supplied from the south through the PRV on Highway 54.
- Closed pipe xxxx004078.xxxx024592.1 at Davis Drive. The result is that the 16-inch pipe along Davis Drive is disconnected between Parkside Valley Drive and McCrimmon Parkway.

To recalibrate the model, water levels in the elevated tanks and flows at meters were compared with the model results. As shown in Figures 1.7 through 1.23, the model correlated well with the measured data in most cases, and the differences in tank levels between the model and the SCADA were all within 4 feet, which meets the generally accepted industry standard of 5 feet for hydraulic calibration of tank levels.

As shown in Figures 1.7 through 1.9, in the WPZ the model and field data show the best correlation without any change in the original model parameters.

The SPZ shows good correlation between model and field data as shown in Figures 1.10 through 1.12. The results of the model calibration identified that a pipe was wrongly labeled in the Town's GIS database along Lochmere Drive east of Kildaire Farm Road. Town staff confirmed the pipe is actually 12-inch diameter as predicted by the model, instead of the 8-inch diameter per the GIS data. The original CIP recommendations included Project SPZ-8 comprised of installing a new 12-inch pipe at this location. Once the model was updated to

use the 12-inch line, Project SPZ-8 was no longer required and is now deleted from the CIP list.

In the CPZ North District, the flow trends at meters R2 and R3 as shown in Figures 1.18 and 1.19 is not replicated by the model. The constant flat flow at meter R2 is questionable considering both meters R2 and R3 were located on the major pipelines that supply the north district, the Town of Morrisville and the RDU Airport. The ADS report indicated that there was a problem at meter R2 due to low pipe velocity. The model shows good correlation with the field data for the tank levels, with the Field Street tank showing the maximum difference within 4 feet which is within the industry standard.

Master meter flow data are the primary parameter for model calibration of the CPZ Morrisville and RDU Airport districts. As shown in Figures 1.20 thru 1.23, the initial model results (green solid line) show a significant difference at all the meters, especially at the two major supply meters at Highway 54 and Evans Road. The model indicates a balanced supply between the Highway 54 and Evans master meters while the field data shows an average of 0.2 mgd flow through the Evans master meter, which is only 7% of the total demand within the Morrisville and RDU Airport districts. Based on the model result, CH2M HILL suspected closed or partially closed valves were located around the Evans master meter (Figures 1.20 through 1.23) and the Town wished to investigate the area before completing this modeling effort. Town staff confirmed in the field that there was a buried and closed (and previously unknown) 16-inch valve at that location and that all water had been passing through a 4-inch by-pass line. Town staff has since opened the 16-inch valve. The model calibration results at the Lake Crabtree and Holiday Inn master meters also indicated a possible partially closed valve near the Holiday Inn master meter. The discrepancy is not significant but further investigation is recommended since it may impact the available pressure at the RDU Airport.

FIGURE 1.7
WPZ: Carpenter Tank
Hydraulic Model Calibration

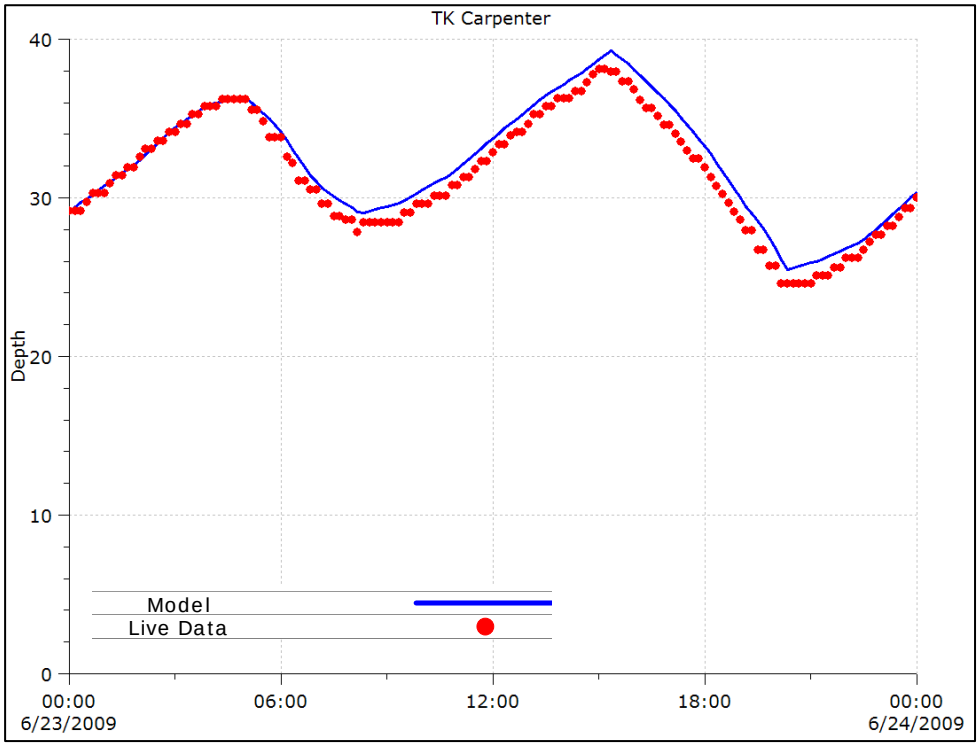


FIGURE 1.8
WPZ: HSPS Flow
Hydraulic Model Calibration

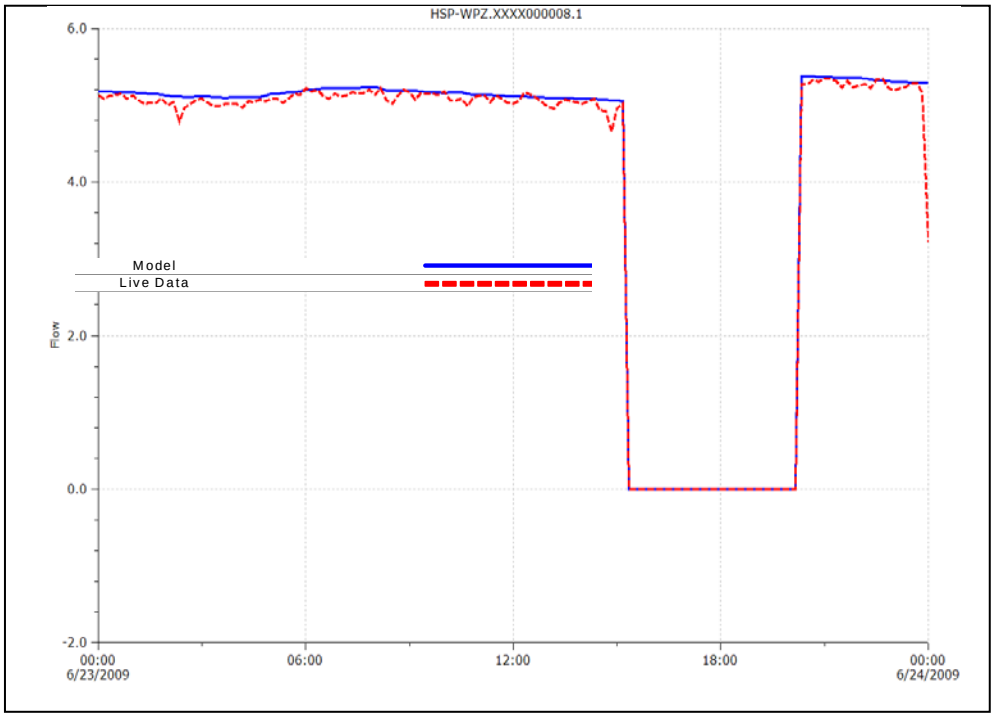


FIGURE 1.9
WPZ: Meter R1 Flow
Hydraulic Model Calibration

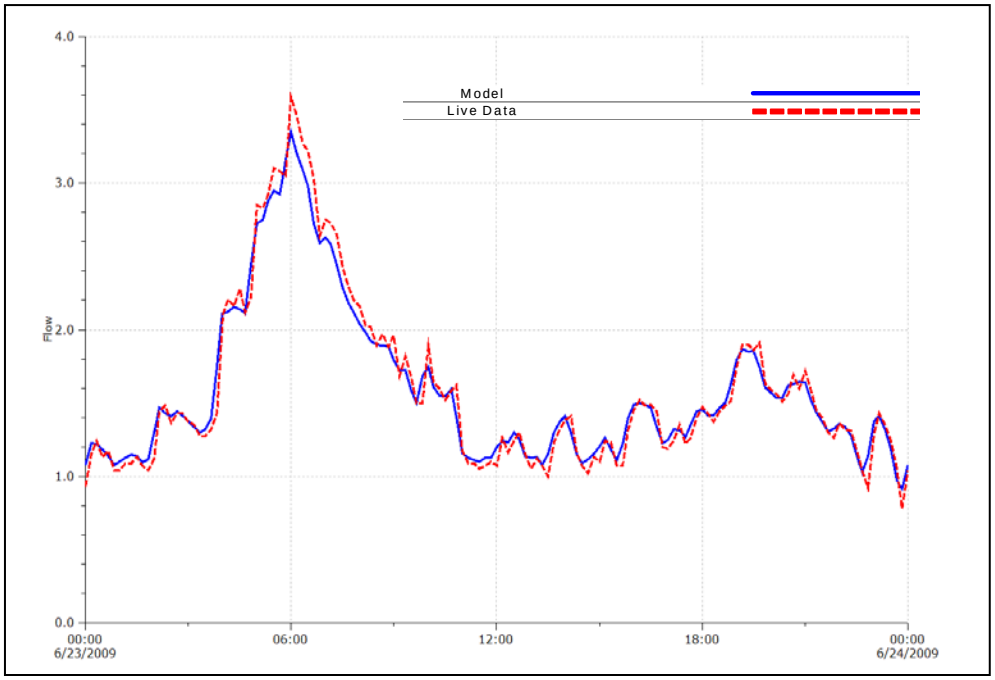


FIGURE 1.10
SPZ: Plumtree Way Tank
Hydraulic Model Calibration

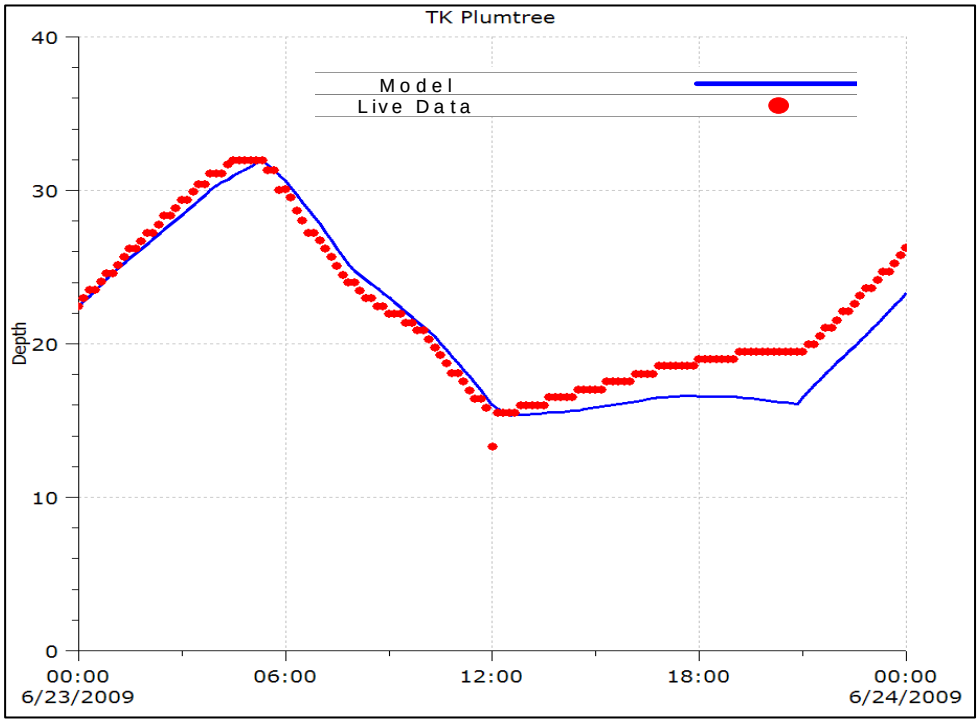


FIGURE 1.11
SPZ: Cary Parkway Control Valve Flow
Hydraulic Model Calibration

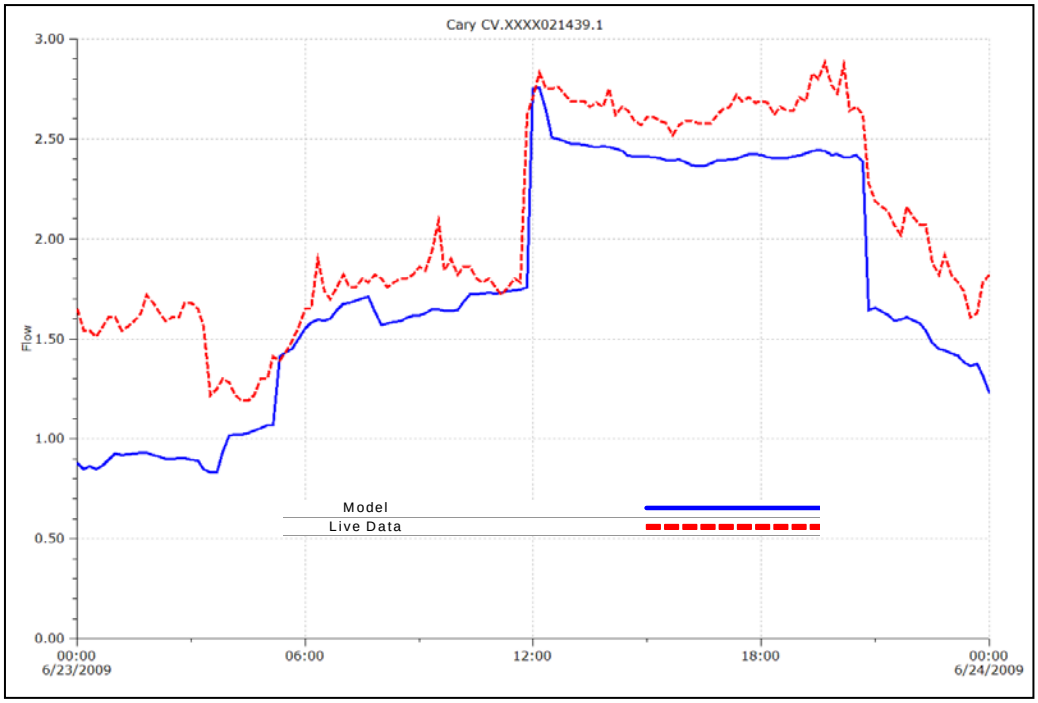


FIGURE 1.12
SPZ: Kildaire Farm Road Control Valve Flow
Hydraulic Model Calibration

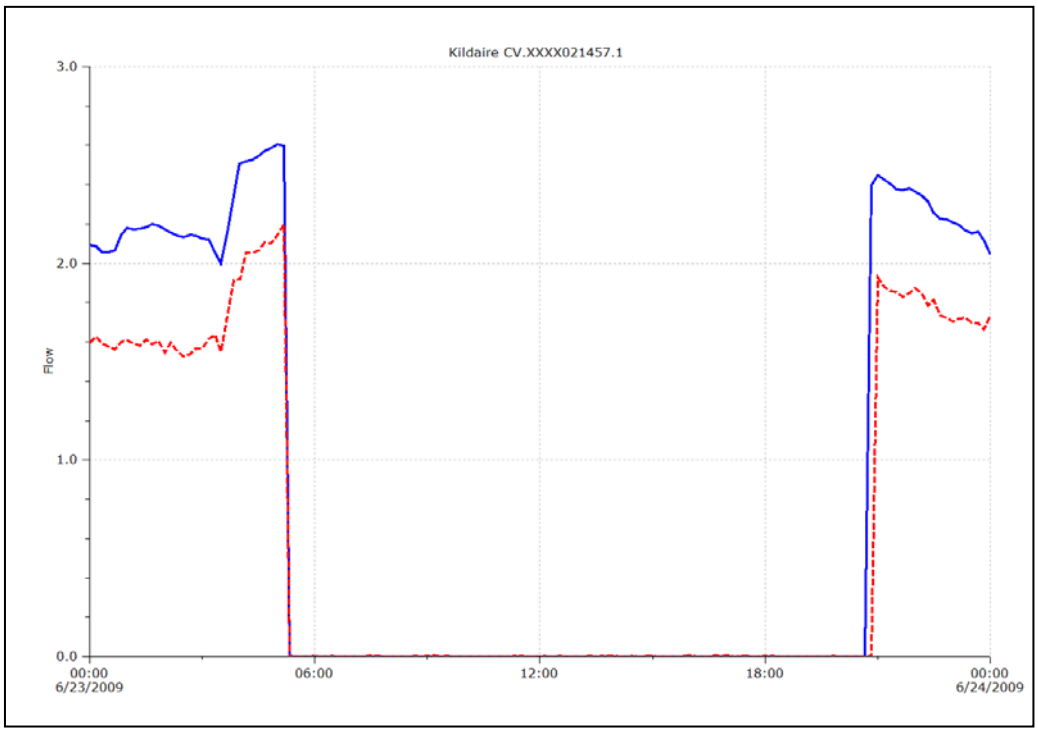


FIGURE 1.13
CPZ: Field Street Tank
Hydraulic Model Calibration

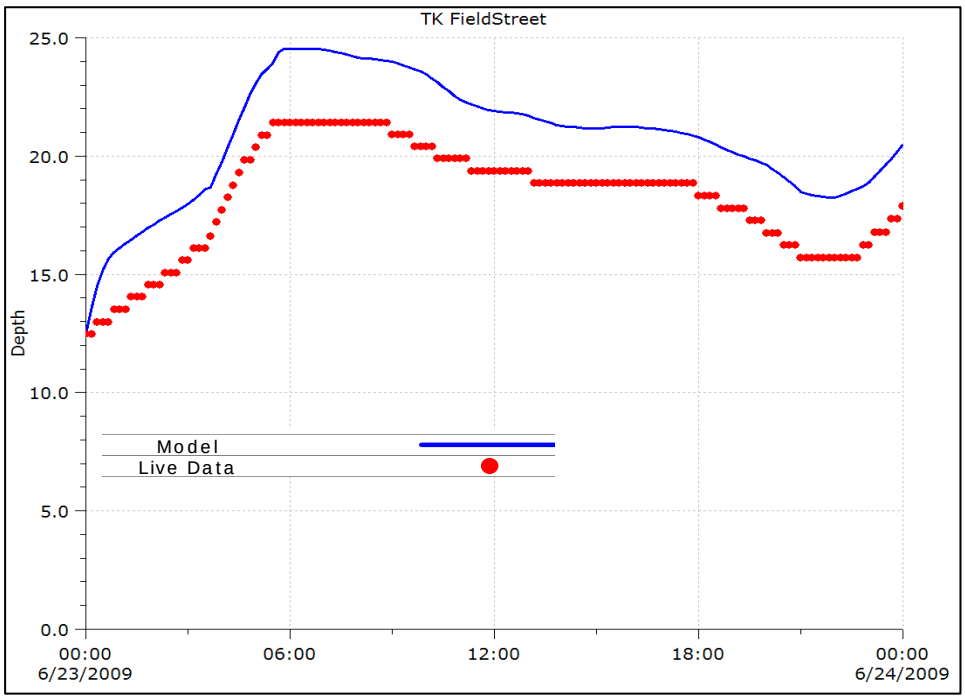


FIGURE 1.14
CPZ: Harrison Tank
Hydraulic Model Calibration

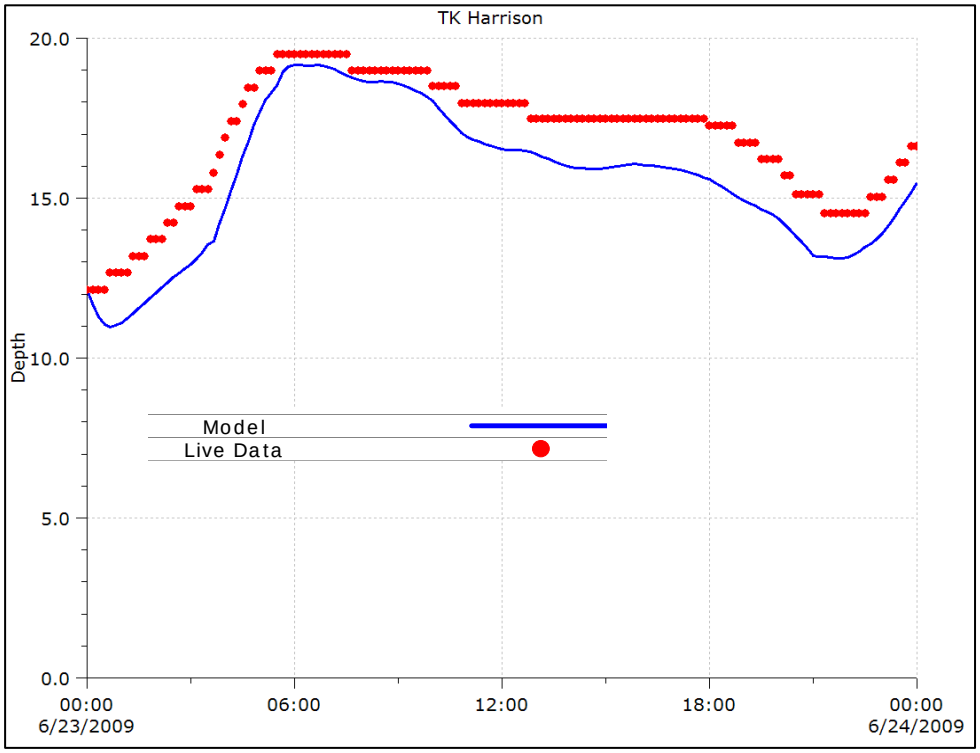


FIGURE 1.15
CPZ: Maynard Tank
Hydraulic Model Calibration

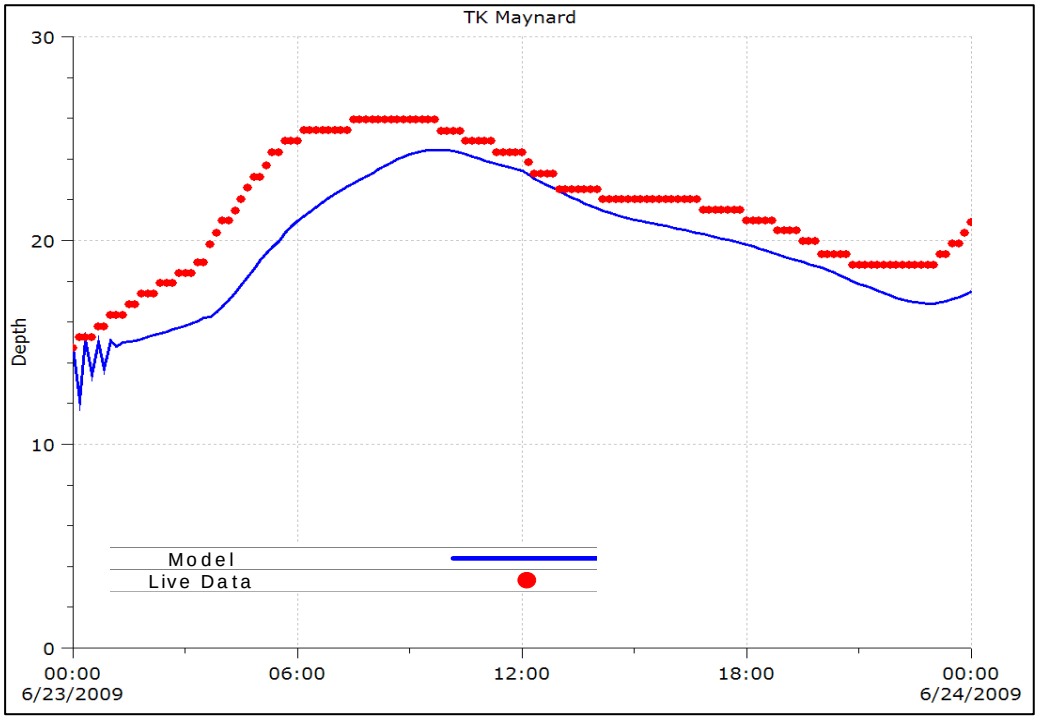


FIGURE 1.16
CPZ: Ridgeview Tank
Hydraulic Model Calibration

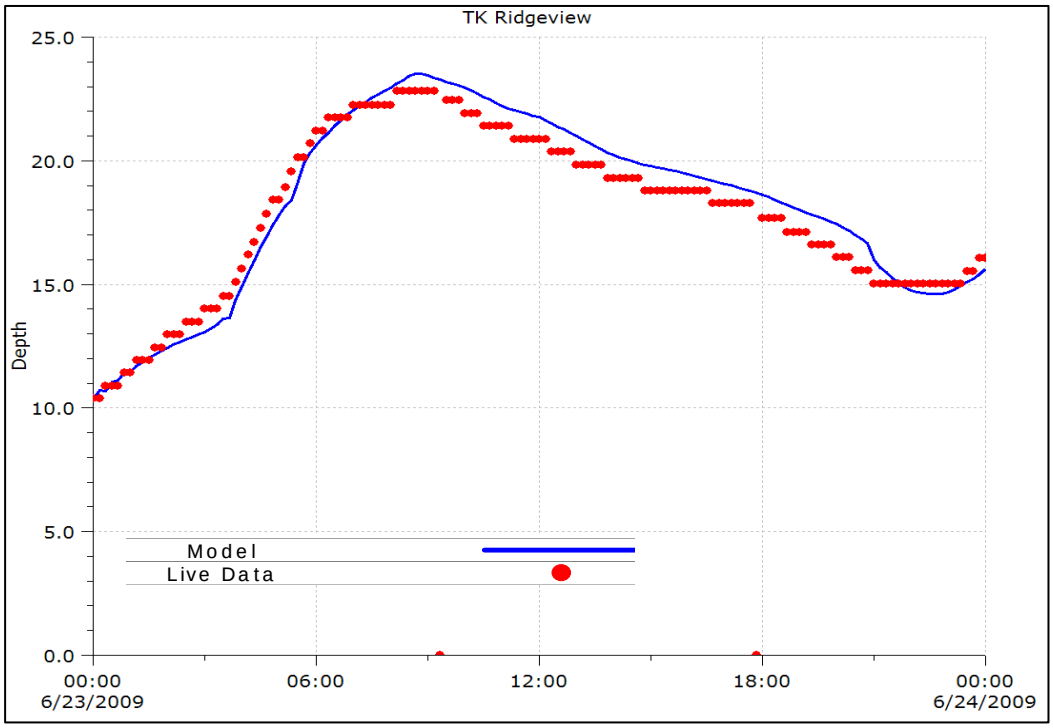


FIGURE 1.17
CPZ: HSPS Flow
Hydraulic Model Calibration

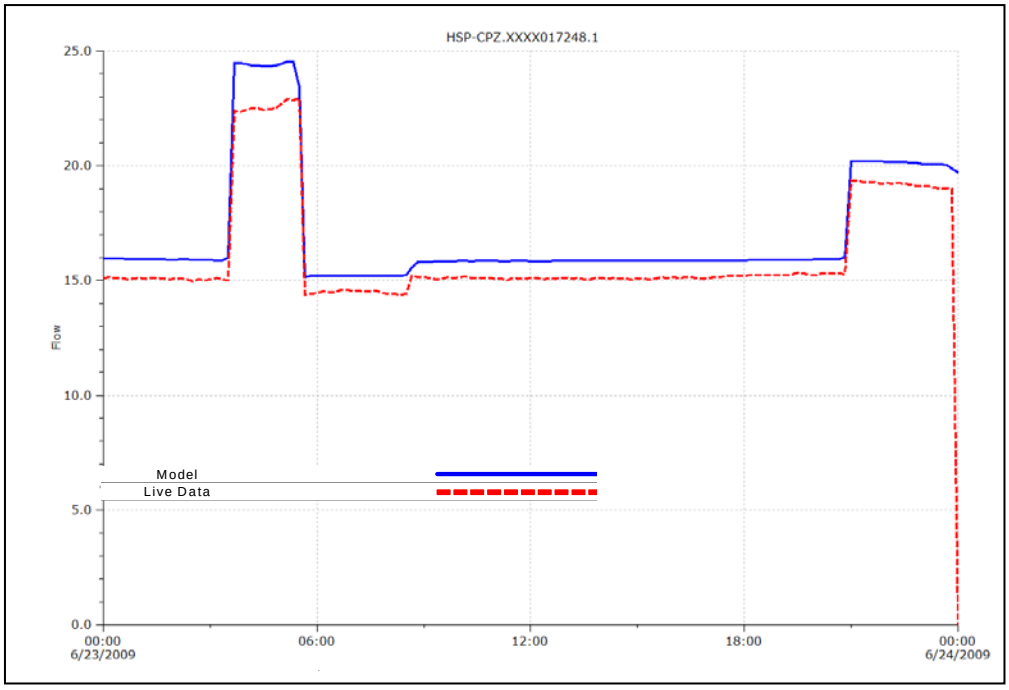


FIGURE 1.18
CPZ: Meter R3 Flow
Hydraulic Model Calibration

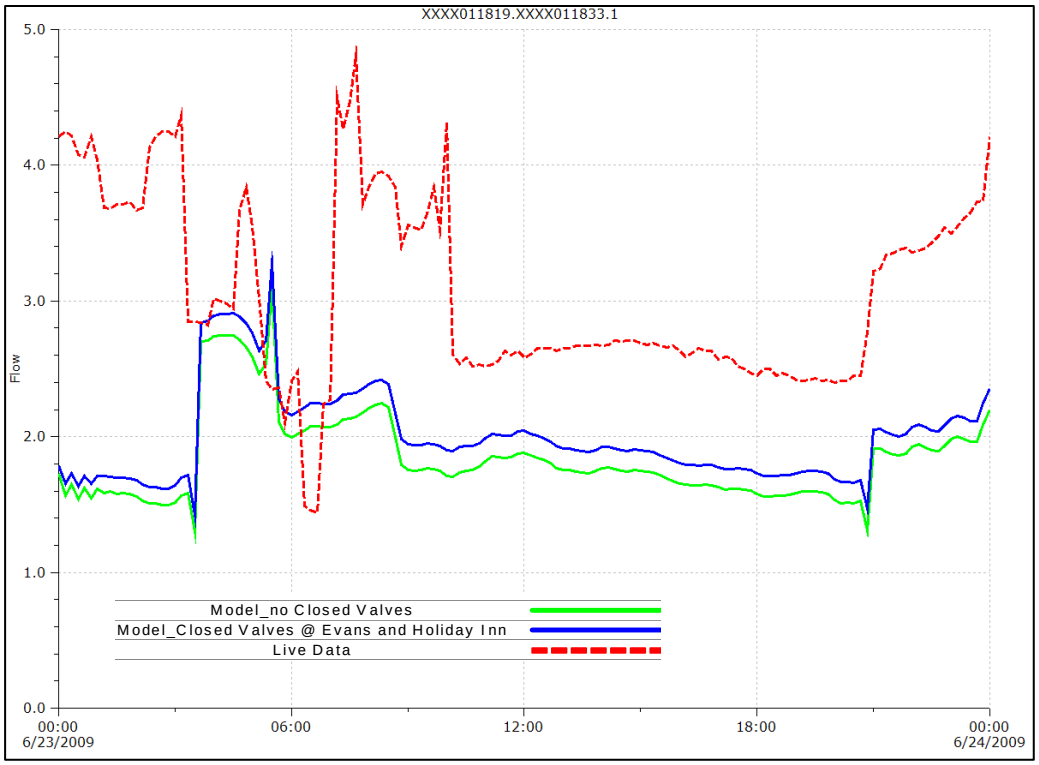


FIGURE 1.19
CPZ: Meter R2 Flow
Hydraulic Model Calibration

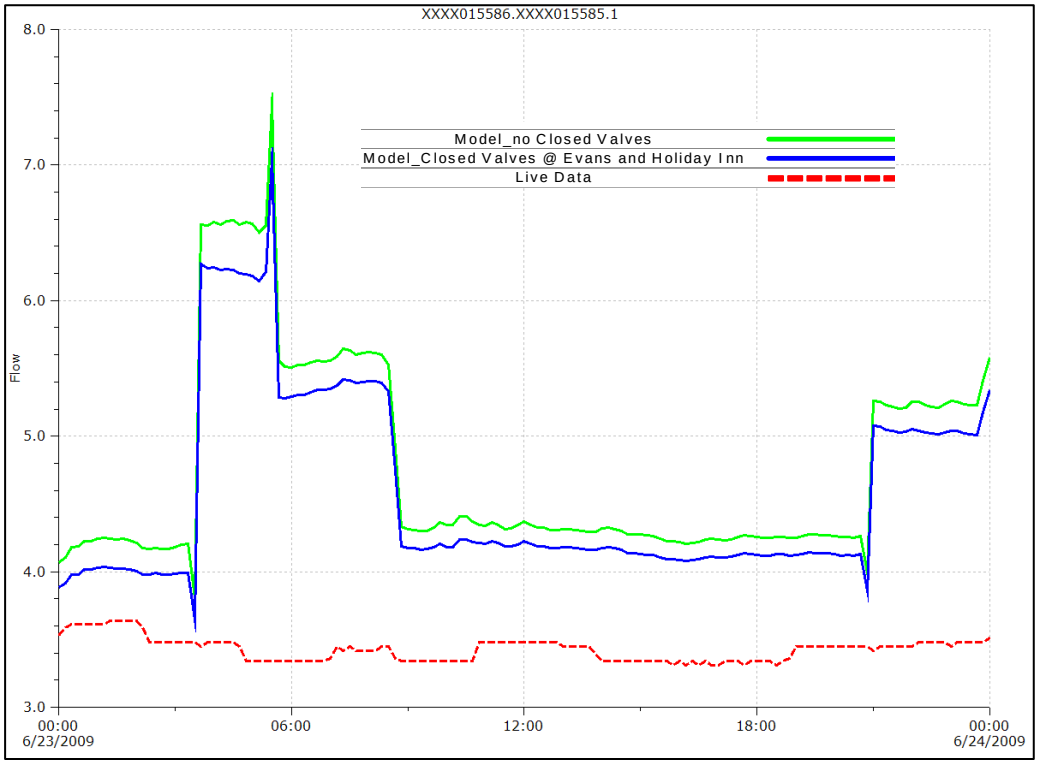


FIGURE 1.20
CPZ: Evans Master Meter Flow
Hydraulic Model Calibration

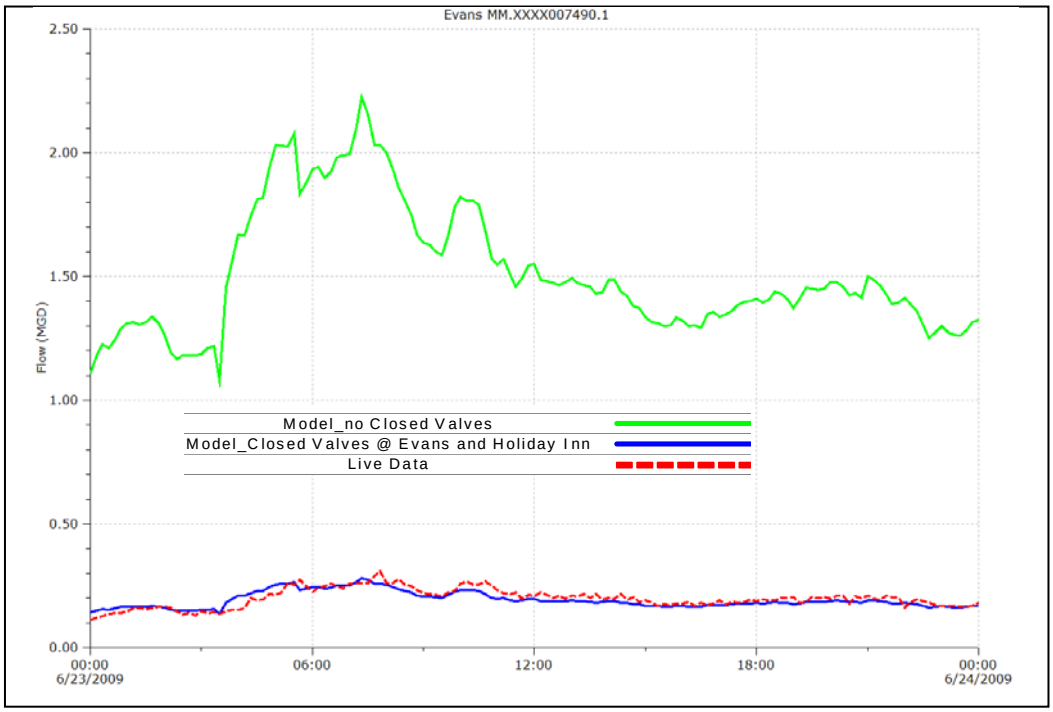


FIGURE 1.21
CPZ: Holiday Inn Master Meter Flow
Hydraulic Model Calibration

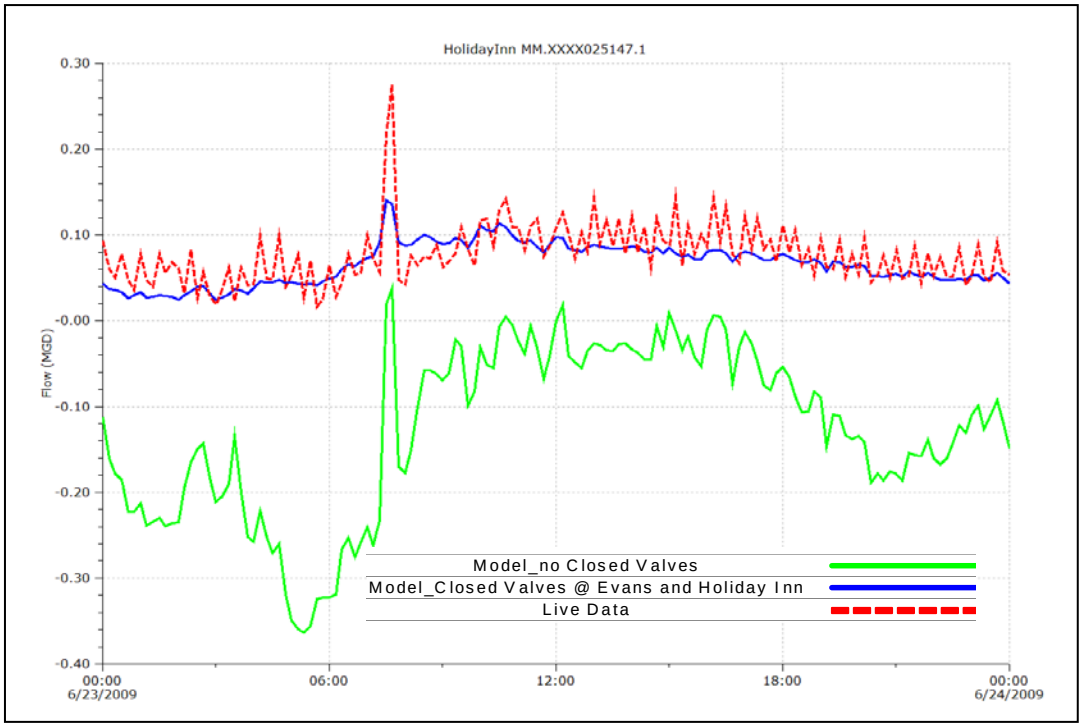


FIGURE 1.22
CPZ: Lake Crabtree Master Meter Flow
Hydraulic Model Calibration

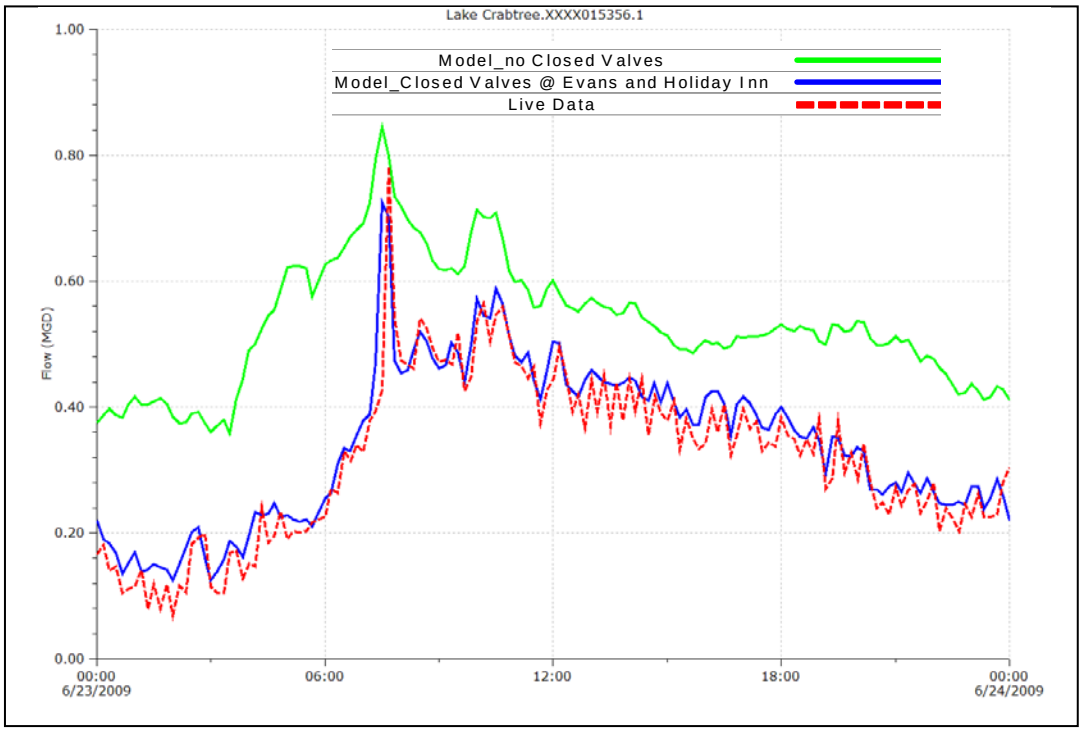
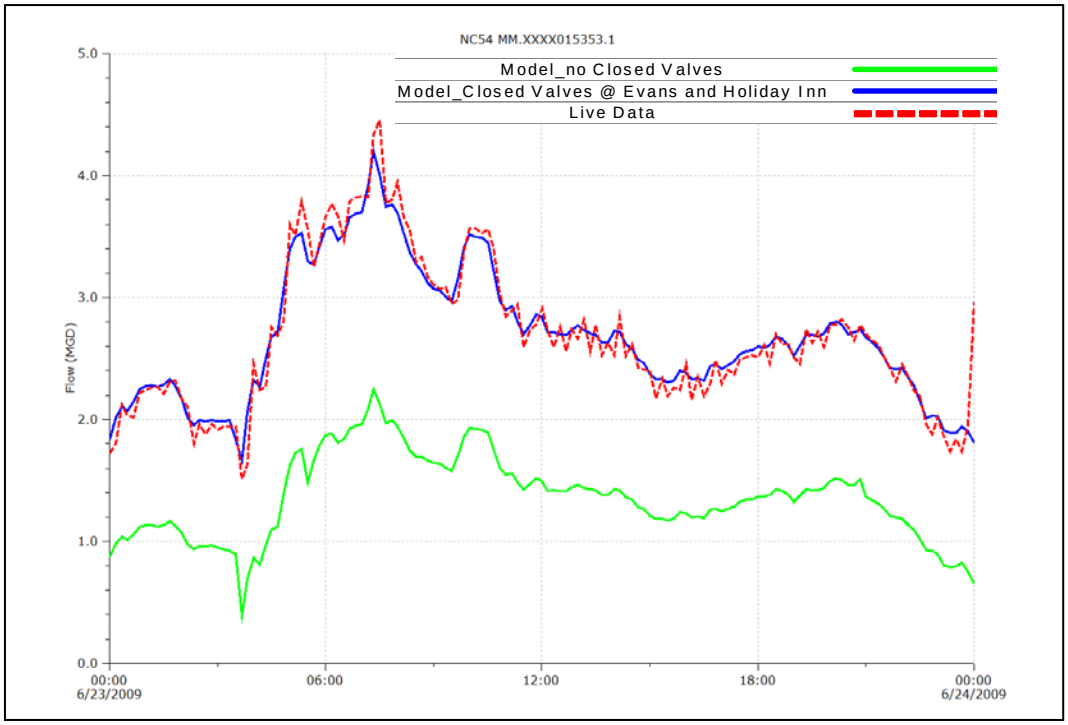


FIGURE 1.23
CPZ: Highway NC 54 Master Meter Flow
Hydraulic Model Calibration



1.2.1 Summary

Based on the field district measurements conducted in June 2009, and the new diurnal demand curves calculated from the field data, the original hydraulic model was successfully recalibrated to better reflect system operations. The recalibrated model correctly identified the location of the closed 16-inch valve near the Evans master meter which was found and opened by Town staff. Although staff has not conducted additional field measurements, it is believed that this closed valve was the cause of low pressures around the RDU Airport and the Aviation Parkway areas.

SECTION 2

Water Quality Model Development

The recalibrated model was set for a long term EPS water age run with the objective to ensure that equilibrium was reached throughout the distribution system during the run. The model was then calibrated to measured water quality data to produce the calibrated water quality model.

2.1 Water Age Analysis

A water age analysis was performed using longer run times, allowing the elevated tanks to fill and draw in stable and repeatable patterns. The tanks in the system stabilized within a 280-hour simulation. Once the tanks reached stabilization, the model predicted the water age range of each of the six tanks as shown in Table 2.1 and Figure 2.1.

TABLE 2-1
Elevated Tank – Modeled Water Age
Water Quality Model Development

Tank	Model-Predicted Water Age (hours)
Carpenter	42 – 52
Field Street	44 – 54
Harrison	71 – 88
Maynard	55 – 75
Ridgeview	75 – 93
Plumtree Way	108 – 128

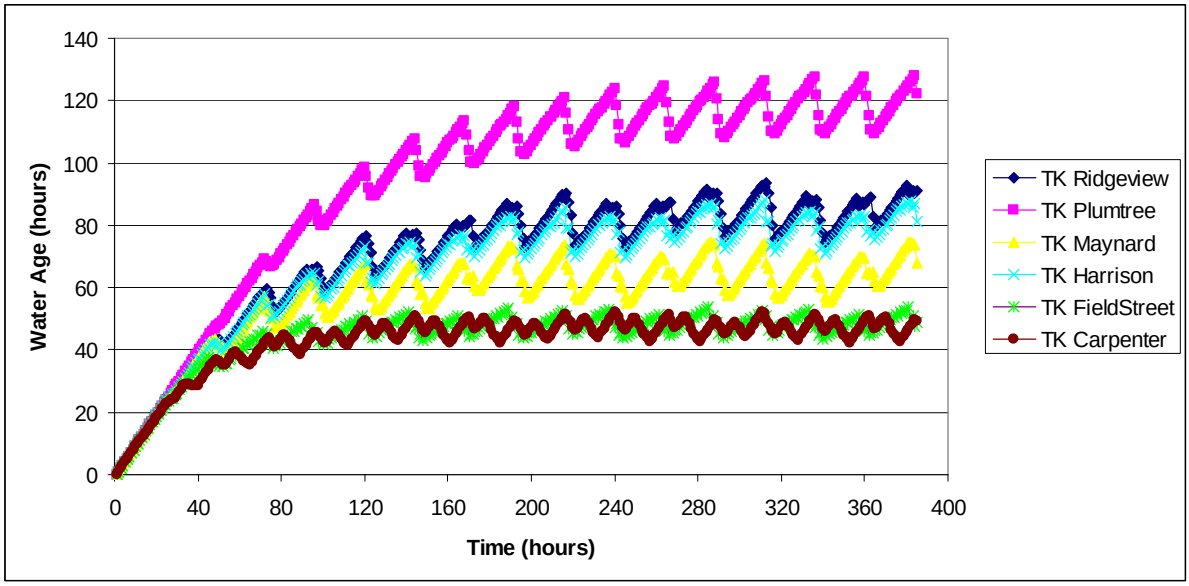
Note: The water age is the range of 24 hours after the system reaches equilibrium

The Plumtree Way Tank has the highest water age, which is not unexpected since it is the tank furthest from the water plant. A three to five day (72 to 120 hour) complete water turnover is recommended for water distribution storage tanks.[1] The turnover time of the Plumtree Way Tank at the time of the field district measurements slightly exceeded the recommended 120 hour maximum. The water age can be reduced by utilizing the control valves at Kildaire Farm Road and Cary Parkway to force more water to be supplied from the Plumtree Way Tank which will lessen the tank turnover time.

After the model achieved repeatable tank fill and draw patterns, the model was calibrated to historical residual chlorine data obtained from the Town.

[1] AWWA. 2002. "Finished Water Storage Facilities". *Environmental Protection Agency*. 15.

FIGURE 2.1
Water Age at Tanks
Water Quality Model Development



2.2 Bulk and Wall Decay Analysis

An important element in water quality model calibration is the determination of the bulk and the wall chlorine decay rates. The Town uses chloramine as the disinfectant in the distribution system. Compared with chlorine, chloramine is more stable and remains in the system for a longer period of time, thus extending disinfectant benefits throughout a distribution system. Accordingly, lower decay rates are usually observed for distribution systems with chloramine disinfection.

The wall chlorine decay coefficient (K_w) represents the decay of chlorine based on its interaction at the walls of the pipes in the network. The bulk chlorine decay coefficient (K_b) represents the decay of chlorine concentration in water as a result of chemical or microbiological reactions. The chlorine decay coefficients (K_w and K_b) were used to develop the hydraulic model into a water quality model by simulating chemical breakdowns in the system.

2.2.1 Bulk Decay Analysis

Water samples were collected by Town staff in February and June 2009 and used to calculate the bulk chlorine decay coefficient (K_b) for the water source under both cold- and warm-weather conditions. The natural logs (ln) of residual chlorine concentration ratios were plotted versus time to determine K_b. K_b is the slope of the following 1st order linear equation:

$$K_b = \text{Ln}\ ([Cl_t]/\ [Cl_{initial}])$$

The K_b coefficients were calculated for the water source during both warm-weather and cold-weather seasons using linear equation trendlines. Both zero Y intercept and variable Y intercept trendlines were reviewed; the variable Y intercept format was selected because it correlated best with the field data based on the R-square (R^2) values. The R-square (R^2) value

is a number from 0 to 1 that indicates how closely the estimated values for the trendline correspond to the collected data. The closer R^2 is to 1, the more reliable the trendline. The trendline equations and resulting K_b value, and R^2 values are summarized in Table 2.2 and shown in Figures 2.2 and 2.3A and B. The recorded residual chlorine measurements and natural log calculations are provided in Appendix B.

2.2.1.1 Warm-Weather Bulk Decay Rate

The R^2 value for the warm-weather bulk decay analysis is 0.9466 indicating that estimated values for the trendline correspond well to the collected data.

2.2.1.2 Cold-Weather Bulk Decay Rate

Two analyses were conducted on the cold-weather data. Several anomalies exist in the cold weather dataset (three data points that indicated the residual increasing over time). Town of Cary staff explained that such anomalies can be due to the use of bench-top equipment that is calibrated every day and that a difference of up to 0.7 mg/l is not considered significant.

The first analysis included the three data points (Figure 2.3A) and resulted in an R^2 value less than 0.7 which denotes a rather less reliable trendline but still within a confident range. The second analysis excluded the three data points (Figure 2.3B) and resulted in an R^2 value of nearly 0.9. The small difference in the K_b coefficient (-0.0008 compared to -0.0006) does not changes the results of the analysis.

The resulting K_b coefficients were adjusted during calibration of the model to account for the uncertainty in the cold-weather data and water chemistry variation in the distribution system. The calibrated K_b for warm-weather conditions was adjusted to -0.0025. It is industry practice to adjust K_b values in the model, based on the starting K_b developed through the jar tests. The adjustment made is within the accepted range of adjustments to K_b.

TABLE 2-2
Bulk Chlorine Decay Rates (K_b)
Water Quality Model Development

Date	Average Water Temp (˚C)	Trendline Equation	K_b	R-square (R^2)
Warm-Weather (July 10 to 19, 2009)	24	y = -0.0014x - 0.0847	-0.0014	0.9466
First Analysis: Cold-Weather (February 3 to 11, 2009)-With data outliers	6.6	y = -0.0006x - 0.037	-0.0006	0.622
Second Analysis: Cold-Weather (February 2009)-Without data outliers	6.6	y = -0.0008x - 0.0179	-0.0008	0.883

FIGURE 2.2
Warm-Weather Bulk Chlorine Decay Trendline
Water Quality Model Development

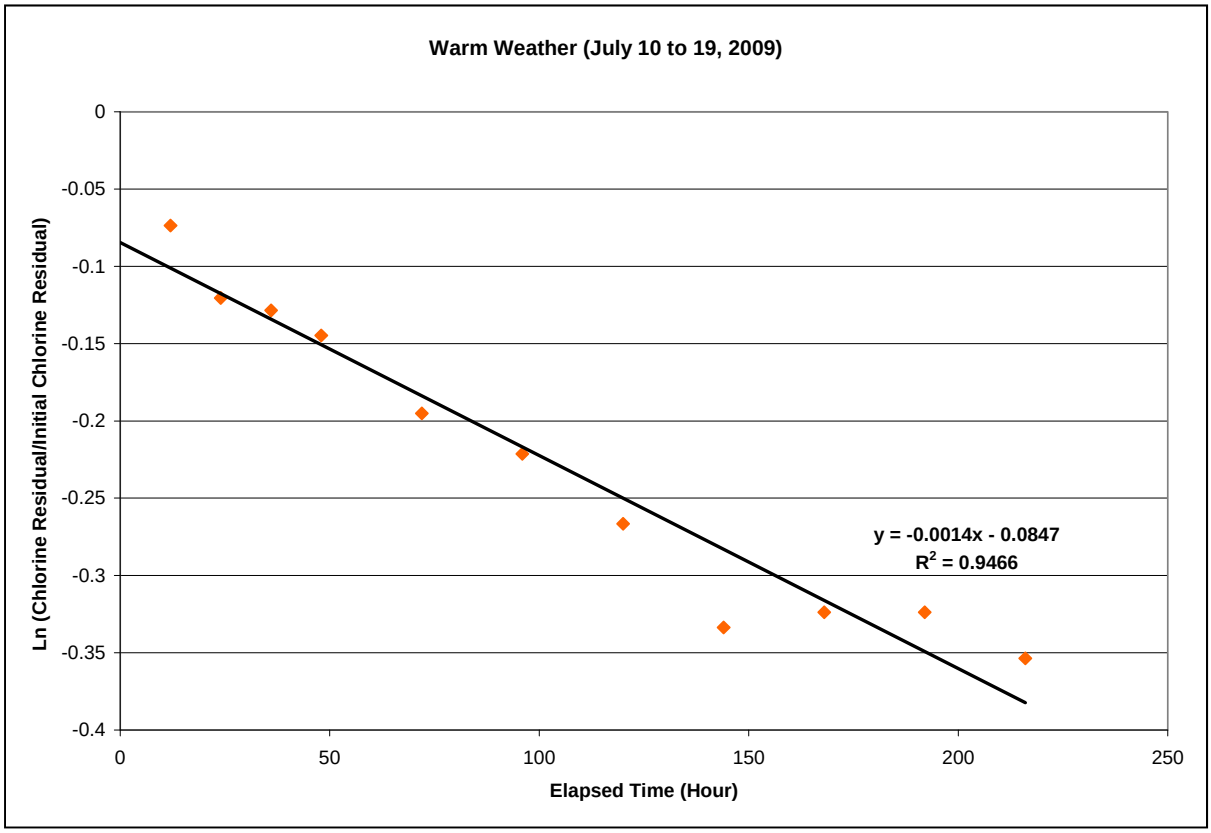


FIGURE 2.3A
First Analysis: Cold-Weather Bulk Chlorine Decay Trendline – With Outlier Data Points
Water Quality Model Development

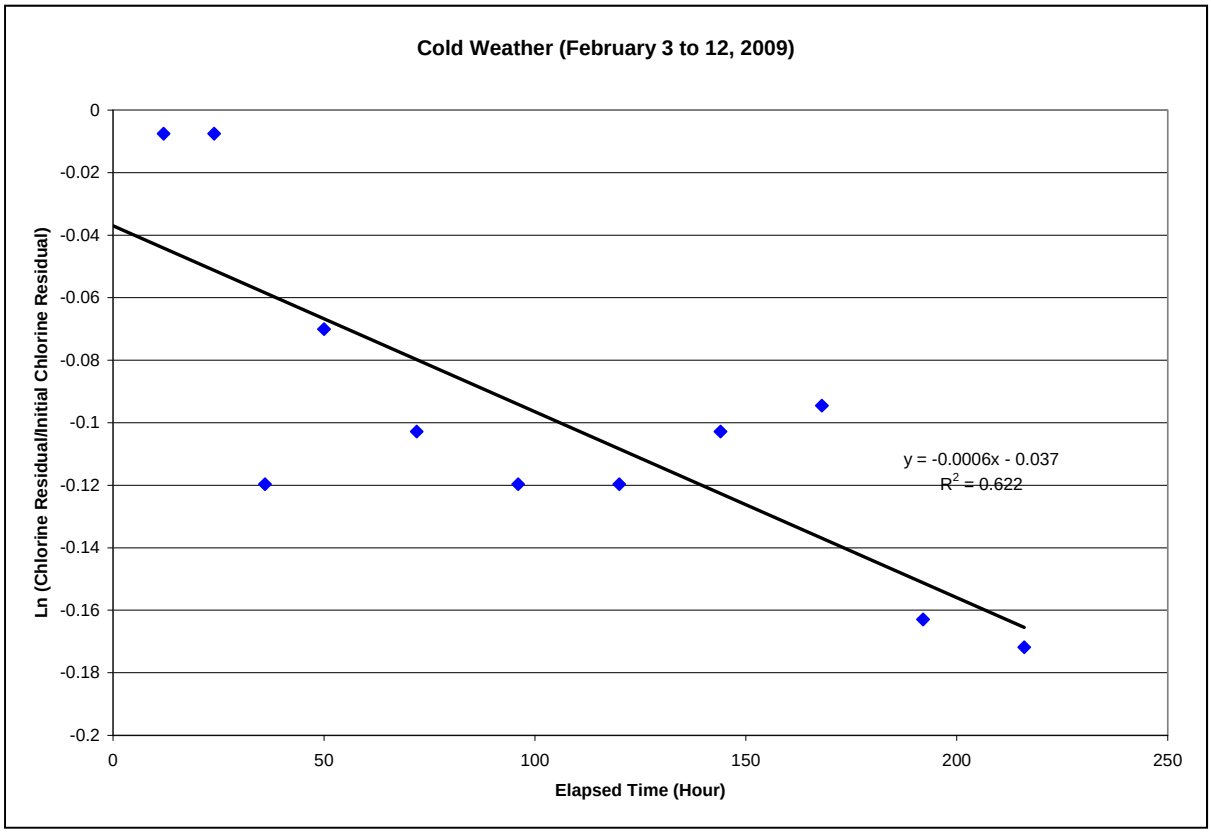
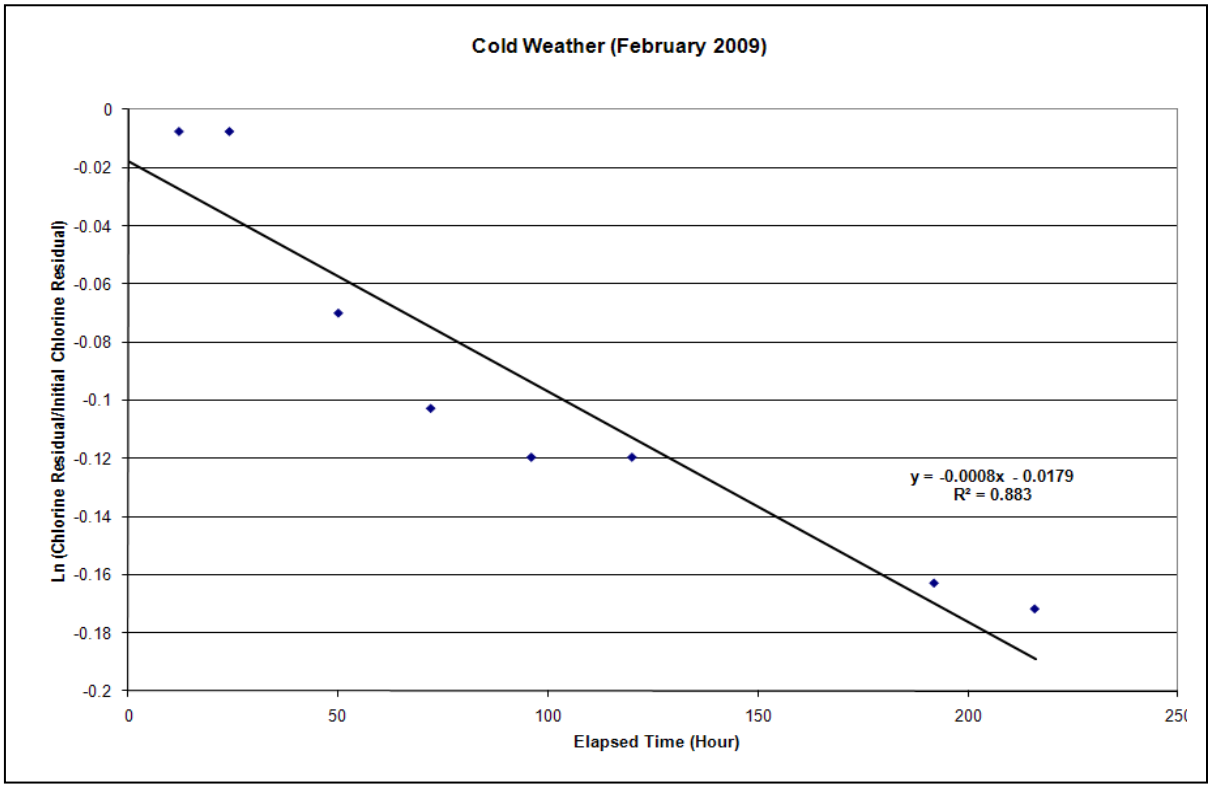


FIGURE 2.3B
Second Analysis: Cold-Weather Bulk Chlorine Decay Trendline – Without Outlier Data Points
Water Quality Model Development



2.2.2 Wall Decay Analysis

The decay of chlorine as it interacts with substances along the wall of a pipe cannot reliably be measured, so the determination of the wall decay coefficients is to some extent trial and error. However, these coefficients can be based initially on values associated with pipe roughness and then adjusted during calibration of the water quality model.[2] A relationship between the wall decay coefficient (K_w) and roughness (*C*) used in previous hydraulic studies by CH2M HILL and the accepted industry standard is:

$$K_w = \alpha \div C \text{ where } \alpha \text{ is a constant}^2$$

An initial value of 0 was chosen for α and was used to establish the initial wall decay coefficients, which were then refined during the calibration process. The value for α was iteratively adjusted and the wall decay coefficients modified accordingly. When the value of α was set to -4, both the warm-weather and cold-weather conditions showed good correlation with the test data. This is a typical value and is within a generally acceptable range of α developed in similar studies using this correlation equation between roughness and wall decay coefficients.[2]

[2] Vasconcelos, J.J., L.A. Rossman, W.M. Grayman, P.F. Boulos, and R.M. Clark. 1997. "Kinetics of chlorine decay." *Journal of the American Water Works Association.* 89(7): 54-65.

2.2.3 Storage Tanks

Bulk decay coefficients for each tank were calculated in the same manner by the model as for other nodes in the system. The tanks were modeled as variable area tanks. Complete mixing was assumed for the water quality analysis. However, CFD modeling and field data can be used to evaluate mixing scenarios if desired by the Town.

2.2.4 Chlorine Sources

Chlorine sources can be modeled different ways in the InfoWorks WS model. The water source was modeled as concentration sources, which fix the chlorine concentration of a water source (such as a modeled reservoir).

The chlorine residual concentrations used for the water source were derived from the values used in the bulk decay testing: 4.7mg/L for warm-weather condition and 4.43 mg/L for cold-weather condition.

2.3 Chlorine Residual Sampling Data Evaluation

The Town regularly samples chlorine concentrations at various locations throughout the distribution system. The historical total chlorine residuals from twenty of these locations were compared to concentrations predicted by the model for warm-weather and cold-weather conditions as shown in Figure 2.4. Sites #1 to #13 are sampled daily and the rest eight sites from #14 to #24 are sampled monthly.

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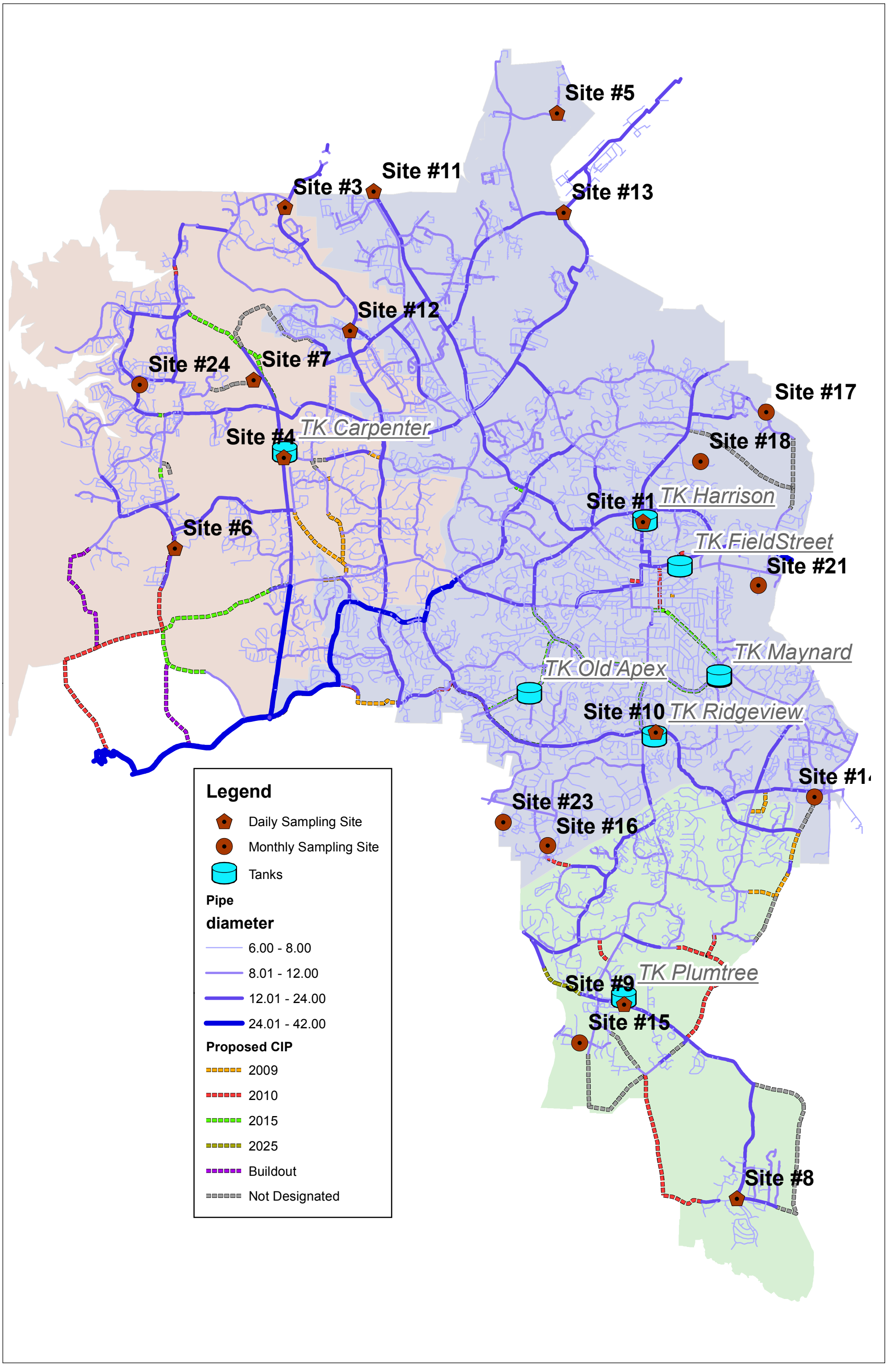

FIGURE 2.4 - Sample Site Locations for Calibration

N W E S 0 4,000 8,000 16,000 Feet

CH2MHILL

2.4 Chlorine Residual Model Calibration

The calibrated EPS model was used for the water quality simulations. The simulations were run for 400 hours with 1-hour hydraulic time steps and 5-minute water quality time steps.

Table 2.2 lists the 20 sample locations along with respective model nodes, average field measured chlorine concentration, modeled concentration, and the comparison between observed and modeled data for both warm-weather and cold-weather conditions. Because chlorine concentration can fluctuate throughout the day, the range of model chlorine concentrations at each test node between 8 a.m. and 5 p.m. was compared to field data.

The generally accepted requirement for water quality model calibration is for the model to be within 0.5 parts per million (ppm), and 0.5 ppm is the generally accepted target for minimum total chlorine residual in a distribution system with chloramine disinfection. If the residual is less than 0.5 ppm to 1 ppm the system will be vulnerable to the onset of biological nitrification.[3]

Table 2.2 compares field and model data using these parameters. The model duplicated field data to within 0.5 ppm for 17 of the 20 sites during warm-weather and 15 of the 20 sites during cold-weather conditions. In the SPZ the model predicted lower chlorine concentrations at Sites No. 8 and No. 15 during both warm- and cold-weather conditions, and at Site 9 during cold conditions. The higher total chlorine residual concentration observed in the field data could be the result of the daily flushing at the southern end of the system. To represent the daily flushing a demand of 300 gpm was added to the south end node in the model. With this change the model predicted concentrations within 0.5 ppm of the field data except at Site No. 15 during warm conditions. The field data for Site No. 15 is collected monthly and exhibited unusually high chlorine residual concentrations. It is recommended that further sampling be conducted at Site No. 15 to confirm the sampling results.

For Site No. 5 at the most northern end of the system the model predicted lower chlorine residual concentrations than the field data during both warm- and cold-weather conditions with the difference at cold conditions greater than 0.5 ppm. According to Town staff, hydrant flushing also occurs at this location and it is believed that the higher chlorine residual observed in the field is due to this hydrant flushing. The model also predicted lower concentrations at Site No. 21 during both warm- and cold-weather conditions which is mostly likely the result of uncertainties related to the Field Street Tank operations.

[3] McGraw-Hill. 2005. Water Treatment Design, 4th edition.

TABLE 2-3
Water Quality Field Measurements and Model-Predicted Results for Chlorine Residual
Water Quality Model Development

Sample Location Address[1]	Model Node ID	Warm-weather Conditions					Cold-weather Conditions				
		Field Average[2] (ppm)	Model Average[3] (ppm)	Field Range[2] (ppm)	Model Range[3] (ppm)	Comparison Between Model and Field (ppm)	Field Average[2] (ppm)	Model Average[3] (ppm)	Field Range[2] (ppm)	Model Range[3] (ppm)	Comparison Between Model and Field (ppm)
#1: Harrison ET	XXXX010946	3.05	2.47	2.4-3.6	1.73-3.49	In range	3.09	1.67	2.5-3.7	0.94-2.69	Within 0.5
#3: Davis Drive	XXXX000243	2.62	2.68	1.9-3.4	2.54-2.83	In range	2.76	2.27	2.4-3.2	1.88-2.49	Within 0.5
#4: Carpenter ET	XXXX000465	2.81	3.82	2.3-3.6	2.97-4.37	Within 0.5	3.08	3.43	2.6-3.4	2.38-4.13	In range
#5: Globe Road	XXXX001419	2.22	1.86	1.2-3.1	1.83-1.90	Within 0.5	2.79	1.47	2.3-3.2	1.43-1.50	Over 0.5
#6: Thomas Brooke	XXXX016642	2.69	2.85	2.1-3.0	2.43– 3.36	In range	2.98	2.15	2.5-3.3	1.67-2.93	Within 0.5
#7: Cary Park	XXXX014491	2.56	2.67	1.9-2.8	2.45-3.07	In range	2.77	2.26	2.3-3.2	1.86-2.51	Within 0.5
#8: West Lake	XXXX018863	2.17	0.74	1.7-2.5	0.54-1.10	Over 0.5	2.56	0.38	2.3-3.2	0.23-0.74	Over 0.5
#9: Plumtree Way ET	XXXX015832	2.07	1.70	1.6-2.7	1.01-2.0	Within 0.5	2.48	1.06	2.1-2.9	0.52-1.67	Over 0.5
#10: Ridgeview ET	XXXX010100	2.74	2.52	2.1-3.5	1.83-3.18	In range	2.99	2.39	2.2-3.6	1.49-2.89	Within 0.5
#11: Hwy 54	XXXX024690	2.65	2.80	2.0-3.4	2.77-2.83	Within 0.5	2.65	2.28	1.9-2.9	2.24-2.35	Within 0.5
#12: Breckenridge	XXXX023449	2.57	2.90	2.2-3.2	2.88-2.93	Within 0.5	2.68	2.51	2.1-3.2	2.49-2.55	Within 0.5
#13: RDU Airport	RDU MM	2.73	3.13	2.3-3.3	3.07-3.20	Within 0.5	2.84	2.80	2.4-3.3	2.67-2.88	In range
#14: 2920 Jones Franklin Rd	XXXX012815	1.99	1.83	NA	1.43-2.14	In range	2.1	1.51	NA	1.29-1.79	Within 0.5

TABLE 2-3
Water Quality Field Measurements and Model-Predicted Results for Chlorine Residual
Water Quality Model Development

Sample Location Address[1]	Model Node ID	Warm-weather Conditions					Cold-weather Conditions				
		Field Average[2] (ppm)	Model Average[3] (ppm)	Field Range[2] (ppm)	Model Range[3] (ppm)	Comparison Between Model and Field (ppm)	Field Average[2] (ppm)	Model Average[3] (ppm)	Field Range[2] (ppm)	Model Range[3] (ppm)	Comparison Between Model and Field (ppm)
#15: 404 Wayfield Ln	XXXX015594	3.35	1.43	NA	0.78-1.68	Over 0.5	2.38	0.78	NA	0.36-1.28	Over 0.5
#16: 111 MacKenan Dr	XXXX001268	2.7	2.92	NA	2.84-2.94	Within 0.5	3.26	2.71	NA	2.66-2.77	Within 0.5
#17: 701 SAS Campus Dr	XXXX002638	2.34	1.96	NA	1.47-2.40	In range	2.1	1.91	NA	1.77-2.10	In range
#18: 940 Reedy Creek Rd	XXXX014389	2.48	2.74	NA	2.29-3.26	In range	1.9	2.35	NA	1.51-2.96	In range
#21: 201 Soccer Park Dr	XXXX017861	2.38	1.01	NA	0.97-1.10	Over 0.5	2.27	0.10	NA	0.05-0.18	Over 0.5
#23: 115 Team Hendrick Way	XXXX001182	2.58	2.31	NA	2.27-2.36	Within 0.5	1.9	1.78	NA	1.73-1.81	Within 0.5
#24: 1075 Residents Club Dr	XXXX018564	2.3	2.06	NA	1.69-2.48	In range	2.09	1.84	NA	0.93-2.34	In range

Note:

1: *Sites #1 to #13 are sampled daily. The other sites are sampled monthly.*

2: *For daily sampling data,field average is the monthly average of the daily combined CL concentrations, and field range is the monthly range of the daily combined CL concentration*

3: *The model average and range are calculated based on the hourly results between 8:00 am and 5:00 pm*

SECTION 3

CIP Evaluation

After completing both the hydraulic model recalibration and the water quality model calibration, CH2M HILL revisited the originally recommended hydraulic improvement CIP projects to verify that each recommended project met the water quality-based criteria. The scope of work of this Addendum did not include providing CIP recommendations for projects based exclusively on water quality requirements.

3.1 Hydraulic Analysis

EPS simulations for the defined planning periods of 2010, 2015, 2025, and build-out were conducted using the recalibrated hydraulic model. The EPS modeling results are shown in Figures C1 through C12 in Appendix C. These model scenarios demonstrate that using the recalibrated model has no impact on the proposed CIP projects for years 2010, 2015 and 2025. However, at build-out, the originally proposed Project CPZ-20 (new high service pumps at the Cary/Apex Water Treatment Plant) is modified from 10 mgd pumps at 485-ft total dynamic head (TDH) to 11 mgd at 485-ft TDH. A constant flow to Apex through the Green Level and Jenks Road master meters was assumed for the future planning periods as in the original model scenarios.

3.2 Water Quality Analysis

Using the water quality model, improvements to the system were investigated based on the water age and total chlorine residuals within the distribution system. While a calibrated water quality model can offer a promising alternative for predicting disinfectant residual in a cost-effective manner, there are inherent uncertainties in the model which must be considered while analyzing the model results. These uncertainties include demand allocation, complex pipe geometry in distribution systems, dynamic flow conditions experienced within the pipelines, and the varied nature of chlorine reactivity. As a result, this analysis was focused on the areas in the system that demonstrated consistently low chlorine concentrations.

For water quality analyses, the summer season with high temperatures is usually considered the worst case condition for water quality considering the higher chlorine bulk decay rate and higher potential for DBP formation. Using a conservative approach, the model inputs to the water quality simulations reflect the warm-weather conditions of July 2009 as follows:

- Demand: 20 MGD
- Chlorine source: 4.25 mg/L
- Chlorine bulk decay: -0.0025
- Chlorine wall decay: -4 for α

According to the EPA, water age can be used as a surrogate to predict disinfection byproduct (DBP) levels in a distribution system.[4] Figure 3.1 shows the results of the water quality modeling with color-coded water age results at the junction nodes. The dead-end nodes with no assigned demand were excluded from the analyses and are shown in gray in the figure. The areas highlighted as orange and pink represent water age greater than 72 hours, and can be expected to have the highest levels of DBPs. Most of these areas are located at the furthest extent of the distribution system and the majority of the water age problems can be attributed to dead-end pipes that are oversized during average day demand conditions but are utilized during fluctuating high demands.

For a distribution system using chloramines for disinfection, the generally accepted target for minimum total chlorine residual is 0.5 ppm.[5] If the residual is less than 0.5 ppm to 1 ppm the system will be vulnerable to the onset of biological nitrification. Figure 3.2 shows the color-coded daily average chlorine residual predicted by the model: less than 0.5 ppm is color coded as pink, and less than 1 ppm is color coded as orange. Overall, the model results show no low chlorine residual problems throughout the system, except some areas at the furthest extent of the system with low demand and high water age.

A large newly-developed area south of Pittard Sears Road in the WPZ is not included in the existing model demands and as a result the model could predict exaggerated problems in this area. The scattered low chlorine residual predicted at the eastern edge of the system may be affected by uncertainties related to the Field Street Tank and Ridgeview Tank operations and can be improved by reducing the turnover time in the tanks. At the northern edge of the system, a small area near Site No. 5 shows chlorine concentration less than 1 ppm, which is also confirmed by the field data. Continuous hydrant flushing at this location would improve water quality.

At the southern end of the system, the model predicts a relatively large area in which the total chlorine residual is less than 1 ppm. To evaluate the impact of the future pipes proposed in these areas, CH2M HILL conducted an additional existing conditions modeling scenario by adding the pipes categorized as Type 3 in the CIP, including Projects SPZ-10, 11, 2, 12, and 13 into the model. Figures 3.3 and 3.4 show water age and total chlorine residual changes with and without the proposed pipes. In the figures, the changes in water age and chlorine concentrations were presented as different colors at the nodes: light blue is no changes; dark blue is a decrease in water age or increase in chlorine residual; pink is an increase in water age or decrease in chlorine residual. The model predicted that the pipeline Projects SPZ- 10 and SPZ -11 will improve the water age and chlorine residual in the surrounding area. Projects SPZ-2, 12 and 13 may eliminate some dead-end pipes however the model indicates no significant improvement in water quality due to low demands in the area. As shown in Figure 3.3, opening the pipeline included in Projects SPZ-2, 12, and 13 may even increase the water age at some locations due to the reduced flow and increased travel time within the long pipes. CH2M HILL recommends delaying CIP Project SPZ-2 shown as needed in 2010 as described in Section 4 below.

The water quality analyses were also conducted for each defined planning period: 2010, 2015, 2025, and build-out. The maximum day demand (MDD) and water quality

[4] IDSE Guidance Manual, USEPA, 2006

[5] McGraw-Hill. 2005, Water Treatment Design, 4th edition

parameters for warm-weather conditions were used for each simulation. Figures 3.5 through 3.8 show the color-coded total chlorine residual predicted by the model for each scenario. When compared with the existing condition model, the future scenarios show improved water quality due to increased future demand.

The originally proposed CIP improvement projects have been verified and no impact on water quality was predicted other than some adjustments needed in the SPZ as discussed below in Section 3.3.

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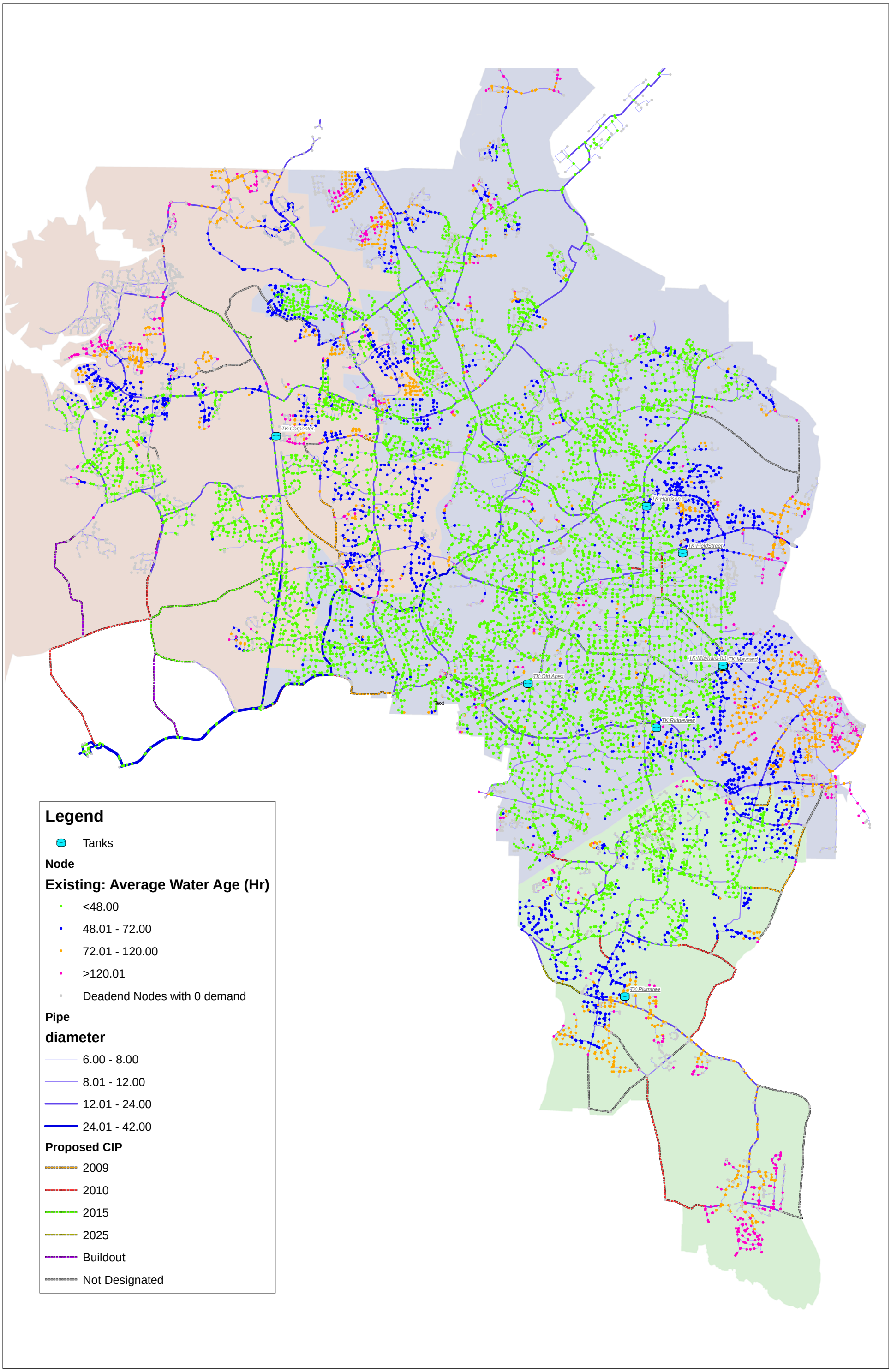

FIGURE 3.1 - Water Age Analysis – July 2009 Existing

N W E S

0 4,000 8,000 16,000 Feet

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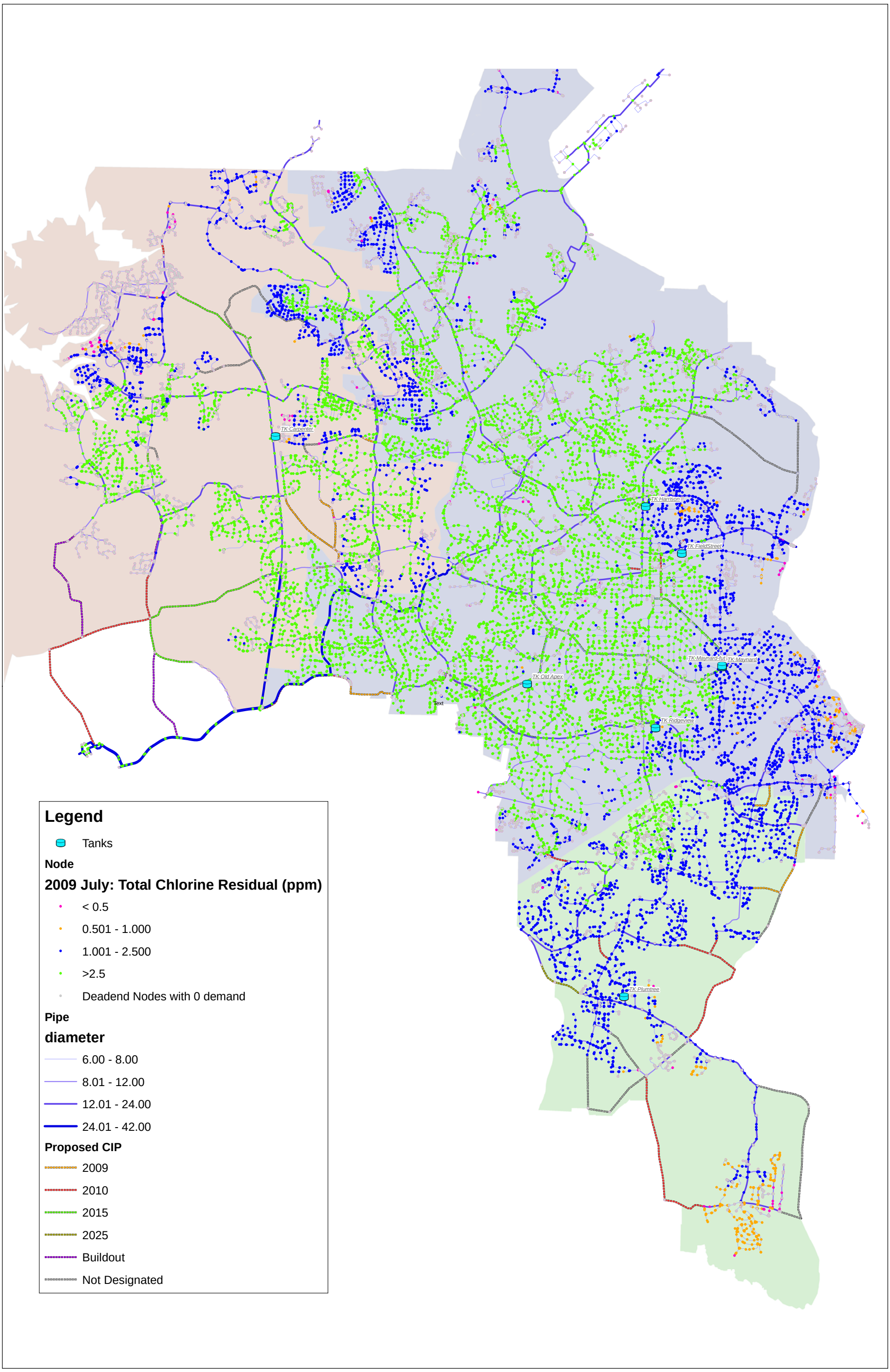


FIGURE 3.2 - Chlorine Residual Analysis – July 2009 Existing

N W E S

0 4,000 8,000 16,000 Feet

CH2MHILL

FIGURE 3.3
SPZ Water Age Analysis: Comparison With and Without Improvements
CIP Evaluation

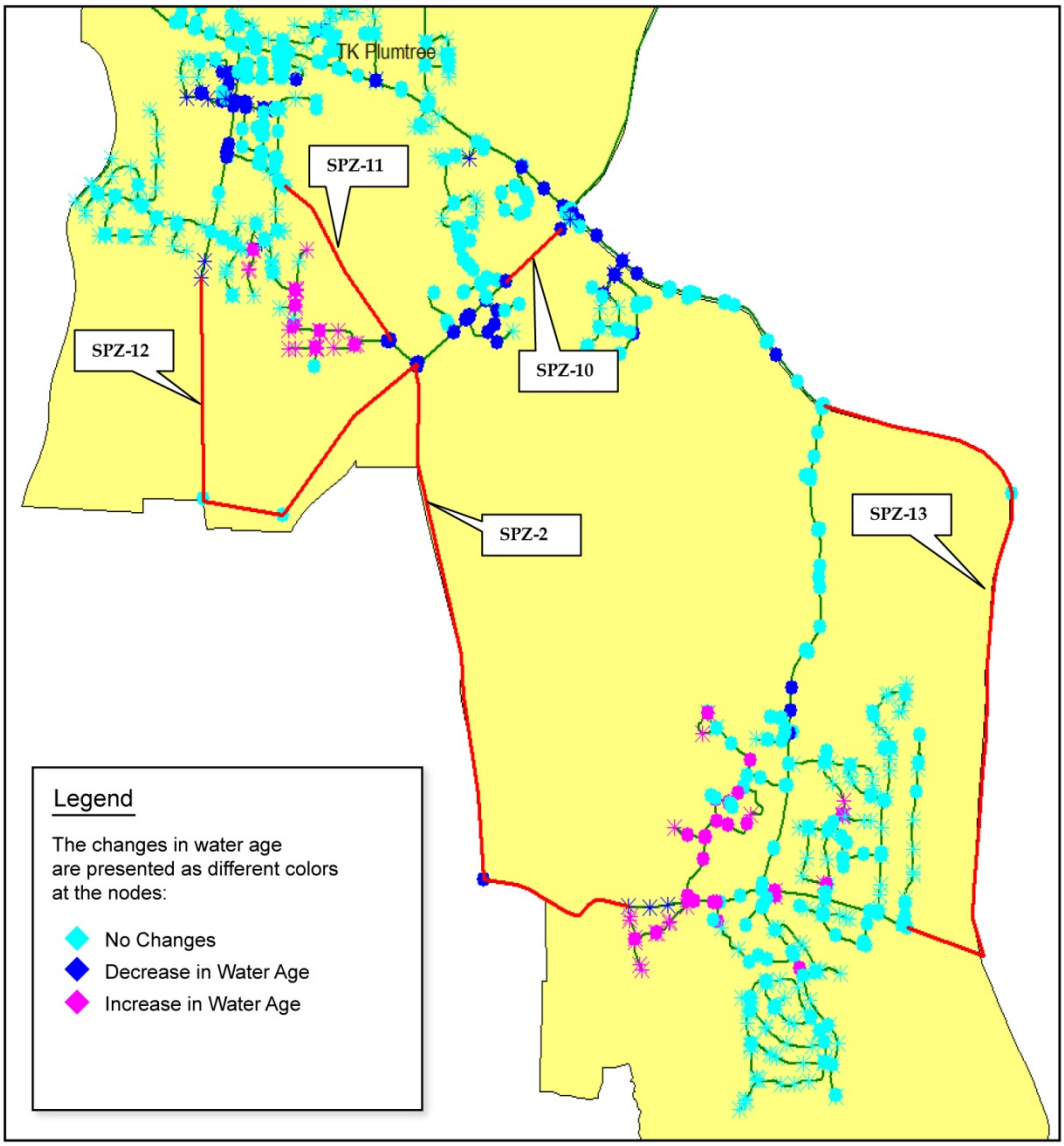
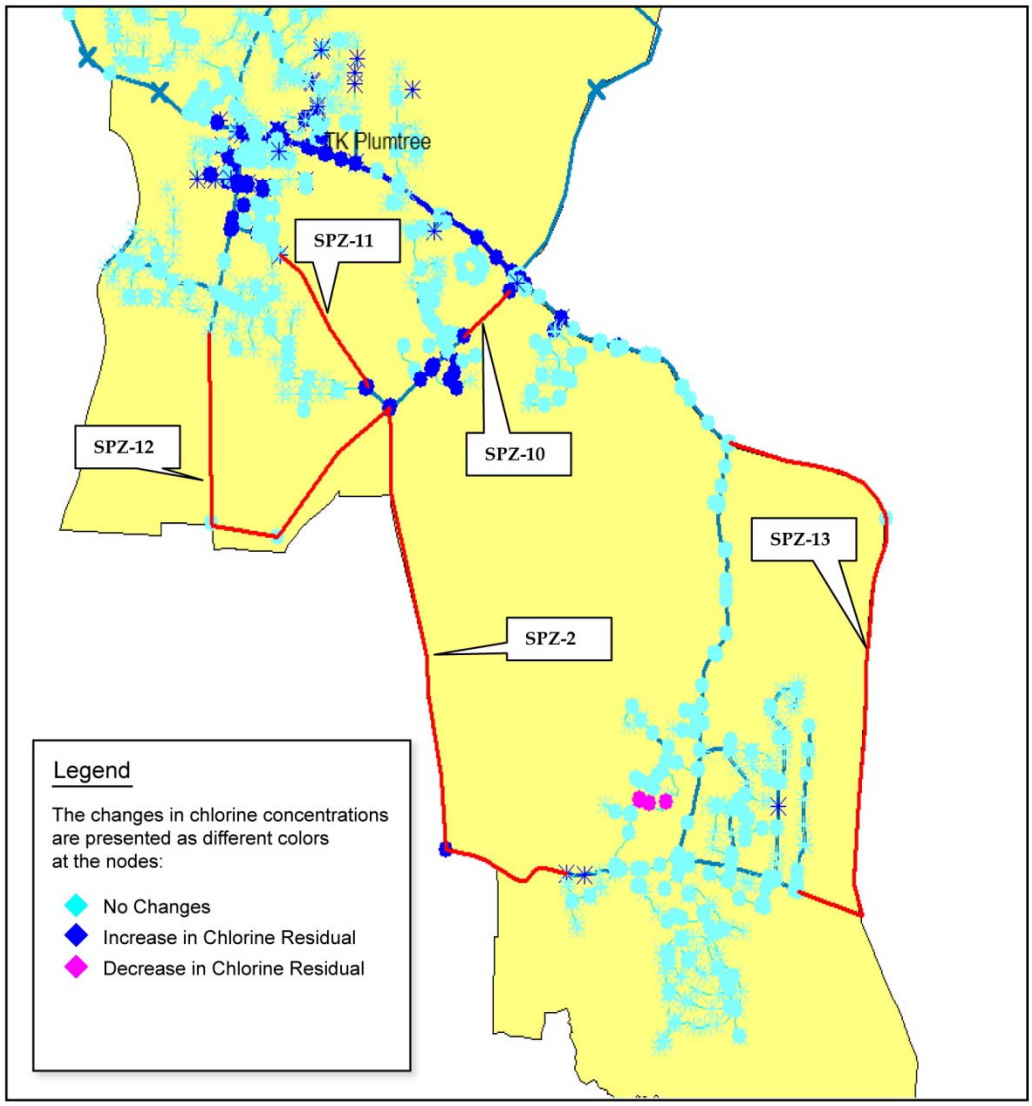


FIGURE 3.4
SPZ Chlorine Residual Analysis: Comparison With and Without Improvements
CIP Evaluation



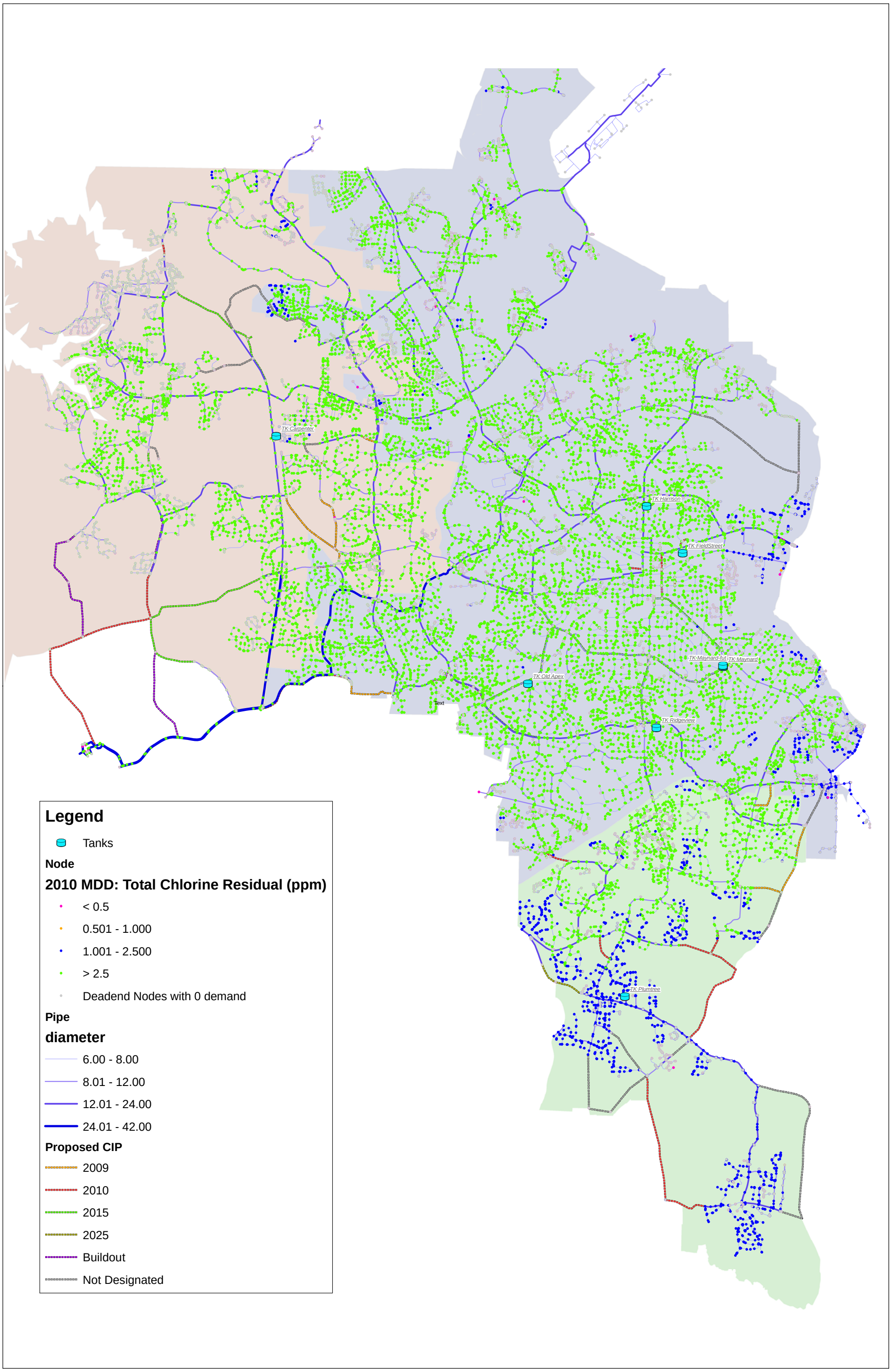


FIGURE 3.5 - Chlorine Residual Analysis – Year 2010

N W E S

0 4,000 8,000 16,000 Feet

CH2MHILL

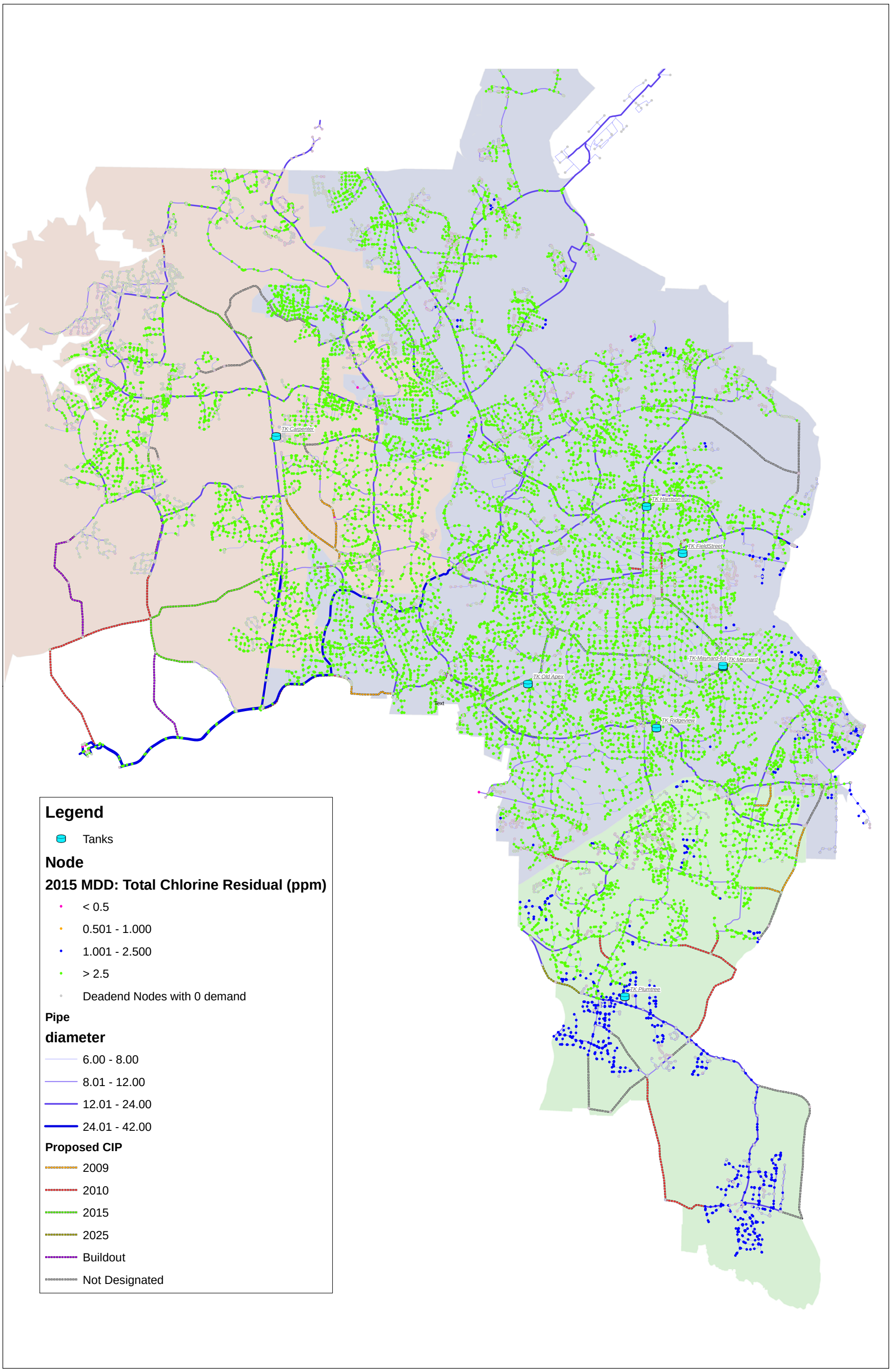


FIGURE 3.6 - Chlorine Residual Analysis – Year 2015

N W E S

0 4,000 8,000 16,000 Feet

CH2MHILL

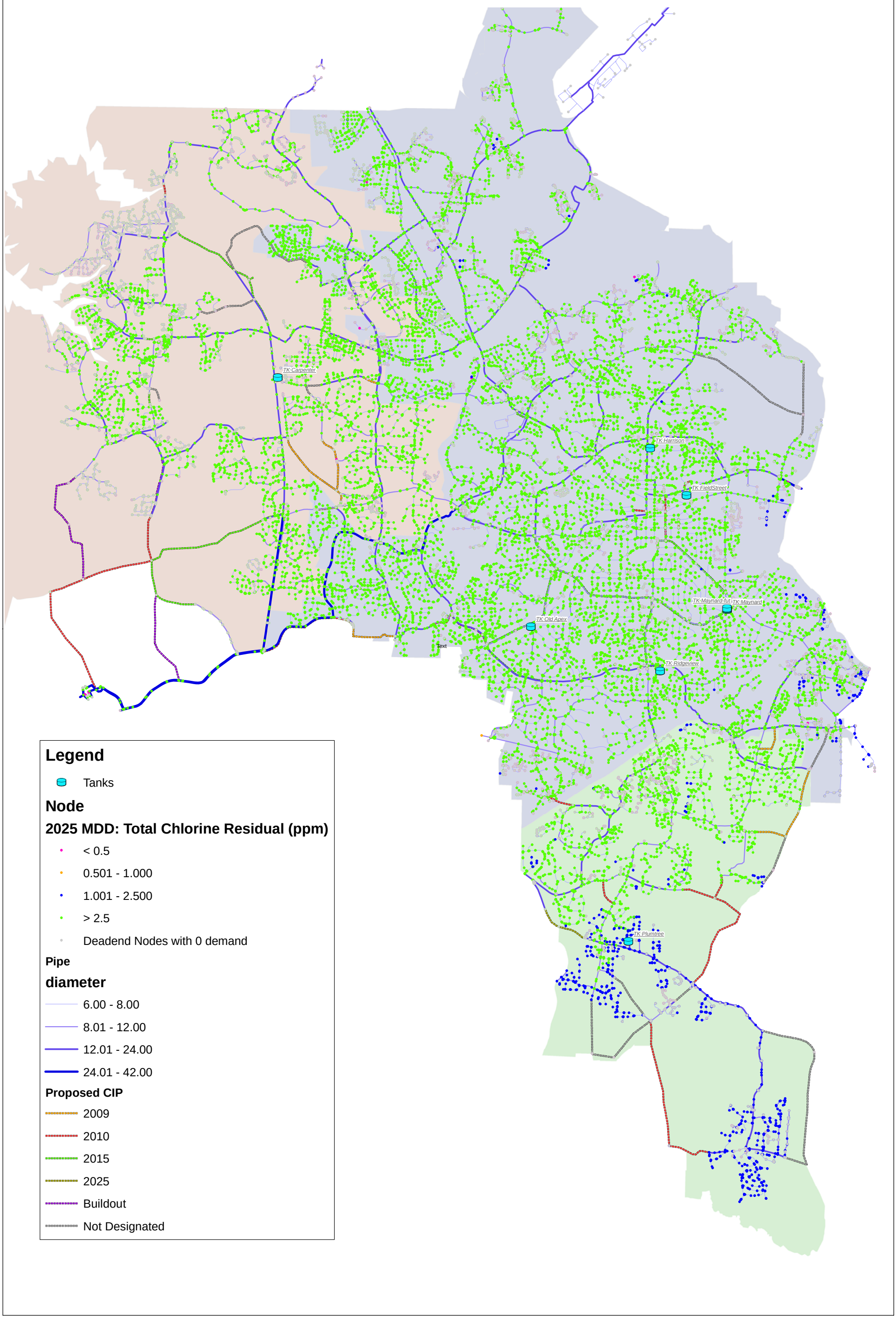


FIGURE 3.7 - Chlorine Residual Analysis – Year 2025

N W E S

0 4,000 8,000 16,000 Feet

CH2MHILL

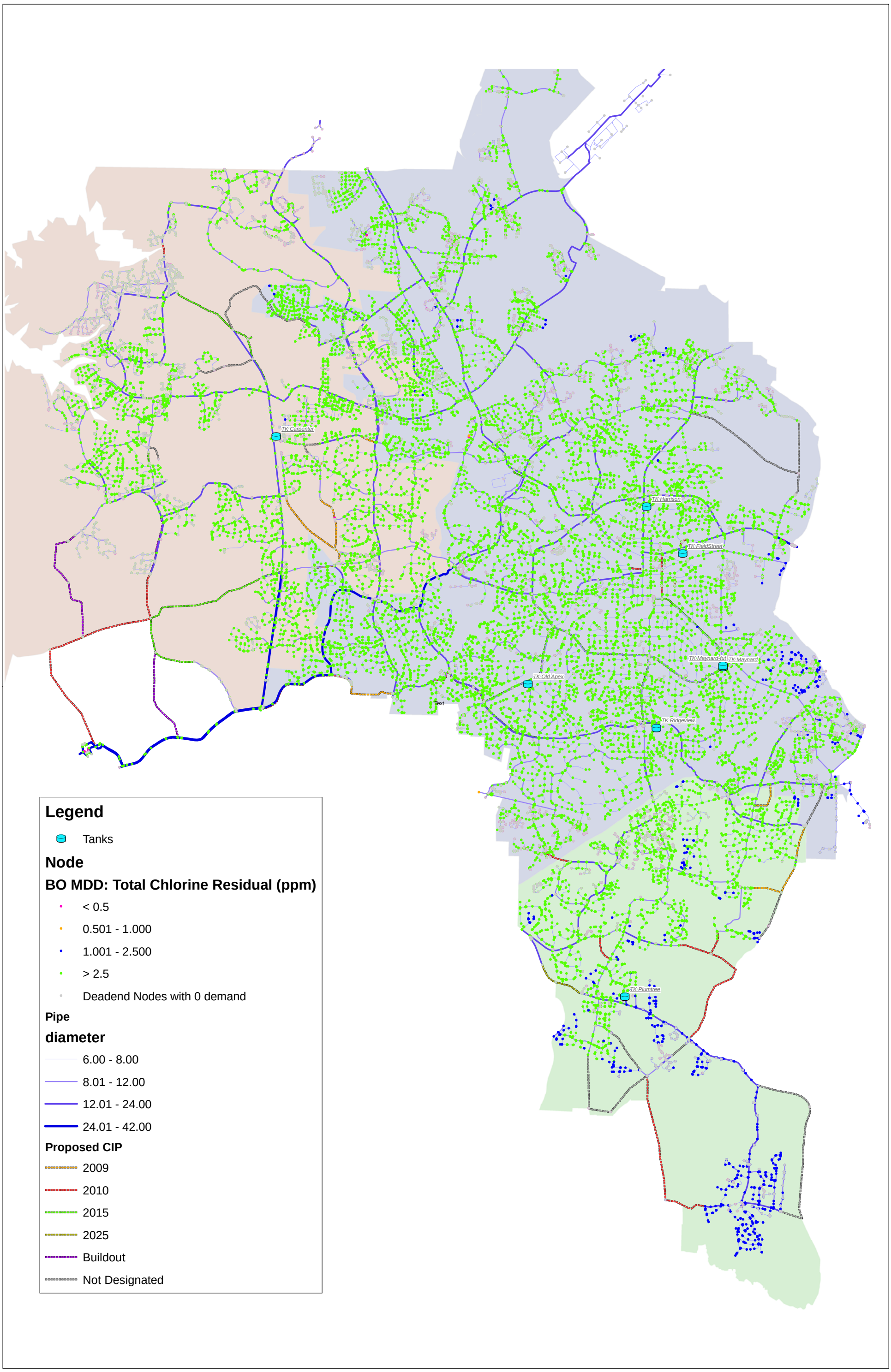


FIGURE 3.8 - Chlorine Residual Analysis – Build-out

N W E S 0 4,000 8,000 16,000 Feet

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3.3 Recommended CIP Changes

Based on the hydraulic and water quality analysis, no major changes were identified for the previous proposed CIP improvement projects other than the following:

- Delete Project SPZ-8 based on the GIS correction
- For build-out, the originally proposed new high service pumps at the Cary/Apex Water Treatment Plant of 10 MGD at 485-ft TDH (Project CPZ-20) need to be upgraded to 11 MGD at 485-ft TDH
- Projects SPZ-10 and SPZ-11 were changed to category Type 2 for water quality enhancement and added to the 2010 CIP
- Project SPZ-2 may need to be delayed based on the outcome of the proposed analysis described below in Sections 4 and 5.

SECTION 4

Recommended Additional Studies to Improve SPZ Water Quality

The water quality analyses described in this Addendum has focused on the effects of previously proposed capital improvement projects. This analysis has shown that water age in the lower half of the SPZ will be improved in the out years as demands increase. However, for the next 5 to 15 years, demands will be relatively low in this area of the system and will likely continue to pose water quality problems. To improve the water quality in this area of the SPZ, it is recommended that evaluating an "operational" strategy to reduce water age in the SPZ be conducted.

CH2M HILL recommends evaluating the hydraulic and water quality effects of taking the Plumtree Way Tank out of service after the proposed Highway 1 control valve (SPZ-6) is constructed. Potentially, optimized operation of this new control valve in conjunction with the Kildaire Farm Road and Cary Parkway control valves will allow the Town to take the Plumtree Way Tank out of service while still satisfying peak design flows and pressures. The following additional modeling scenarios are proposed for further study:

- Hydraulic Evaluation
  - Evaluate a total of nine (9) demand conditions for 2008 MDD, 2010 MDD and 2025 MDD with the Plumtree Way Tank on-line and off-line with some of the recommended CIP projects (SPZ-2, SPZ-5 and SPZ-6)
  - Evaluate operation of the Highway 1 control valve (Project SPZ-6) in conjunction with the Kildaire Farm Road and Cary Parkway control valves
- Water Quality Evaluation of Three Demand Scenarios
  - Hypothetical Summer Conservation Demand – 13.4 mgd (including Apex) with 2010 model network
  - 2010 ADD – 19.1mgd
  - 2025 MDD – 41.2 mgd

Findings of these evaluations are presented in Section 5.

SECTION 5

SPZ Hydraulic and Water Quality Model Update and Analysis

Additional evaluations of the SPZ to improve water quality as outlined in Section 4 were conducted in December 2009 and January 2010. The goal of the evaluation was to determine the hydraulic capacity and water quality impacts of taking the Plumtree Way Tank out of service and to evaluate strategies to improve chlorine residual levels in the SPZ. The additional evaluations included:

- Water Demand Update
- Model Pipe Network Update
- Hydraulic Evaluation
- Water Quality Evaluation of Three Demand Scenarios:
  - Hypothetical Summer Conservation Demand – 13.4 mgd
  - 2010 ADD – 19.1mgd
  - 2025 MDD – 41.2 mgd

5.1 Water Demand Update

CH2M HILL updated water demands in the InfoWorks model based on 2008 billing data provided by the Town in GIS format. The total billed consumption was 11.9 mgd. As described in report Sections 2.5 and 2.6, the non-revenue water is estimated at 9% and bulk water sales are approximately 0.5 mgd. When added to the total billed consumption, the total 2008 finished water demand was estimated at 13.5 mgd. This value corresponds with the Cary/Apex WTP production records for 2008, which reported an annual average finished water rate of 13.43 mgd.

The 2007 average day demand (ADD) was estimated to be 14.7 mgd (Section 2.7.1) which is approximately 1.2 mgd higher than the 2008 estimated ADD of 13.5 mgd. The production data from the Cary/Apex WTP support this value as it revealed a 1.5 mgd reduction in water usage from 2007 to 2008, and flow to Apex revealed the same decreasing trend, from 2.7 mgd in 2007 to 2.4 mgd in 2008. Table 5-1 presents a comparison of 2007 and 2008 ADD for each pressure zone.

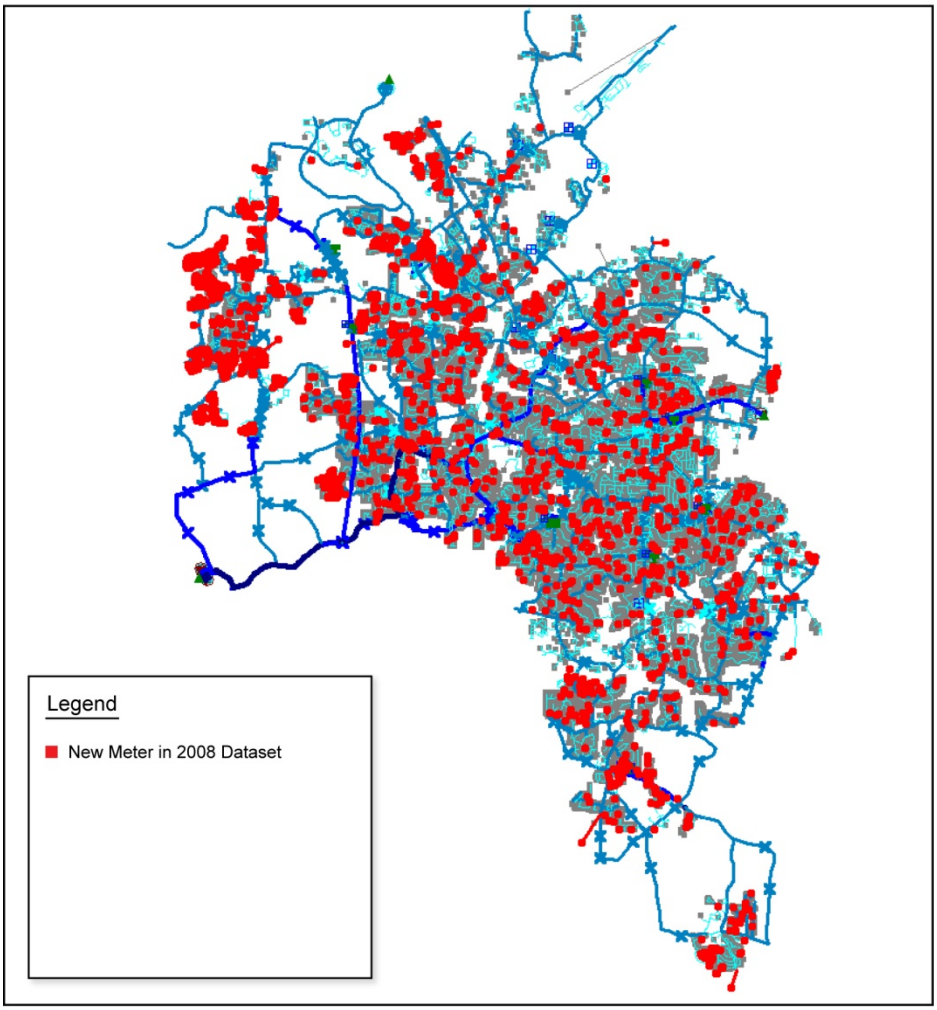
TABLE 5-1
Comparison of 2007 and 2008 Town of Cary Average Day Water Demand

Demand	Existing 2008 ADD[a] (mgd)	2007 ADD[b] (mgd)
Bulk Water Sales	0.5	0.5
Non-Revenue Water[c]	1.07	1.2
CPZ	7.55	8.2
WPZ	2.61	2.9
SPZ	1.73	1.9
Apex: Green Level[d]	2.03	2.08
Apex: Jenks Road[d]	0.35	0.66
Total (Town of Cary + Town of Apex)	15.84	17.4
Town of Cary Only Total	13.46	14.7

[a] Based on 2008 billing data provided by Town
[b] From Report Section 2.7.1
[c] 9% of total billed
[d] 2008 Apex demands based on recorded flow data provided by Town

The GIS meter database was imported into the InfoWorks model as 56,704 customer points. There were 53,400 existing meters from the 2007 data and 3,304 new meters for the 2008 period. The 3,304 new meters represent an ADD of 0.21 mgd. The existing meter demands in the model were automatically updated based on the meter ID. As shown in Figure 5-1 the new meters, represented as red dots, were imported into the model as new customer points, which were allocated to the nearest pipes using the demand allocation tool in InfoWorks.

FIGURE 5-1
Representation of Customer Meter Points in Town of Cary Water System
(Red points represent the new 3,304 meters in the 2008 dataset)



5.2 Model Pipe Network Update

CH2M HILL updated the piping network in the model based on the most current GIS data provided by the Town. The Town's GIS file was imported into the InfoWorks model as a background layer so that new pipes could be added to the model and proposed pipes could be removed. To verify the accuracy of the Town's GIS piping network file, the most current meter data was also used to help support the updates. For example, if a pipe was labeled as proposed in GIS but active meters were located along the pipeline, then it was assumed that the GIS file was in error, and the pipe was subsequently added to the InfoWorks model as an existing pipe. Figure 5-2 shows an example in the vicinity of Serene Forest Drive at the south end of the SPZ – the entire subdivision was labeled as proposed in the Town's GIS, but approximately half of the subdivision had active customer meters. Therefore, the meter data was used to "override" the Town's GIS piping network file and label the pipes as

existing. This extra step in the model update process provides the Town with the most accurate water age results and prevented the model from predicting a misleadingly high water age in this area. Figure 5-3 depicts an example of using customer meter data to override the Town's GIS piping network file along O'Kelly Chapel Road in the WPZ.

FIGURE 5-2
Model Pipe Network Update in Southern Pressure Zone

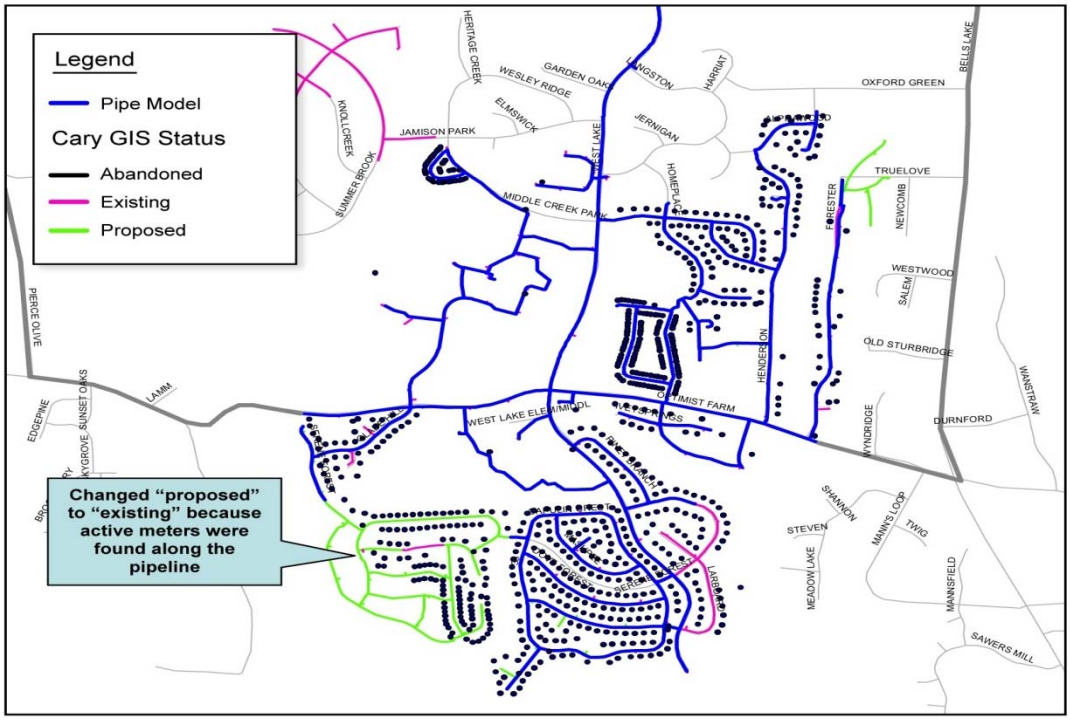
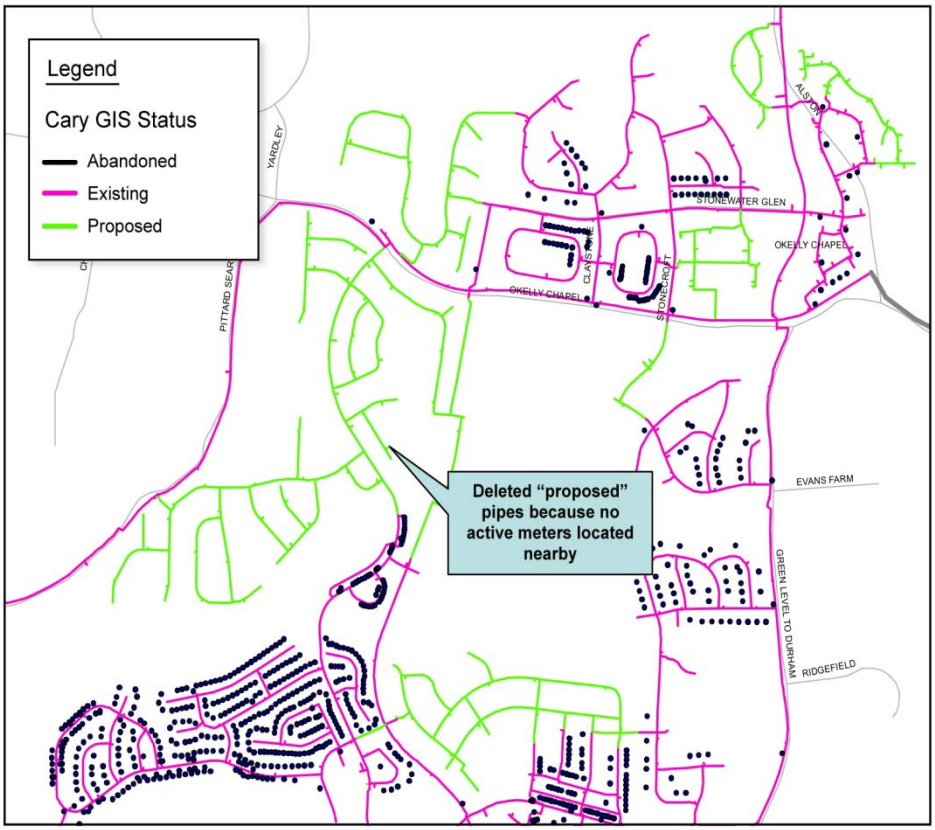


FIGURE 5-3
Model Pipe Network Update in Western Pressure Zone



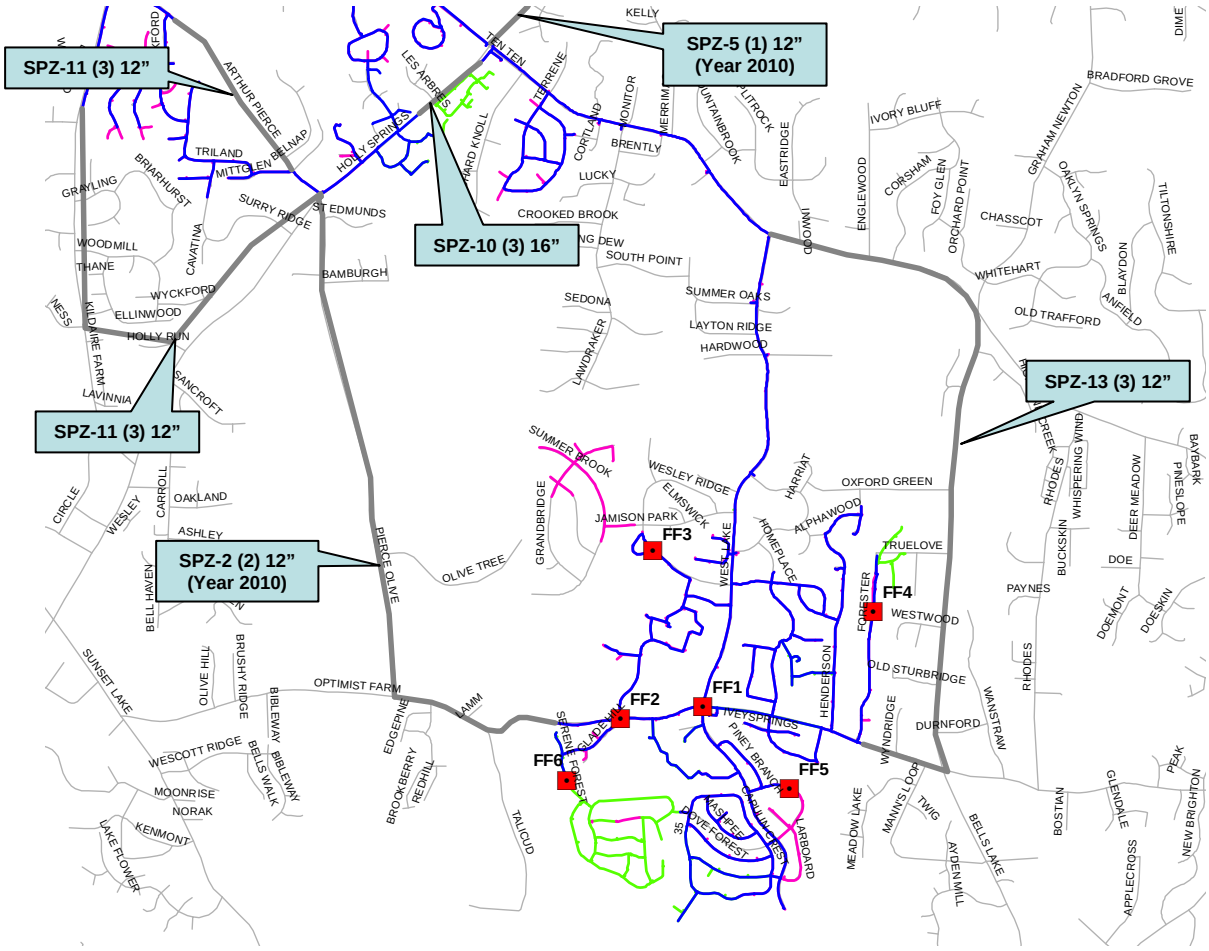
5.3 SPZ Hydraulic Evaluation

Prior to evaluating the water quality impacts of removing the Plumtree Way Tank from service, CH2M HILL conducted a hydraulic modeling analysis to determine if peak hour pressures and fire flow demands could be met under this system configuration for the following demand conditions: existing 2008 MDD, 2010 MDD, and 2025 MDD.

5.3.1 Fire Flow Analysis

The fire flow analysis was conducted at six locations at the south end of the SPZ as shown in Figure 5-4 with and without the Plumtree Way Tank in service.

FIGURE 5-4
Hydraulic Evaluation
Future pipelines with (3) designation were not included in fire flow analysis



Boundary conditions were established in the model with the Ridgeview, Maynard, and Plumtree Way Tanks at half-full water level. Table 5-2 lists the simulated available fire flows at 20 psi at the six locations with and without the Plumtree Way Tank in service for the three demand conditions under various CIP piping configurations (Scenarios A through I described below). It should be noted that the fire flow test results are static simulations which represent instantaneous values. To determine the available fire flow over the required fire flow duration, an extended period simulation (EPS) analysis would be required.

5.3.1.1 Fire Flow Analysis – Scenarios A, B, and C (Existing 2008 MDD Conditions)

Three fire flow simulations were conducted for Existing 2008 MDD conditions (3.2 MGD in the SPZ) as summarized in Table 5-2.

- Scenario A - Plumtree Way Tank on-line
- Scenario B – Plumtree Way Tank off-line

- Scenario C – Plumtree Way Tank off-line but with the proposed Highway 1 Control Valve (SPZ-6) on-line.

When the tank is off-line (Scenario B), the simulated fire flow results are 700-1,200 gpm lower than the simulation with the tank on-line (Scenario A). Activating the proposed Highway 1 Control Valve (CV) in the model when the tank is off-line only increased the available fire flow by 100-200 gpm (the comparison of Scenario C to B).

5.3.1.2 Fire Flow Analysis – Scenarios D, E, and F (Year 2010 MDD Conditions)

A second fire flow modeling analysis was conducted for 2010 MDD conditions (4.0 MGD in the SPZ) with and without the Plumtree Way Tank in service and including the following Year 2010 CIP piping projects that were recommended in Section 7:

- SPZ-6: Highway 1 Control Valve Station and 16-inch piping
- SPZ-5: Holly Springs Road and Ten-Ten Road 12-inch piping
- SPZ-2: Pierce Olive Road and Optimist Farm Road 12-inch piping

The following model runs were conducted for Year 2010 MDD Conditions:

- Scenario D – Recommended 2010 CIP with Plumtree Way Tank on-line
- Scenario E – Recommended 2010 CIP with Plumtree Way Tank off-line
- Scenario F – Recommended 2010 CIP excluding project SPZ-2 with Plumtree Way Tank off-line

Scenario E modeling results show a slight reduction of available fire flow by 100-400 gpm as compared with the tank on-line (Scenario D). The available fire flow decreased much less than it decreased in Scenario B (2008 MDD with tank off-line) due to the improvements represented by the three recommended CIP projects (SPZ-6, SPZ-5, and SPZ-2).

It was originally contemplated that SPZ-2 might improve water quality because it completed a loop at the southern end of the SPZ. However, the water age modeling revealed that SPZ-2 actually increased water age. For this reason, Scenario F was evaluated to determine if the pipeline could be delayed beyond 2010 if the Plumtree Way Tank was off-line. Scenario F results show that the available fire flow was reduced by an additional 300-800 gpm at the six sites when compared with Scenario E (tank off-line, 2010 CIP).

Fire Flow Analysis – Scenarios G, H, and I (Year 2025 MDD Conditions)

A third fire flow analysis was conducted for 2025 MDD conditions (5.1 MGD in the SPZ) with and without the Plumtree Way Tank on-line. In Section 7, there were no recommended trunk main piping improvements after the Year 2010. For this reason, the piping network configuration for Scenarios G and H are the same as D and E. The reduction in available fire flow for Scenario H as compared to Scenario E is attributed to the increase in MDD in the SPZ from the year 2010 to 2025.

To increase the available fire flow for 2025 MDD conditions with the Plumtree Way Tank off-line, Scenario I evaluated the alternative of constructing SPZ-10 (Holly Springs Road at Ten-Ten Road 16-inch main) which was designated as a Category 3 project during the

Master Plan Study, meaning that project was not necessary under the study design conditions. By constructing SPZ-10 by 2025, the available fire flow was still 200-600 gpm lower at the six sites as compared to Scenario G (tank on-line, recommended CIP).

TABLE 5-2
Simulated Available Fire Flow (GPM) at 20 PSI Under Various Piping Configurations and MDD Conditions

		Existing 2008 MDD with Updated Demands and Piping			Year 2010 MDD with Section 7 CIP Recommendations			Year 2025 MDD with Section 7 CIP Recommendations		
		Tank On-line	Tank Off-line		Tank On-line	Tank Off-line		Tank On-line	Tank Off-line	
		Scenario								
		A	B	C	D	E	F	J	H	I
ID	Node			With SPZ-6			Without SPZ-2			With SPZ-10
FF1	XXXX015656	> 3,500	2,300	2,600	> 3,500	3,300	2,900	> 3,500	2,900	3,100
FF2	XXXX015676	3,100	2,200	2,400	> 3,500	3,200	2,400	> 3,500	2,800	3,400
FF3	XXXX018450	2,500	1,900	2,000	2,800	2,400	2,100	2,700	2,100	2,200
FF4	XXXX020803	2,600	1,900	2,100	2,800	2,400	2,300	2,800	2,100	2,200
FF5	XXXX025477	2,900	2,100	2,200	2,700	2,400	2,200	2,700	2,100	2,200
FF6	XXXX025866	2,900	2,200	2,300	2,200	2,100	1,800	2,200	1,900	2,000

Notes:
The fire flow run in the model is a static simulation, and thus the results are instantaneous values
For each fire flow run, the SPZ control valves were fully open
SPZ-6 (Highway 1 Control Valve and 16-inch pipe)
SPZ-2 (Pierce Olive and Optimist Farm Road 12-inch pipe)
SPZ-10 (Holly Springs Road at Ten-Ten Road 16-inch pipe)

Fire Flow Analysis Summary

The fire flow modeling analysis revealed that if the Plumtree Way Tank was taken out of service, the available fire flow would in all cases be reduced even if additional piping projects were implemented.

The southern part of the SPZ is primarily zoned as residential, which typically requires a 1,000 gpm available fire flow. The minimum predicted fire flow at the six locations described above with the tank off-line was greater than 1,500 gpm. Therefore, removing the tank from service should not have a negative impact on available fire flow in the residential areas.

However, for the commercial areas, fire flow requirements may exceed the available fire flow if the tank is taken off-line. It is recommended that the Town conduct a detailed review of commercial sprinkler designs in the southern part of the SPZ to verify that reduced available fire flows under the Scenarios described above do not impact existing fire suppression systems.

The Town of Cary Fire Marshal's office indicated that the West Lake Elementary and Middle Schools, which are close to FF1 and FF2, are un-sprinklered buildings. The Fire Marshal also indicated that the "target" fire flow should be 4,000-5,000 gpm based the NC Fire Code calculations. However, this fire flow target was not the value used in the original design of these facilities, and the NC Fire Code has not been adopted into Cary's local building code. Most importantly, this fire flow rate does not currently exist at the two schools and would not be a realistic design goal for this part of the Town's water distribution system considering the existing water quality problems and regulatory requirements. If the Town wishes to provide this level of fire flow with the Plumtree Way Tank off-line, a dedicated fire water system could be configured at the schools by incorporating existing piping around the schools into a dedicated fire loop that could be supplied by new local fire pumps and a ground storage tank. Alternatively, sprinkler systems could be added to the schools to reduce the needed fire flow.

Fire Flow Analysis Conclusions

Based on the above hydraulic modeling analysis, existing water quality regulations, historical water quality data in the SPZ, and available information on fire flow requirements at the southern end of the SPZ, CH2M HILL recommends that the Town continue to pursue the alternative to temporarily remove the Plumtree Way Tank from service. This recommendation is contingent on the findings of an in-depth evaluation of commercial sprinklered and unsprinklered building fire flow designs at the southern end of the SPZ.

5.4 SPZ Pressure Analysis

An EPS model run was conducted for existing 2008, 2010, and 2025 MDD conditions with and without the Plumtree Way Tank in service. Two scenarios were simulated for the operation of the existing and future Highway 1 control valves:

- Operation Scenario 1: Keep existing Cary Parkway and Kildaire Farm Road CVs wide open, and the future Highway 1 CV open only during the daytime

- Operation Scenario 2: Set all of the existing and future Highway 1 CVs as pressure reducing valves (PRV) with pressure settings of 109 psi at Cary Parkway, 64 psi at Kildaire Farm Road, and 95 psi at the future Highway 1 location

Table 5-3 provides the results of this analysis. An advantage of taking the Plumtree Way Tank off-line is that the hydraulic grade line (HGL) of the SPZ can be raised as needed to provide higher pressures at high elevation areas. However, this also increases pressures in low elevations areas where pressures are already high. As shown in Table 5-3, minimum pressures during peak hour demand conditions changed only slightly when the Plumtree Way Tank was taken off-line. Minimum pressures were above 36 psi for all demand conditions and tank configurations. Without PRVs the maximum pressures increased around 10-15 psi and the pressure swings around 18-27 psi when the tank was off-line. PRVs were able to minimize pressure swings and reduce the maximum pressure, and the pressure results are close to existing 2008 conditions. Overall, the results of the analysis show that pressures can be maintained within acceptable design ranges and could be increased slightly with the Plumtree Way Tank off-line.

TABLE 5-3
Simulated Pressures in the Southern Pressure Zone in PSI

Pressure (psi)	Existing 2008 MDD with Updated Demands and Piping		Year 2010 MDD with Section 7 CIP Recommendations			Year 2025 MDD with Section 7 CIP Recommendations		
	Tank On-line	Tank Off-line	Tank On-line	Tank Off-line		Tank On-line	Tank Off-line	
		Both Cary PW and Kildaire Farm Rd CVs wide open		Operation Scenario 1: Both Cary PW and Kildaire Farm Rd CVs wide open; HWY 1 CV open only for daytime	Operation Scenario 2: Set all CVs as PRVs		Operation Scenario 1: Both Cary PW and Kildaire Farm Rd CVs wide open; HWY 1 CV open only for daytime	Operation Scenario 2: Set all CVs as PRVs
Max Pressure Swing Range on MDD	20	24	12	18	10	23	27	19
Min Peak Hour Pressure	42	46	44	47	43	37	38	38
Average MDD pressure	84	94	83	92	83	82	87	82
Max MDD pressure	138	151	133	147	134	133	144	137

Notes:

Pressure values reported are based on a 3-day EPS model run and statistical summary of all nodes in SPZ

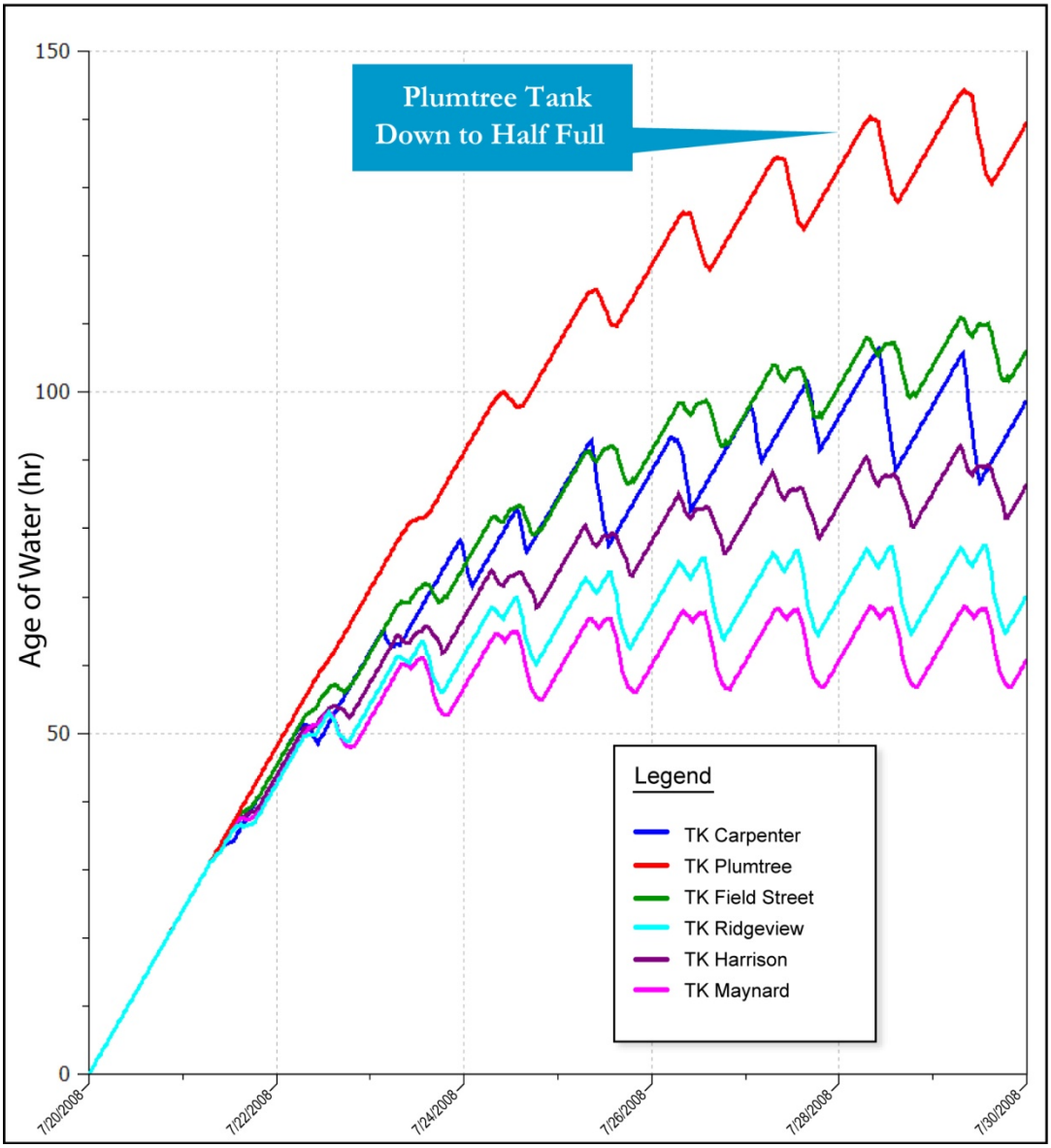
5.5 SPZ Water Quality Evaluation

Prior to conducting the water quality modeling analysis, the following demand conditions, model parameters and pump controls were discussed with and approved by the Town:

- Demand conditions
  - Hypothetical Summer Conservation (HSC) Demand – 13.4 mgd (including Apex) with 2010 model network; SPZ demand = 2.72 mgd
  - 2010 ADD – 19.1mgd; SPZ demand = 4.0 mgd
  - 2025 MDD – 41.2 mgd; SPZ demand = 5.1 mgd
- Temperature Condition: Warm
- Parameters:
  - Initial CL concentration: 4.25 parts per million (ppm)
  - Kb: -0.0025
  - Kw: -4/C
- Pump Controls:
  - All the elevated tanks operate within the top 15-feet of the tank
  - The Old Apex Ground Storage Tank pump is "on" with the control logic used previously in the study

For each demand condition, the updated model was set for a long term EPS run with the objective to ensure that equilibrium was reached throughout the distribution system. Achieving equilibrium means that all of the water at "Time = 0" has been consumed at the demand points in the model. Figure 5-5 shows the water age at all the elevated tanks for HSC demand (13.4 MG) demand condition which reached equilibrium within a 240-hour model simulation.

FIGURE 5-5
Tank Water Age at Hypothetical Summer Conservation Demand of 13.4 MGD with Proposed 2010 CIP Piping



Appendix D includes graphs showing the water levels at all the tanks from the EPS runs for the three demand conditions.

To evaluate water quality impacts of taking the Plumtree Way Tank out of service, two scenarios (with and without the tank on-line) were examined for the three demand conditions. Figures 5-6 through 5-11 show the color-coded total chlorine residual predicted by the model for each scenario: Figures 5-6 and 5-7 depict the HSC demand of 13.4 MGD, Figures 5-8 and 5-9 depict the 2010 ADD, and Figures 5-10 and 5-11 depict the 2025 MDD.

For lower demand conditions such as the 2010 ADD (19.1 MGD) and especially the HSC demand of 13.4 MGD, the model predicted an increase in chlorine residual for the scenarios with the Plumtree Way Tank off-line and the proposed Highway 1 CV in service. As shown in Figure 5-12, for the HSC demand condition, the chlorine residual is predicted to increase by more than 0.3 ppm in most of the SPZ areas with the tank off-line and the proposed Highway 1 CV in service.

Water quality is also impacted by the combined operation of the three control valves at Kildaire Farm Road, Cary Parkway, and the proposed Highway 1 location. As shown in Figure 5-12, chlorine residuals increase in the western areas due to the flow from the proposed Highway 1 CV while the levels decrease along the eastern part of the SPZ due to a reduction in flow from the Cary Parkway CV. This simulation result shows the importance of an optimized control valve operation to keep water moving through all areas of the SPZ as described below.

Figures 5-13A and B show the different impacts on chlorine residual at the south end of the SPZ and the southeastern corner of the CPZ from the combined operations of the proposed Highway 1 and Cary Parkway control valves. As shown in Figure 5-13A, using the proposed Highway 1 CV as the only supply connection to the SPZ would increase the chlorine residual along most of western and southern part of the SPZ, especially at the south end where water quality has been of concern. However, this configuration would cause dead ends at Kildaire Farm Road and Cary Parkway due to the closed valves, and increase the water age to the southeastern corner of the CPZ. To understand the sensitivity of the water quality impact from the control valves operation, an additional scenario with balanced operation between the proposed Highway 1 and Cary Parkway control valves was conducted as shown in Figure 5-13B. While improvements were made to the southeastern corner of the CPZ, the chlorine residual at the south end of the SPZ decreased.

5.6 SPZ Hydraulic and Water Quality Model Update and Analysis Recommendations

Based on the hydraulic and water quality modeling analysis, it is recommended that the Town consider removing Plumtree Way Tank from service for an indefinite period in order to improve water quality in the SPZ. While this step may not completely resolve the low chlorine residual issues at the southern end of the SPZ, the modeling analysis shows that it will provide some benefit. Due to the relatively low water demand in this portion of the SPZ over the next decade, it is recommended that unidirectional flushing be conducted on the branch mains in this portion of the system especially during low summer demand periods.

With the Plumtree Way Tank out of service, the hydraulic analysis revealed a slight reduction in available fire flow at the southern end of the SPZ even with the new Highway 1 control valve in service. While the available fire flow for residential properties remained above the criteria of 1,000 gpm at 20 psi residual pressure, the impact to commercial and/or institutional facilities must be evaluated on a case by case basis due to individual facility fire suppression designs. For this reason, CH2M HILL recommends that the Town continue to investigate the small number of commercial and institutional properties located at the southern end of the SPZ to determine their specific fire flow and pressure requirements.

After this review, a second modeling analysis could be conducted by the Town to determine if these facilities would actually be compromised by taking the Plumtree Way Tank out of service. Even if the second modeling analysis shows that some of the commercial and/or institutional properties are compromised with the tank out of service, the cost to make local fire flow improvements to these properties may be small compared to overall benefit of improving chlorine residual levels in this part of the system. In addition, it is recommended that before taking the Plumtree Way Tank out of service for any significant length of time the previously proposed CIP piping projects and control valve (SPZ-2, 5, and 6) be constructed and placed into service. In the interim, the Town may wish to conduct several short term tests during low demands with the Plumtree Way Tank isolated from the system in order to refine the hydraulic model calibration.

Based on the hydraulic and water quality analyses conducted for this study, the best operation of the SPZ with the Plumtree Way Tank out of service would be to operate all of the existing and future control valves as pressure reducing valves (PRVs) with pressure settings of 109 psi at Cary Parkway, 64 psi at Kildaire Farm Road, and 95 psi at the future Highway 1 location. This type of operation at the Kildaire Farm Road and Cary Parkway control valves has not worked in the past due to the need to "turn over" water in the Plumtree Way Tank. However, with the new Highway 1 control valve in service and with the Plumtree Way Tank out of service, a PRV control is the best strategy in terms of ease of operation, water quality, stability of pressures, and fire flow requirements.

While the Plumtree Way Tank remains on-line, it is recommended that operations staff continue to operate the Kildaire Farm Road and Cary Parkway control valves evenly to provide the best water quality in the SPZ and CPZ. As well, it is recommended that unidirectional flushing be conducted on the branch mains in the SPZ during low summer demands.

FIGURE 5-6
Simulated Chlorine Residual (PPM) in Southern Pressure Zone (2010 CIP Piping, Tank On-line, HSC 13.4 MGD Demand)

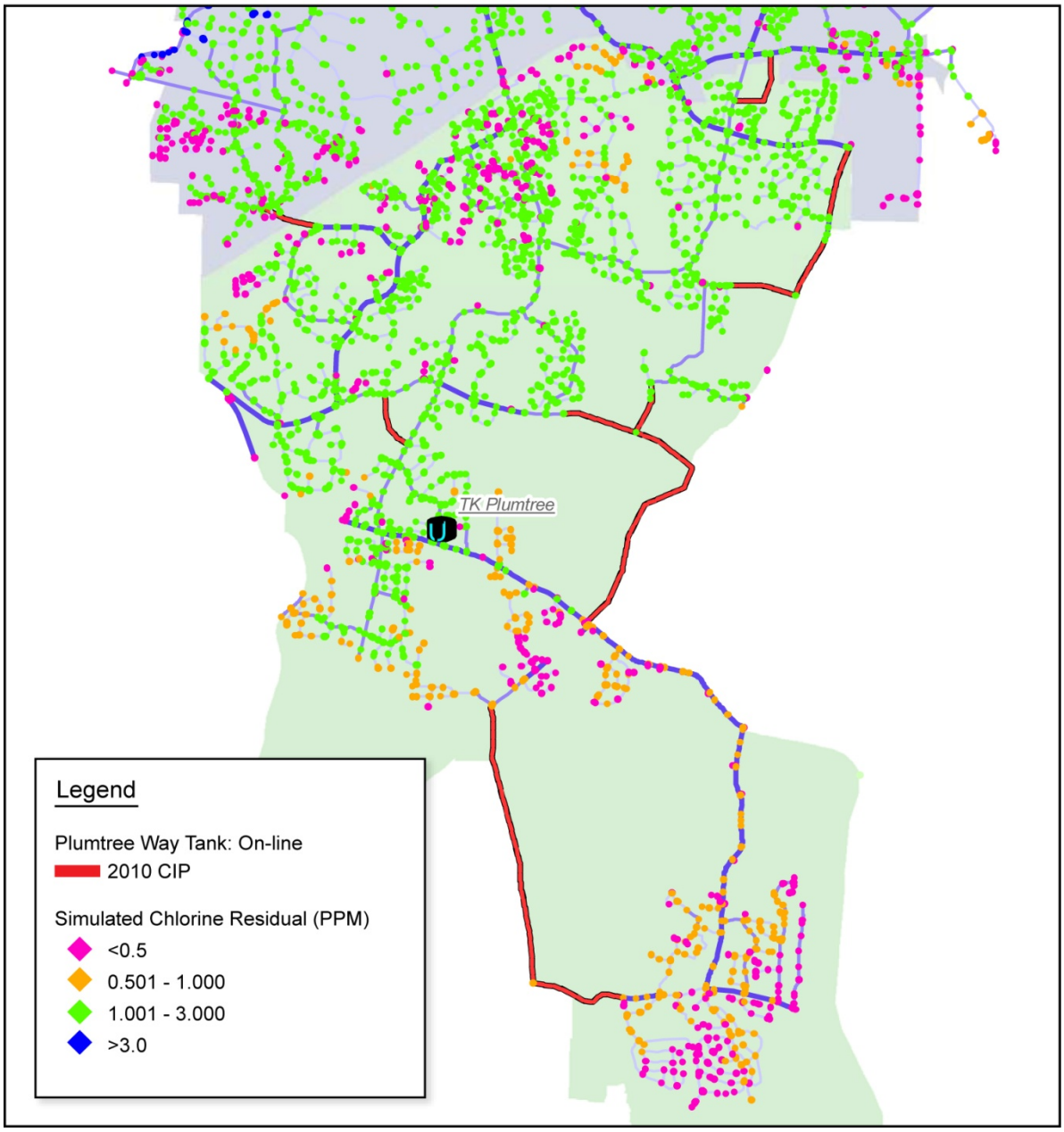


FIGURE 5-7
Simulated Chlorine Residual (PPM) in Southern Pressure Zone (2010 CIP Piping, Tank Off-line, HSC 13.4 MGD Demand)

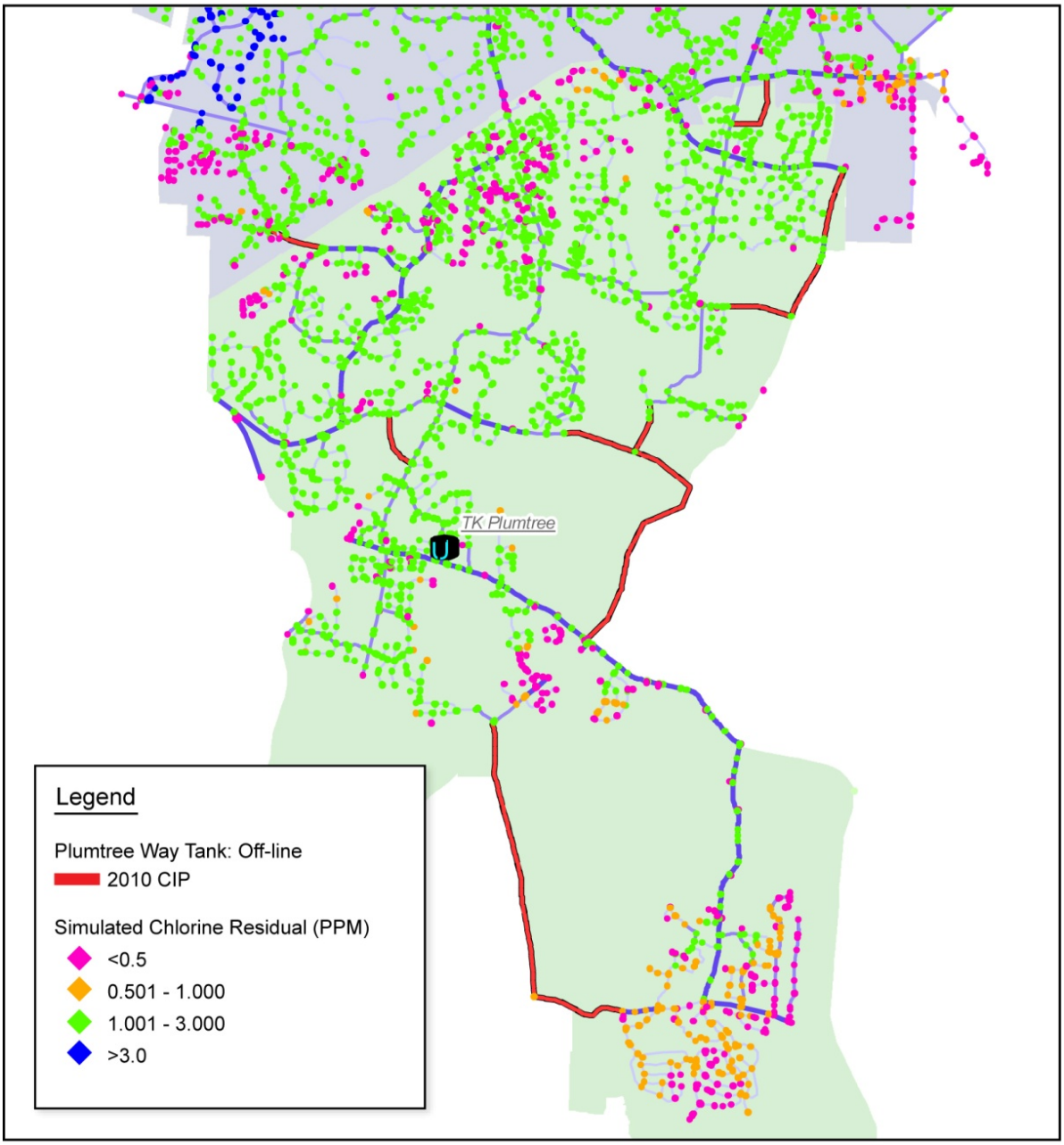


FIGURE 5-8
Simulated Chlorine Residual (PPM) in Southern Pressure Zone (2010 CIP Piping, Tank On-line, 2010 ADD)

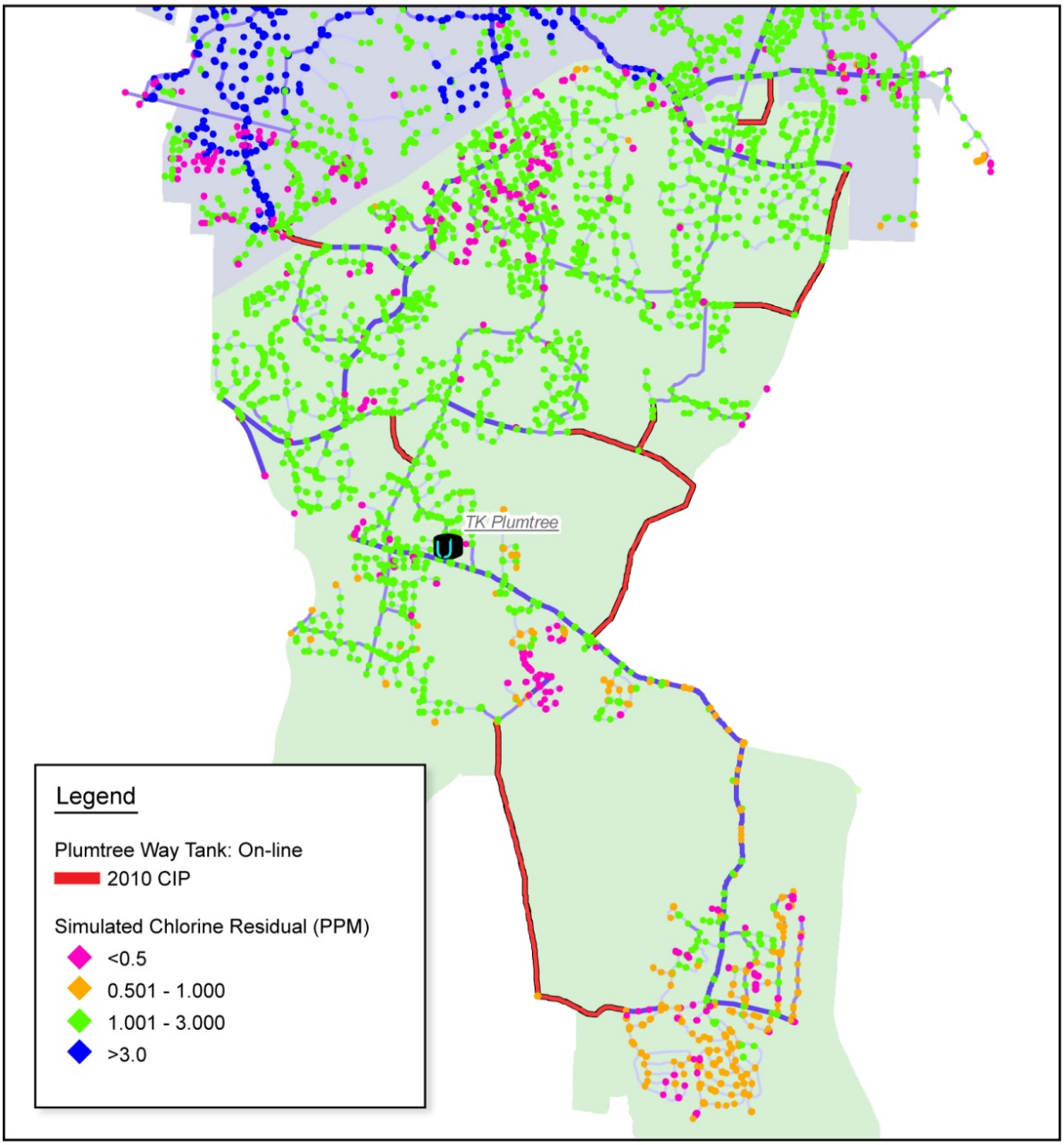


FIGURE 5-9
Simulated Chlorine Residual (PPM) in Southern Pressure Zone (2010 CIP Piping, Tank Off-line, 2010 ADD)

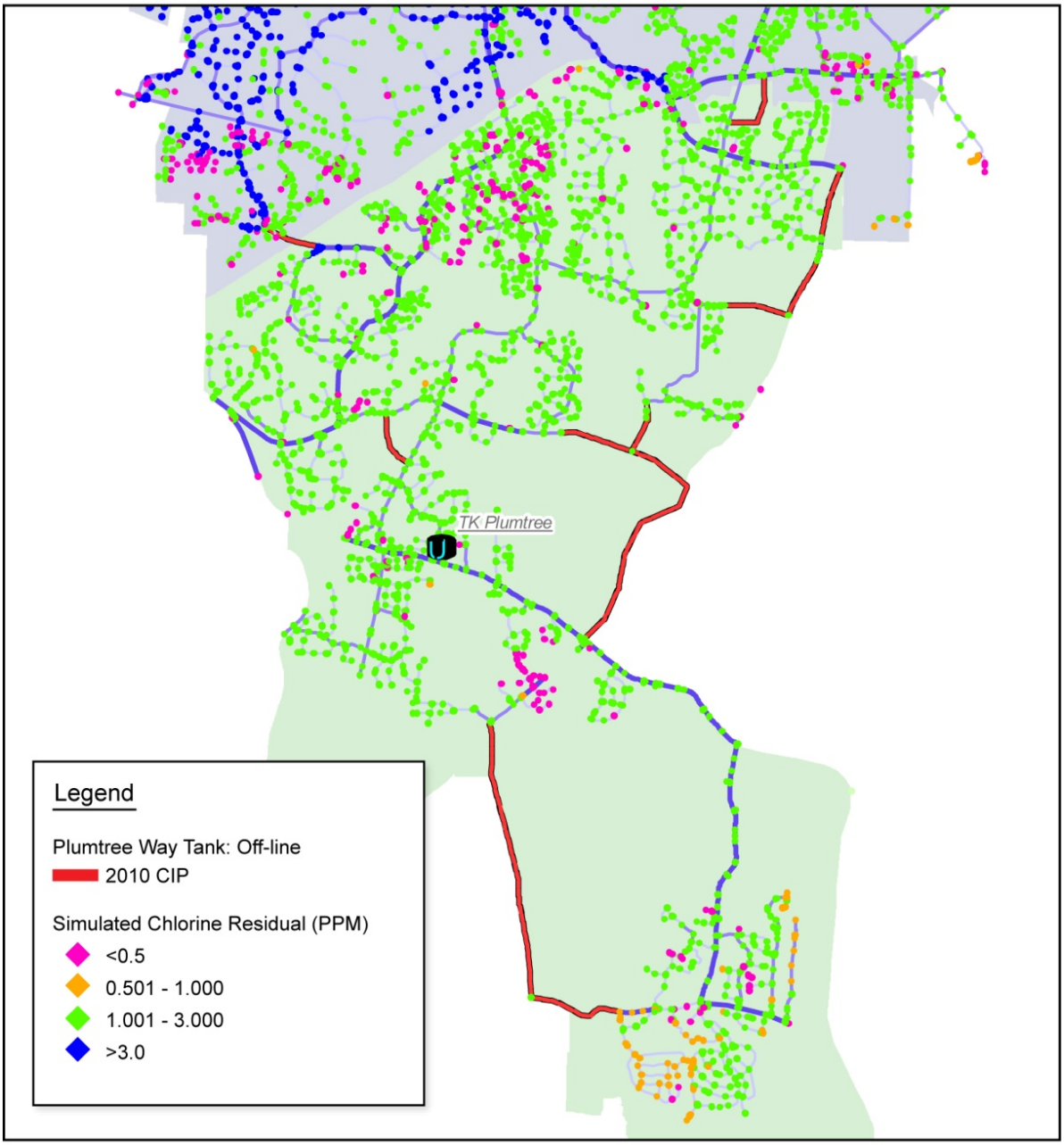


FIGURE 5-10
Simulated Chlorine Residual (PPM) in Southern Pressure Zone (2025 CIP Piping, Tank On-line, 2025 MDD)

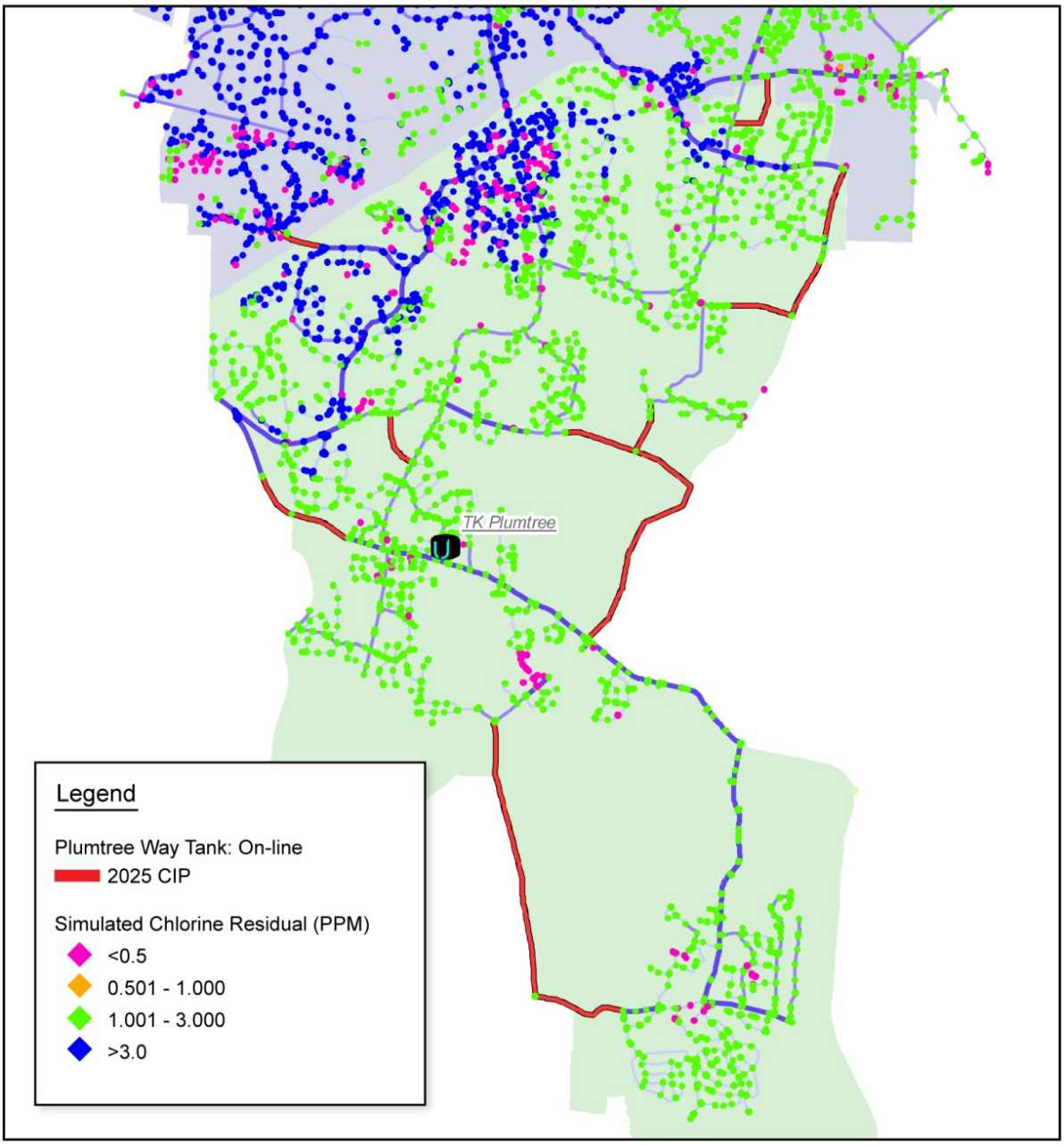


FIGURE 5-11
Simulated Chlorine Residual (PPM) in Southern Pressure Zone (2025 CIP Piping, Tank Off-line, 2025 MDD)

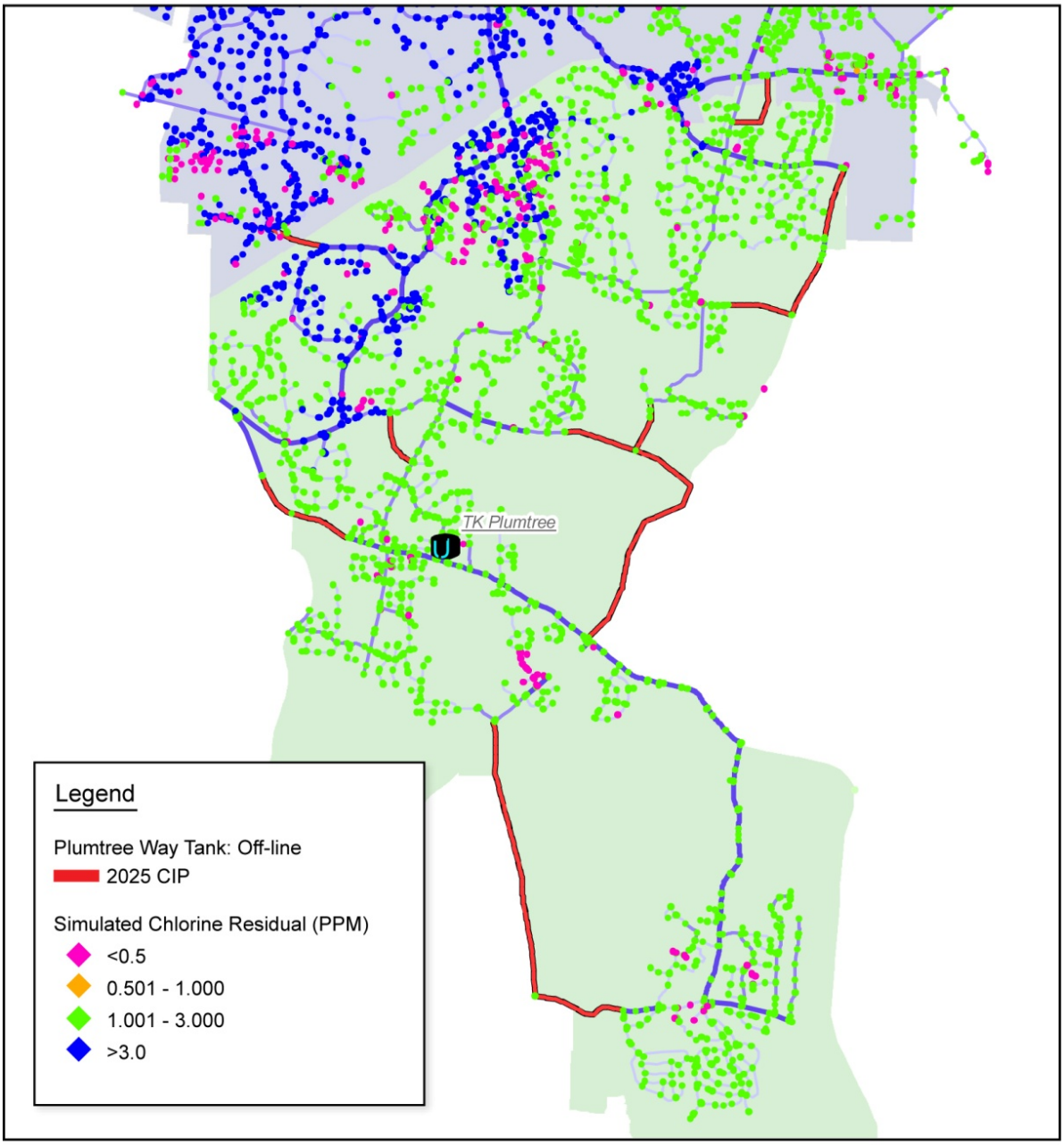


FIGURE 5-12
Simulated Chlorine Residual Change in SPZ: Tank On-line vs. Off-line (2010 CIP Piping, HSC 13.4 MGD Demand)
Highway 1 Control Valve is set as the primary supply of SPZ

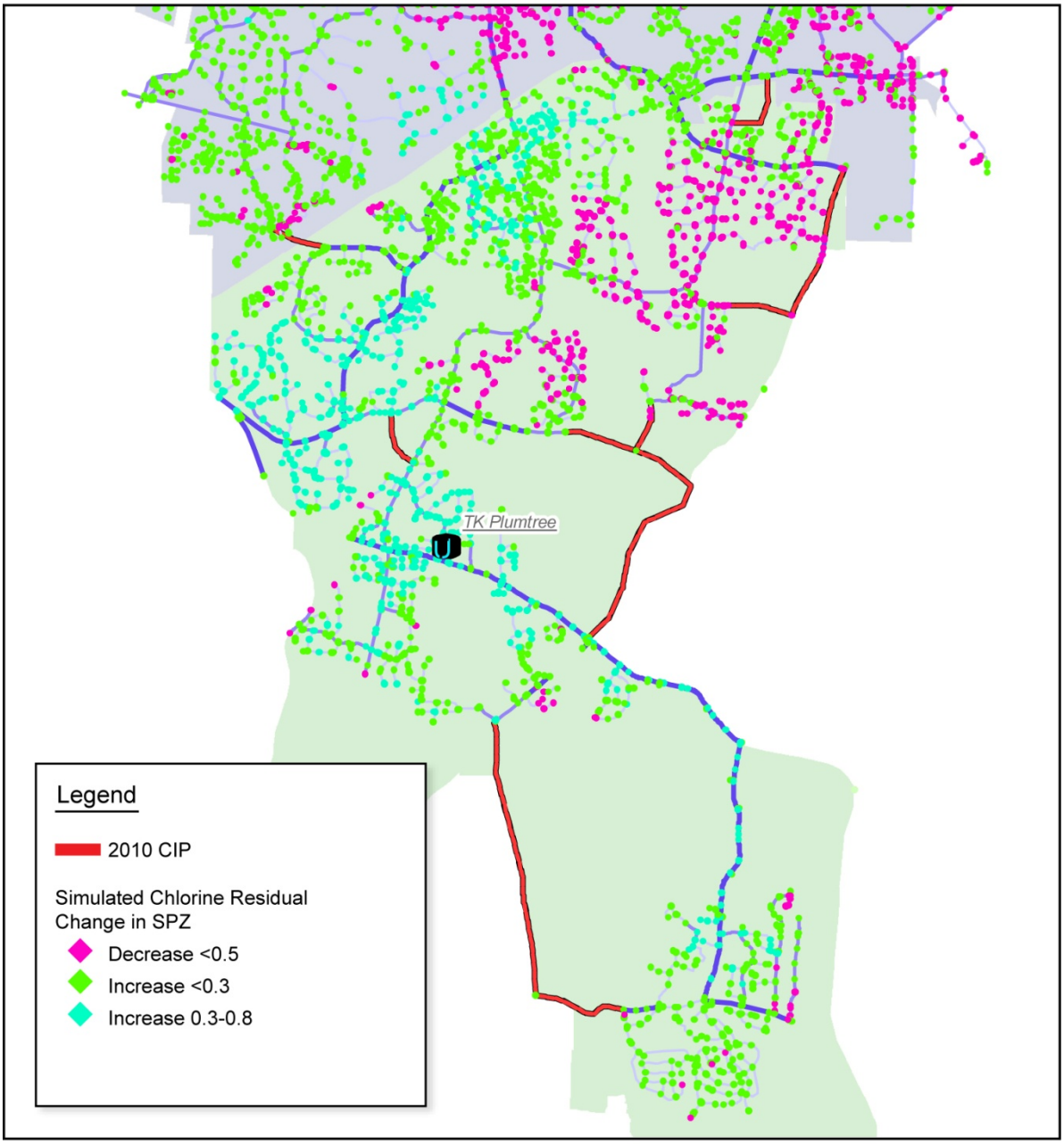


FIGURE 5-13A
Simulated Water Quality Impact of Only Opening the Proposed Highway 1 Control Valve
Hypothetical Summer Conservation Demand of 13.4 MGD; Plumtree Way Tank Off-line

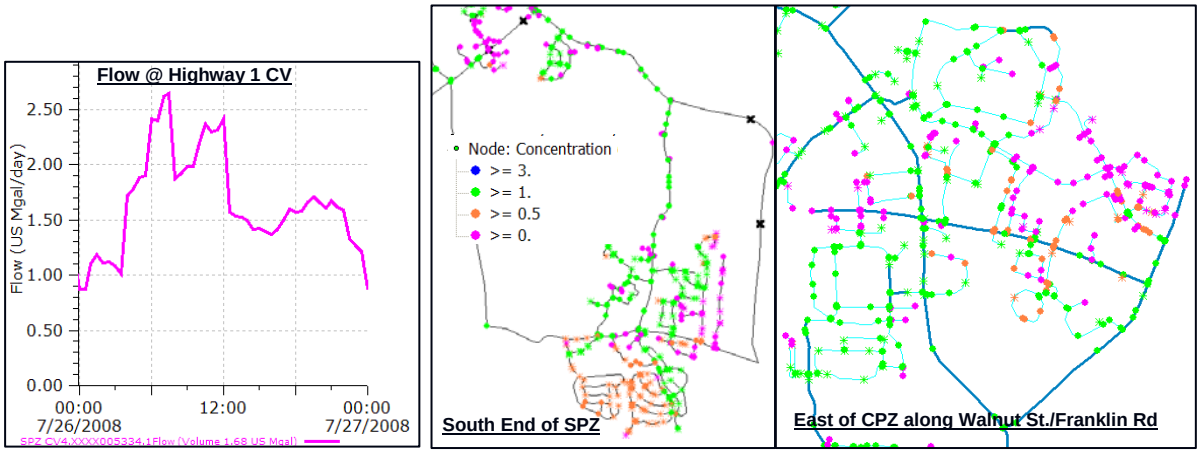
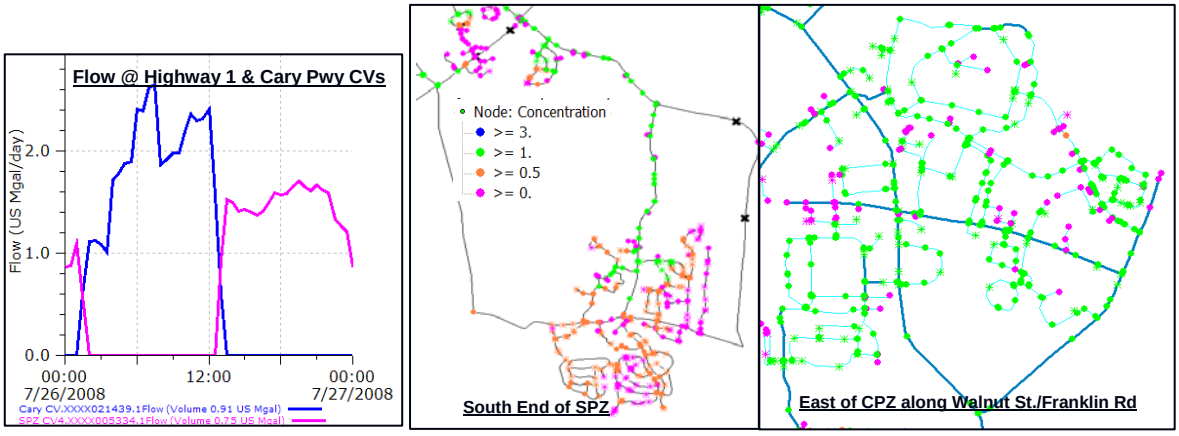


FIGURE 5-13B
Simulated Water Quality Impact of Only Opening the Existing Cary Parkway and Proposed Highway 1 Control Valves
Hypothetical Summer Conservation Demand of 13.4 MGD; Plumtree Way Tank Off-line



Appendix A

ADS Environmental Services Report:

District Measurement and
Analysis Report
Town of Cary, North Carolina
July 2009

District Measurement and Analysis Report Town of Cary, North Carolina

Prepared For:
CH2M Hill, Inc.

July 2009

ADS Project No. 15695

Innovation ▪ Flexibility ▪ Affordability

ADS® ENVIRONMENTAL SERVICES

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Equipment 1

Flow Measurements 2

Water Distribution System District Measurements 3

Gauging Points 27

Summary 28

Purpose

The purpose of this work is to collect hourly flow (consumption) data for specific areas (districts) in the water system as part of the water quality modeling analysis study.

Scope of Work

The work in Cary, North Carolina consisted of the following items:

- Mobilize, meet with CH2M Hill and City of Cary officials and discuss the schedule of work, review water system maps, confirm the boundaries of the 7 districts, locate the gauging points needed for the Pitometer measurements and review the existing elevated tank data that was used to determine the diurnal flow pattern in each of the 7 districts.

- Conduct in/out flow measurements on the supply mains at the four designated locations to determine the flow pattern at 1 minute intervals over a two day period. The Pitometer and recorder were used for the measurements. At each gauging point, an inside diameter measurement and velocity profile measurement was conducted to verify the usability of each gauging point.

- Submit a report of the work at the completion of the project including the results of all measurements; locations, the location of all gauging points; flow charts showing the variation of flow into each district and a summary of the entire project.

Distribution System Tests

Distribution system tests provide information to create accurate computer models and identify weaknesses that need to be corrected. Tests eliminate the guesswork and provide the necessary data for calibrating and verifying models. Frequently, an additional benefit of testing is discovering unusual conditions such as closed valves.

Equipment

Pressures were measured with electronic pressure recorders at the elevated tanks.

Average velocities for the flow measurements were calculated from velocity profiles. In a profile, velocities are measured at certain locations inside the pipe. These velocities are plotted against the distance from the bottom of the pipe at equal area points so the average velocity can be calculated. The velocity factor is the average velocity divided by the velocity at the center of the pipe. Multiplying velocity factors by subsequent measurements of center velocities calculates the average velocities.

Velocities were measured using the “Cole” Pitometer rod. A Pitometer rod consists of a pair of calibrated orifices. The differential head between the orifices is related to the velocity of the fluid. Differential heads were recorded using a Pitometer Computer Recorder (PCR).

The PCR consists of a differential pressure (DP) cell and a recorder. The DP cell coverts the pressure into digital information. This information is collected and stored by a recorder. The PCR was field calibrated before every test.

Flow Measurements

Pitometer measurements use a pitot tube that is inserted into a pipe carrying the same flow rate as the meter. Pitometer pitot tubes have two orifices, one facing upstream and the other facing downstream. The velocity of the flowing water causes the pitot tube to produce a differential pressure. The velocity can be calculated from the following equation:

$$V = c \times (2 \times g \times hw/12)^{0.5}$$

Where:

V	=	velocity in feet per second
c	=	a coefficient established by laboratory calibration
g	=	acceleration of gravity, 32.174 feet per second
hw	=	differential pressure in inches of water

A velocity traverse relates point velocities from the above equation to the average velocity in the pipe. The average velocity determines the flow rate. A traverse determines the shape of the velocity profile by positioning the pitot tube along the pipe diameter at 10 points, chosen in such a way that averaging the point velocities calculates the average velocity in the pipe. Dividing the average velocity by the center velocity calculates the velocity factor, a constant summarizing the profile at a particular gauging point. The velocity factor theoretically varies less than five percent over the typical velocity range for water mains. The center velocity can be monitored and converted to flow using the following equation:

$$Q = 0.6463 \times VC \times VF \times A$$

Where:

Q	=	quantity of flow in gallons per minute
VC	=	velocity at the center of the pipe in feet per second
VF	=	velocity factor
A	=	area of the pipe in square feet

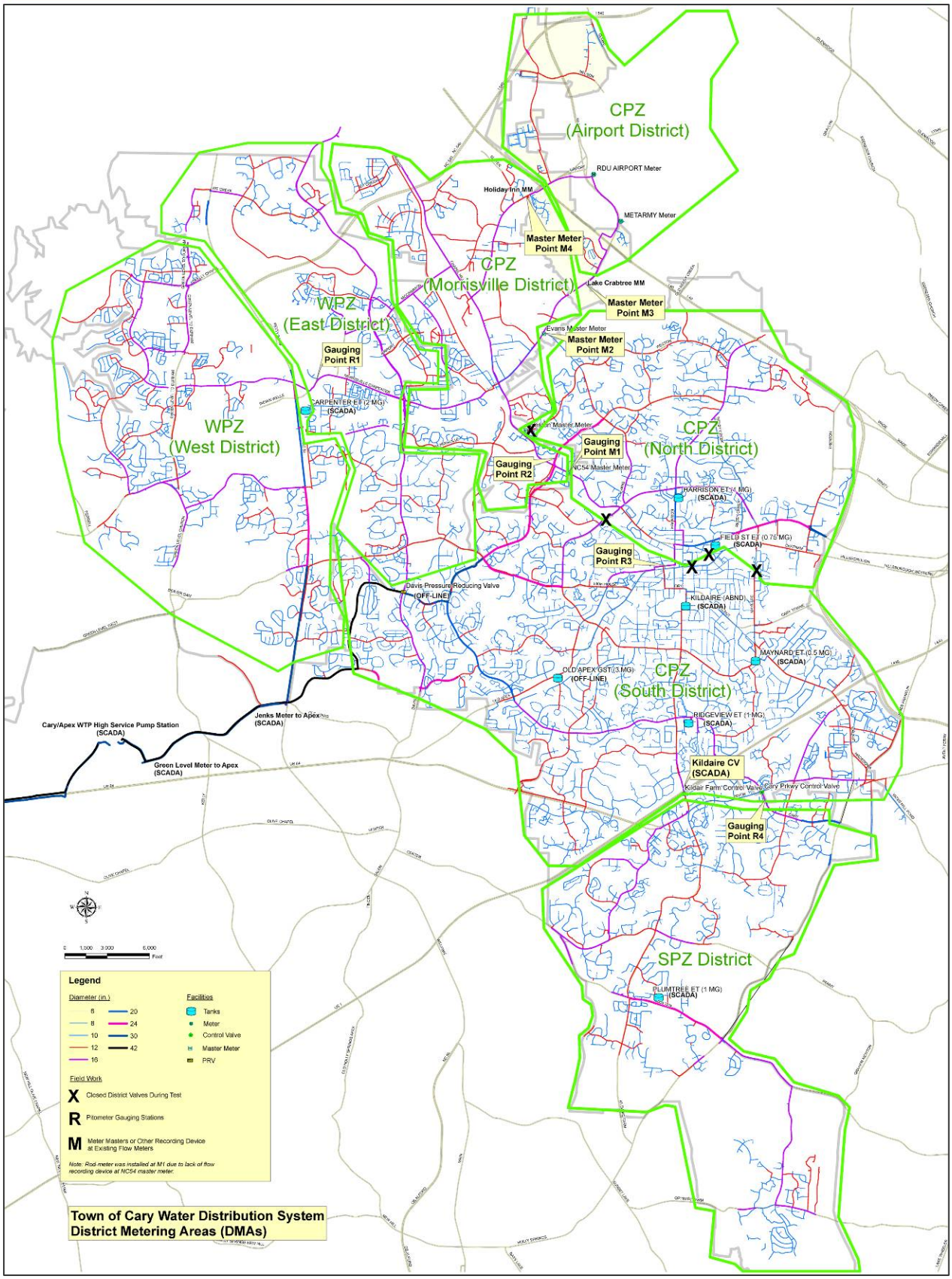
Water Distribution System District Measurements

The water distribution system of Cary, NC was divided into seven water districts. These districts were named the following:

WPZ ED:	Western Pressure Zone – East District
WPZ WD:	Western Pressure Zone – West District
CPZ Airport:	Central Pressure Zone – Airport District
CPZ MD:	Central Pressure Zone – Morrisville District
CPZ SD:	Central Pressure Zone – South District
CPZ ND:	Central Pressure Zone – North District
SPZ:	Southern Pressure Zone*

*The Southern Pressure Zone originally had two districts, a North and a South, but it was combined into one.

The water districts location can be seen on the following map.


CPZ
(Airport District)
RDU AIRPORT Meter
Holiday Inn MM
METARMY Meter
Master Meter
Point M4
CPZ
(Morrisville District)
Lake Crabtree MM
Master Meter
Point M3
WPZ
(East District)
Evans Master Meter
Master Meter
Point M2
Gauging
Point R1
CARPENTER ET (2 MG)
(SCADA)
WPZ
(West District)
Gauging
Point M1
CPZ
(North District)
Gauging
Point R2
NC54 Master Meter
HARRISON ET (1 MG)
(SCADA)
FIELD ST ET (0.75 MG)
(SCADA)
Gauging
Point R3
Davis Pressure Reducing Valve
(OFF-LINE)
KILDAIRE (ABND)
(SCADA)
MAYNARD ET (0.5 MG)
(SCADA)
OLD APEX GST (3 MG)
(OFF-LINE)
CPZ
(South District)
Jenks Meter to Apex
(SCADA)
Cary/Apex WTP High Service Pump Station
(SCADA)
RIDGEVIEW ET (1 MG)
(SCADA)
Green Level Meter to Apex
(SCADA)
Kildaire CV
(SCADA)
Kildair Farm Control Valve
Cary Pkwy Control Valve
Gauging
Point R4
SPZ District
PLUMTREE ET (1 MG)
(SCADA)
Legend
Diameter (in.)
6
8
10
12
16
20
24
30
42
Facilities
Tanks
Meter
Control Valve
Master Meter
PRV
Field Work
X Closed District Valves During Test
R Pitometer Gauging Stations
M Meter Masters or Other Recording Device at Existing Flow Meters
Note: Rod-meter was installed at M1 due to lack of flow recording device at NC54 master meter.
Town of Cary Water Distribution System
District Metering Areas (DMAs)

For the seven district measurements, the data was collected over ten minute time periods. The results of the ten minute periods are represented on the hydrographs.

The numerical results were presented in spreadsheet format to CH2M Hill at the end of the measurement period.

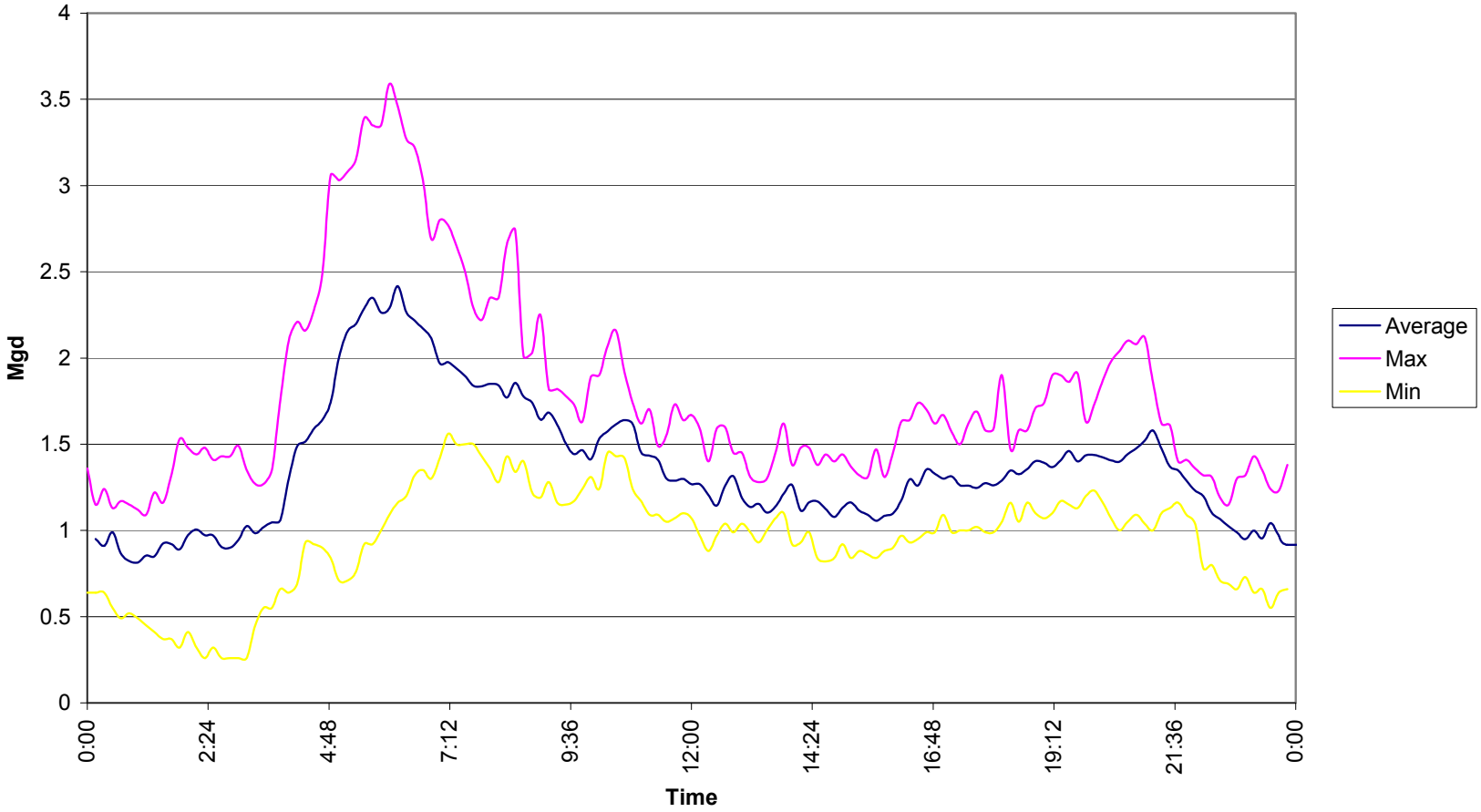
For this report, the ten minute readings have been averaged over an hour period; thus lessening the numerical calculation errors that cause significant deviations in the data. The hourly average readings are presented in the bar graphs.

There was an attempt to measure every district from June 17 to June 24. But, due to measurement difficulties not all districts were measured for the full period. The tables with missing data are the result of problems encountered during the measurements.

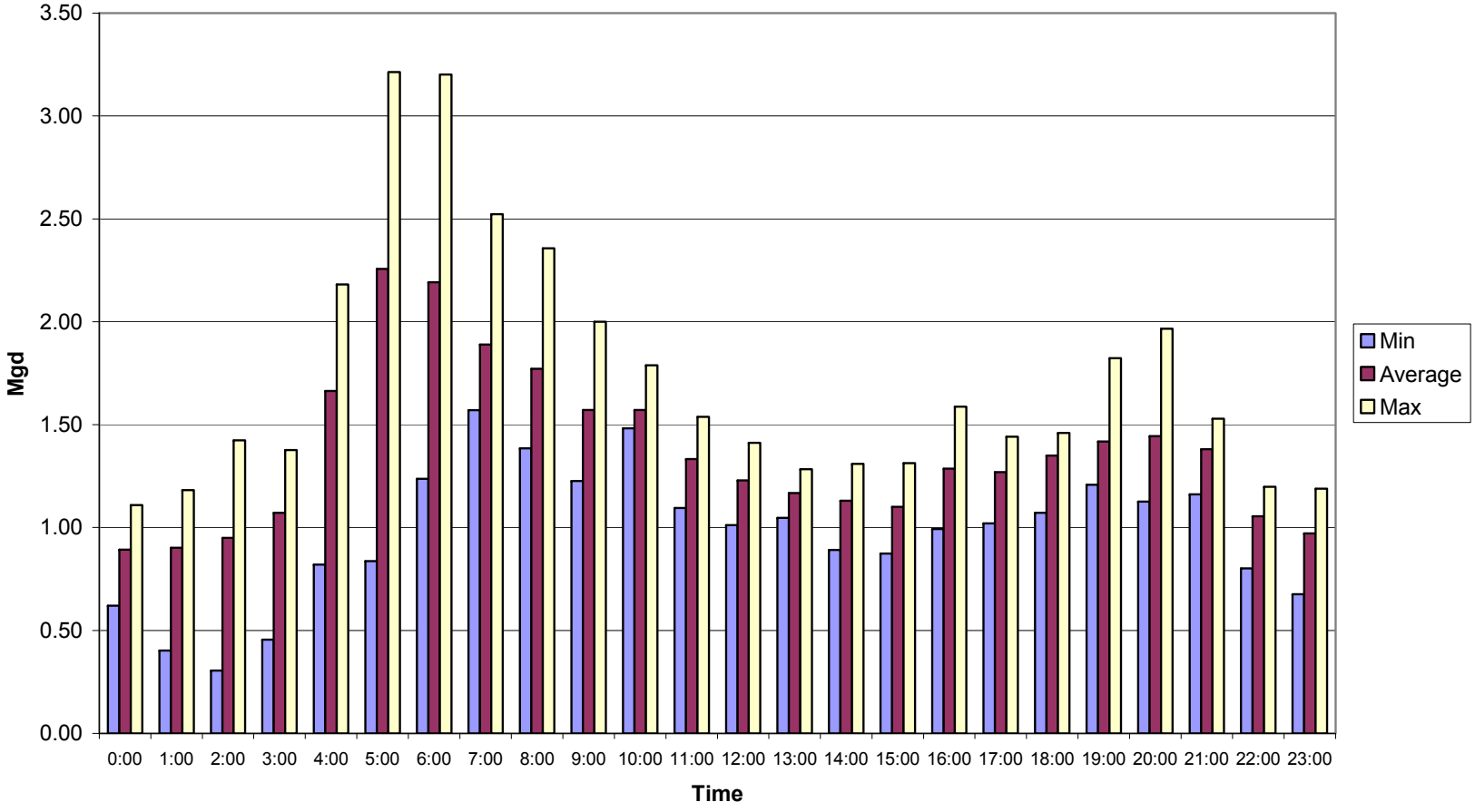
The following tables and hydrographs represent the District Measurements for the Town of Cary, North Carolina.

Cary NC, District Measurements Western Pressure Zone Eastern District (WPZ ED)													
	Daily Hourly Averages (Mgd)										Hourly Minimums, Averages, and Maximums (Mgd)		
Time	6/17/2009	6/18/2009	6/19/2009	6/20/2009	6/21/2009	6/22/2009	6/23/2009	6/24/2009		Time	Min	Average	Max
0:00		0.62	0.74	1.10	0.91	0.79	1.11	0.99		0:00	0.62	0.89	1.11
1:00		0.96	0.58	1.18	1.05	0.40	1.08	1.06		1:00	0.40	0.90	1.18
2:00		0.57	0.63	1.42	1.16	0.31	1.38	1.18		2:00	0.31	0.95	1.42
3:00		0.72	1.20	1.38	1.26	0.46	1.34	1.16		3:00	0.46	1.07	1.38
4:00		1.22	1.38	1.86	2.16	0.82	2.18	2.02		4:00	0.82	1.66	2.18
5:00		1.23	1.96	2.71	2.88	0.84	2.97	3.21		5:00	0.84	2.26	3.21
6:00		1.90	1.84	2.05	2.16	1.24	3.20	2.96		6:00	1.24	2.19	3.20
7:00		1.57	1.76	1.59	1.69	1.58	2.51	2.52		7:00	1.57	1.89	2.52
8:00		1.39	1.77	1.47	1.71	1.71	1.99	2.36		8:00	1.39	1.77	2.36
9:00		1.30	1.23	1.72	1.66	1.41	1.69	2.00		9:00	1.23	1.57	2.00
10:00		1.51	1.51	1.50	1.48	1.79	1.64			10:00	1.48	1.57	1.79
11:00		1.18	1.34	1.42	1.54	1.43	1.10			11:00	1.10	1.33	1.54
12:00		1.15	1.24	1.41	1.37	1.01	1.20			12:00	1.01	1.23	1.41
13:00		1.28	1.05	1.19	1.13	1.23	1.13			13:00	1.05	1.17	1.28
14:00	1.11	1.31	1.24	1.09	1.08	0.89	1.19			14:00	0.89	1.13	1.31
15:00	1.21	1.08	0.95	1.31	1.11	0.87	1.17			15:00	0.87	1.10	1.31
16:00	1.03	1.21	0.99	1.49	1.59	1.26	1.43			16:00	0.99	1.29	1.59
17:00	1.05	1.02	1.44	1.38	1.34	1.38	1.28			17:00	1.02	1.27	1.44
18:00	1.33	1.07	1.46	1.41	1.44	1.30	1.45			18:00	1.07	1.35	1.46
19:00	1.22	1.21	1.25	1.40	1.58	1.44	1.82			19:00	1.21	1.42	1.82
20:00	1.13	1.53	1.20	1.29	1.97	1.42	1.59			20:00	1.13	1.44	1.97
21:00	1.22	1.40	1.38	1.16	1.52	1.53	1.45			21:00	1.16	1.38	1.53
22:00	0.80	1.09	0.95	1.20	1.07	1.08	1.19			22:00	0.80	1.05	1.20
23:00	0.68	0.75	1.11	1.13	0.82	1.14	1.19			23:00	0.68	0.97	1.19

Cary NC, District Measurements
Western Pressure Zone East District (WPZ ED)
Average Day, Maximum Day, and Minimum Day
From June 17 to June 24, 2008

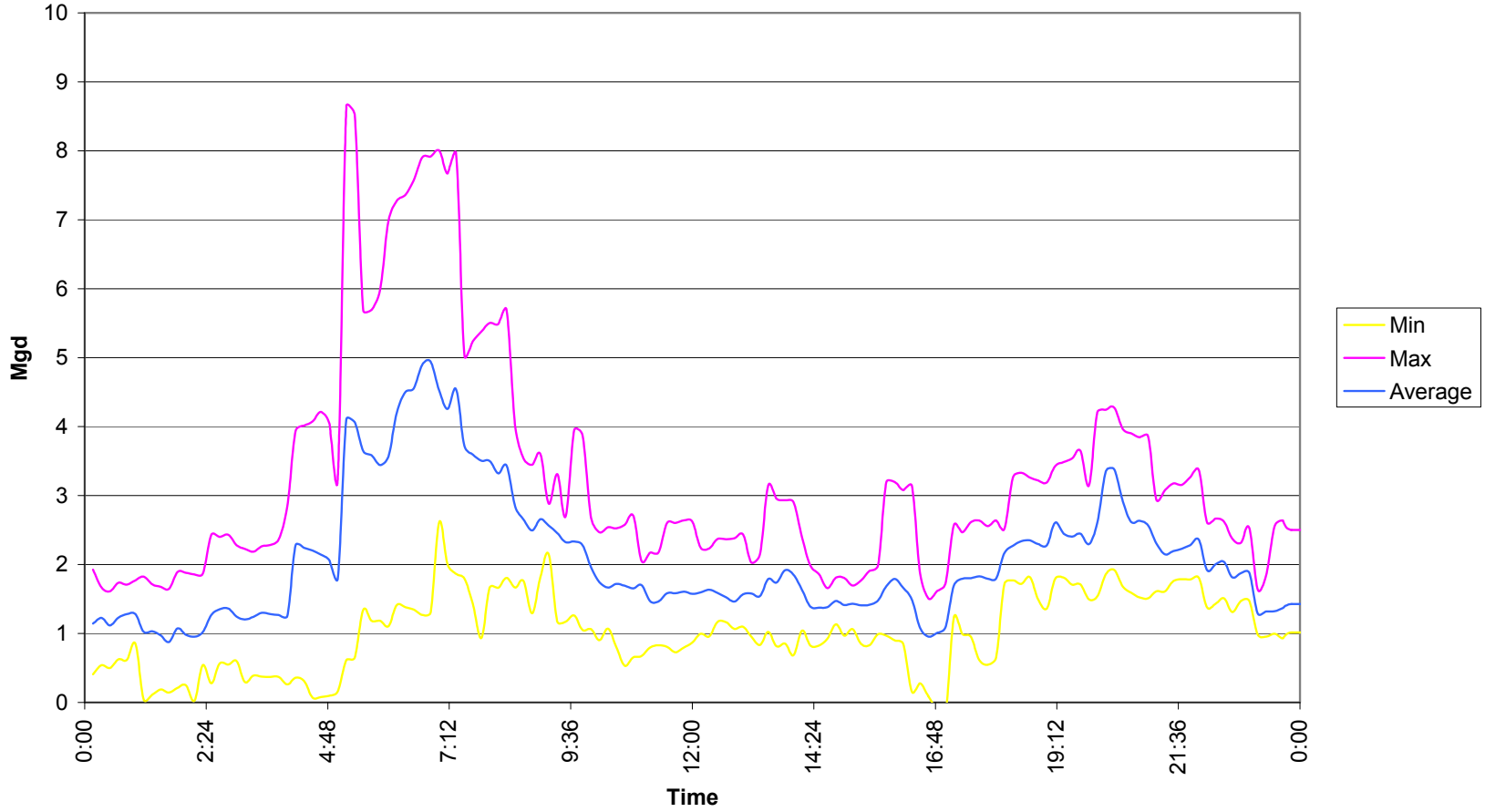


Cary, NC
Western Pressure Zone Eastern District, Hourly Averages (WPZ ED)
Average Day, Maximum Day, and Minimum Day
June 17 to June 24, 2009

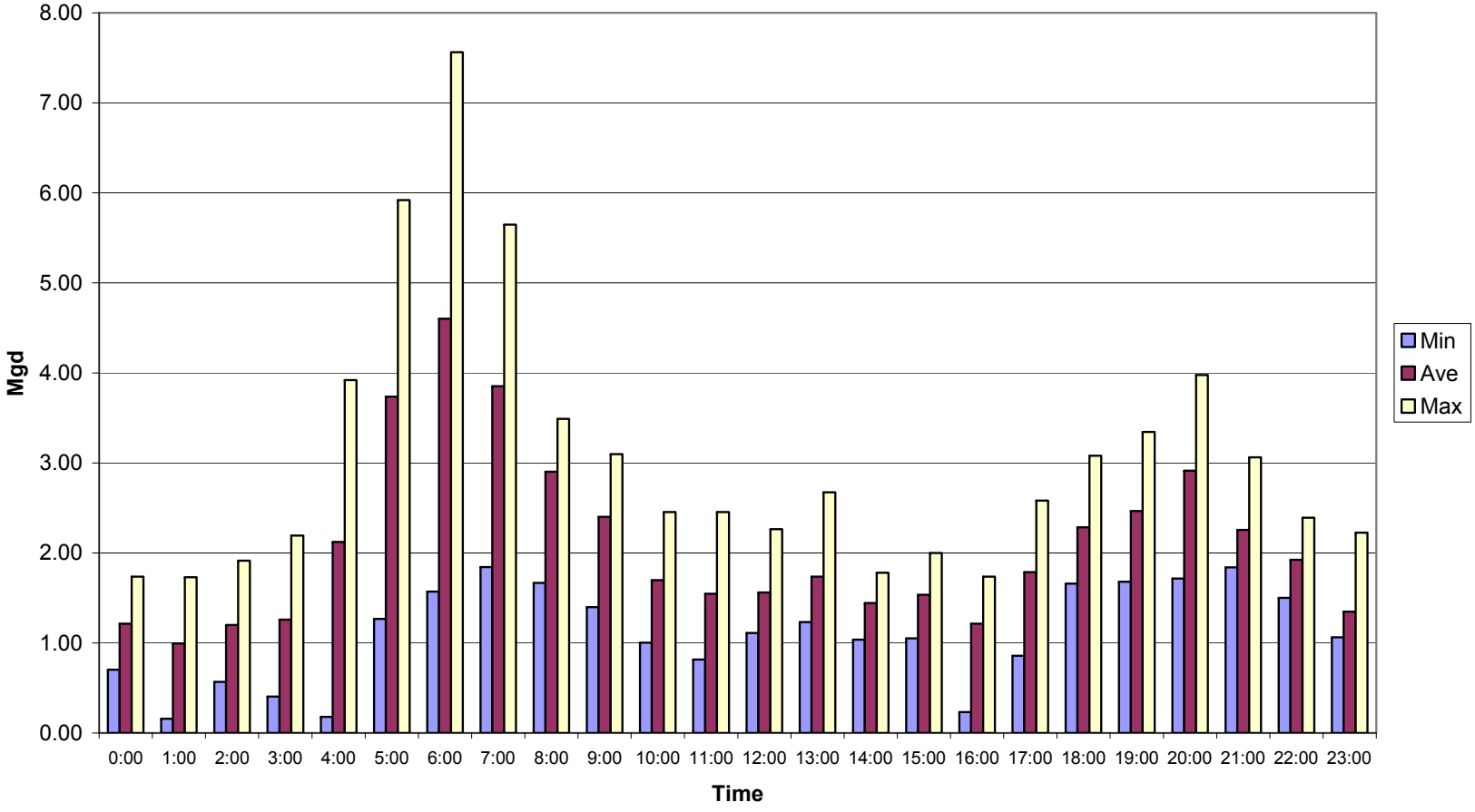


Cary NC, Western Pressure Zone, Western District, (WPZ WD)												
	Daily Hourly Averages (Mgd)									Hourly Minimums, Averages, and Maximums (Mgd)		
	6/18/2009	6/19/2009	6/20/2009	6/21/2009	6/22/2009	6/23/2009	6/24/2009			Min	Ave	Max
0:00	1.53	0.70	1.25	1.43	0.71	1.74	1.13		0:00	0.70	1.21	1.74
1:00	1.03	0.86	0.86	0.93	0.16	1.73	1.40		1:00	0.16	0.99	1.73
2:00	1.23	0.76	1.23	1.68	1.01	0.57	1.91		2:00	0.57	1.20	1.91
3:00	1.05	0.60	1.34	2.19	0.40	1.46	1.75		3:00	0.40	1.26	2.19
4:00	0.54	2.36	3.92	3.45	0.18	2.21	2.19		4:00	0.18	2.12	3.92
5:00	1.54	3.36	3.18	5.42	1.27	5.46	5.92		5:00	1.27	3.74	5.92
6:00	1.57	3.59	4.91	4.58	2.68	7.33	7.56		6:00	1.57	4.60	7.56
7:00	2.12	3.48	4.56	4.08	1.84	5.65	5.25		7:00	1.84	3.85	5.65
8:00	1.67	3.03	2.77	3.29	2.86	3.49	3.21		8:00	1.67	2.90	3.49
9:00	2.08	1.40	2.47	2.62	3.05	2.10	3.10		9:00	1.40	2.40	3.10
10:00	1.29	1.00	2.45	2.35	1.47	1.62			10:00	1.00	1.70	2.45
11:00	0.82	2.45	1.87	2.03	0.93	1.18			11:00	0.82	1.55	2.45
12:00	1.79	1.48	1.56	2.26	1.11	1.17			12:00	1.11	1.56	2.26
13:00	1.23	2.67	1.75	1.40	1.82	1.55			13:00	1.23	1.74	2.67
14:00	1.03	1.78	1.05	1.48	1.71	1.59			14:00	1.03	1.44	1.78
15:00	2.00	1.81	1.83	1.05	1.27	1.24			15:00	1.05	1.53	2.00
16:00	1.48	1.23	1.74	1.18	0.23	1.42			16:00	0.23	1.21	1.74
17:00	1.25	0.86	2.26	2.58	1.49	2.28			17:00	0.86	1.79	2.58
18:00	1.79	2.46	1.66	2.33	2.39	3.08			18:00	1.66	2.28	3.08
19:00	1.68	1.79	3.34	2.92	2.48	2.59			19:00	1.68	2.47	3.34
20:00	1.71	2.88	2.18	3.98	3.29	3.43			20:00	1.71	2.91	3.98
21:00	1.84	1.94	1.84	3.06	2.08	2.76			21:00	1.84	2.25	3.06
22:00	1.79	1.50	1.98	1.83	2.39	2.03			22:00	1.50	1.92	2.39
23:00	2.22	1.15	1.19	1.35	1.11	1.06			23:00	1.06	1.35	2.22

Cary, NC District Measurements
Western Pressure Zone Western District (WPZ WD)
Average Day, Max Day, Min Day
June 18 to June 24, 2009

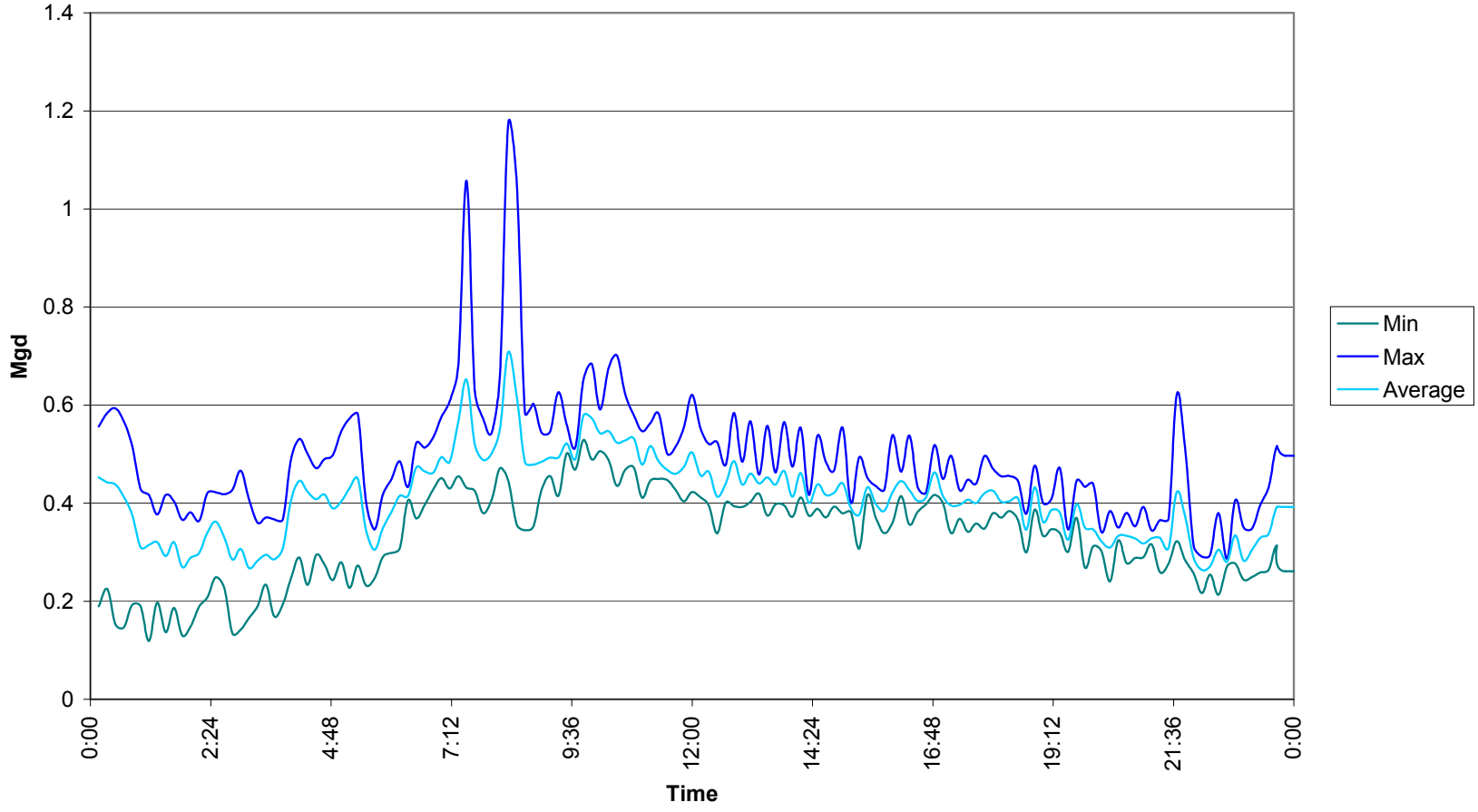


Cary NC, District Measurements
Western Pressure Zone, Western District Hourly Averages (WPZ WD)
Average Day, Minimum Day and Maximum Day
June 18 - June 24, 2008

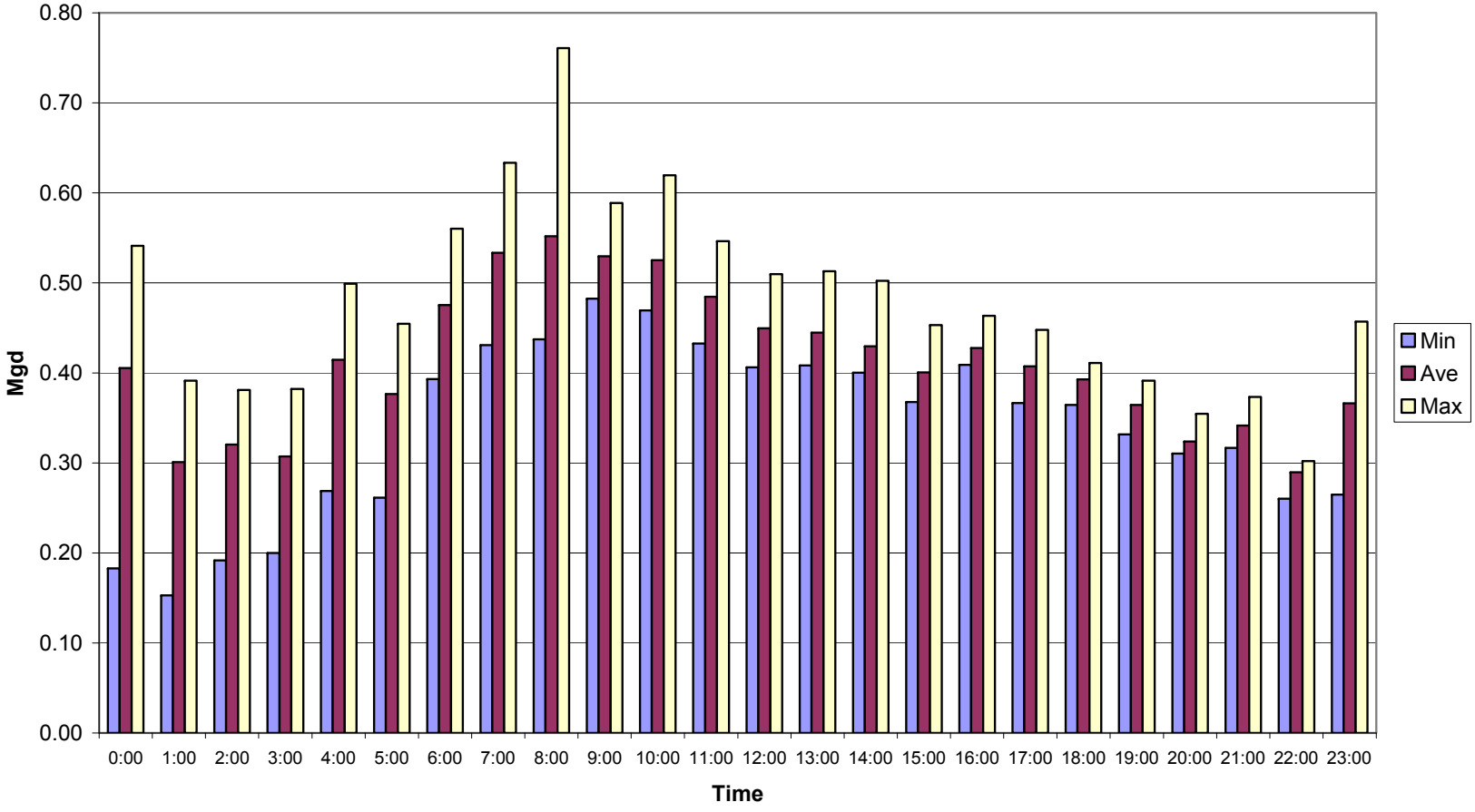


Cary, NC District Measurements Central Pressure Zone Airport District (CPZ-Airport)										
	Daily Hourly Averages (Mgd)							Hourly Minimums, Averages, and Maximums (Mgd)		
	6/20/2009	6/21/2009	6/22/2009	6/23/2009	6/24/2009			Min	Ave	Max
0:00		0.44	0.46	0.18	0.54		0:00	0.18	0.41	0.54
1:00		0.32	0.34	0.15	0.39		1:00	0.15	0.30	0.39
2:00		0.36	0.35	0.19	0.38		2:00	0.19	0.32	0.38
3:00		0.33	0.32	0.20	0.38		3:00	0.20	0.31	0.38
4:00		0.47	0.50	0.27	0.42		4:00	0.27	0.41	0.50
5:00		0.44	0.45	0.26	0.35		5:00	0.26	0.38	0.45
6:00	0.56	0.46	0.47	0.39	0.49		6:00	0.39	0.48	0.56
7:00	0.53	0.46	0.43	0.63	0.62		7:00	0.43	0.53	0.63
8:00	0.54	0.44	0.45	0.57	0.76		8:00	0.44	0.55	0.76
9:00	0.55	0.50	0.48	0.59			9:00	0.48	0.53	0.59
10:00	0.53	0.48	0.47	0.62			10:00	0.47	0.53	0.62
11:00	0.50	0.46	0.43	0.55			11:00	0.43	0.48	0.55
12:00	0.45	0.41	0.43	0.51			12:00	0.41	0.45	0.51
13:00	0.44	0.41	0.41	0.51			13:00	0.41	0.44	0.51
14:00	0.41	0.40	0.40	0.50			14:00	0.40	0.43	0.50
15:00	0.37	0.40	0.38	0.45			15:00	0.37	0.40	0.45
16:00	0.41	0.43	0.41	0.46			16:00	0.41	0.43	0.46
17:00	0.37	0.38	0.43	0.45			17:00	0.37	0.41	0.45
18:00	0.39	0.36	0.40	0.41			18:00	0.36	0.39	0.41
19:00	0.39	0.35	0.33	0.39			19:00	0.33	0.36	0.39
20:00	0.35	0.32	0.31	0.31			20:00	0.31	0.32	0.35
21:00	0.33	0.37	0.35	0.32			21:00	0.32	0.34	0.37
22:00	0.30	0.30	0.26	0.29			22:00	0.26	0.29	0.30
23:00	0.41	0.46	0.26	0.33			23:00	0.26	0.37	0.46

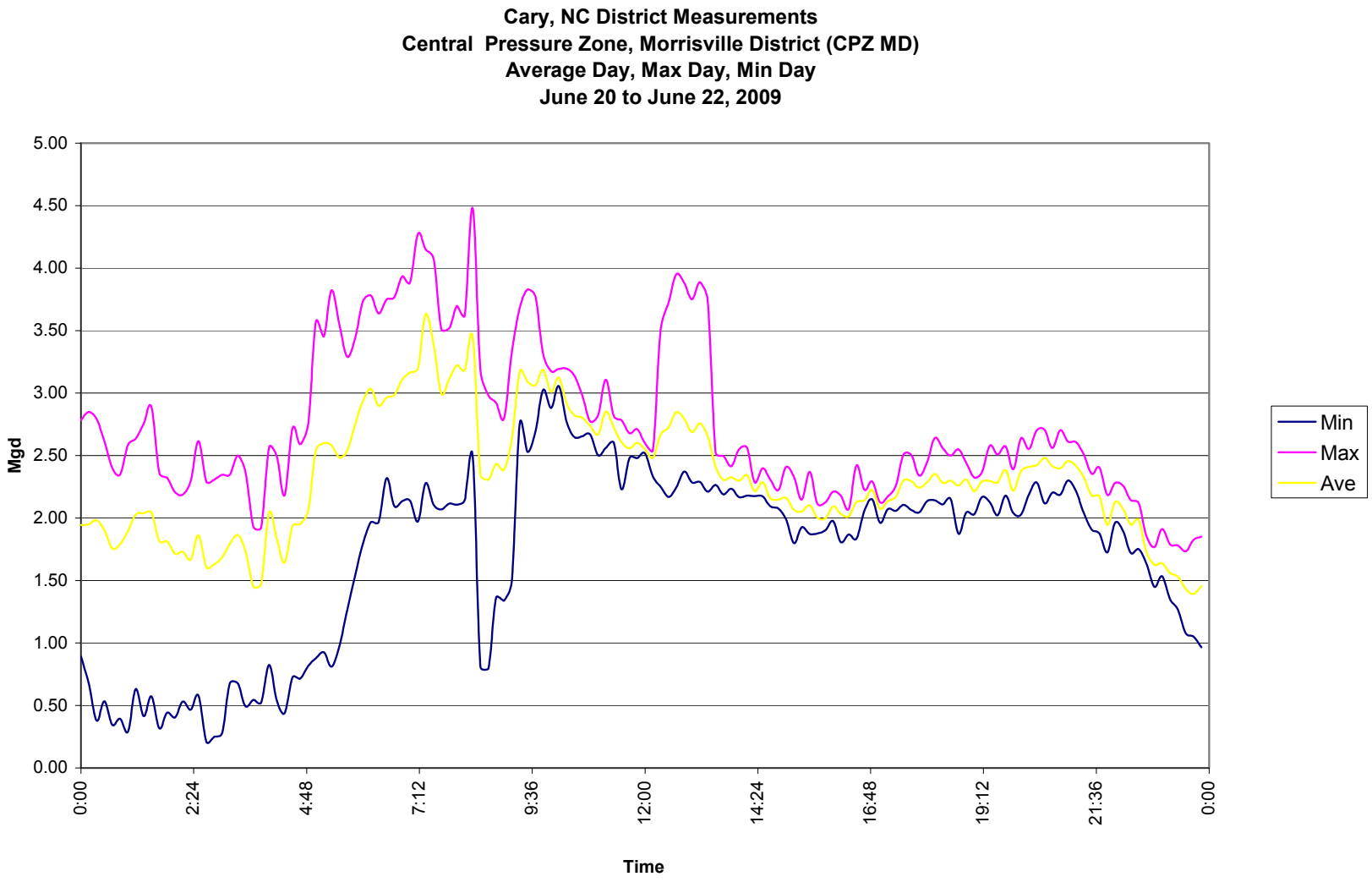
Cary, NC District Measurements
Central Pressure Zone, Airport District Measurement (CPZ Airport)
Average Day, Maximum Day, and Minimum Day
June 20 to June 24, 2009



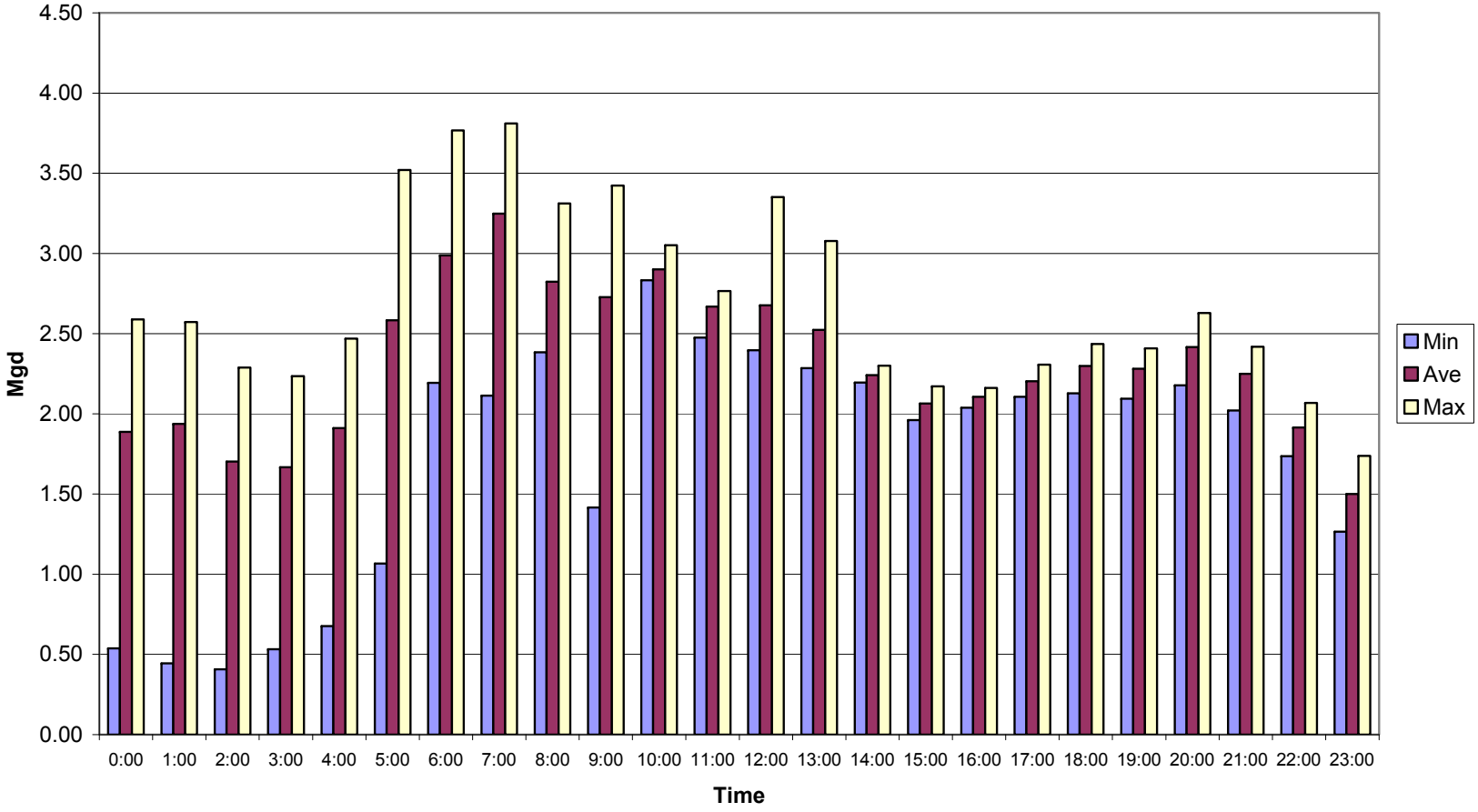
Cary, NC District Measurements
Central Pressure Zone, Airport District (CPZ Airport)
Average Day, Maximum Day, and Minimum Day
June 20 - June 24, 2008



Cary, NC, District Measurements Central Pressure Zone Morrisville District (CPZ MD)										
	Daily Hourly Averages (Mgd)						Hourly Minimums, Averages, and Maximums (Mgd)			
Time	6/20/2009	6/21/2009	6/22/2009	6/23/2009	6/24/2009		Time	Min	Ave	Max
0:00		2.52	0.54	1.91	2.59		0:00	0.54	1.89	2.59
1:00		2.48	0.44	2.26	2.57		1:00	0.44	1.94	2.57
2:00		2.18	0.41	1.93	2.29		2:00	0.41	1.70	2.29
3:00		2.12	0.53	1.79	2.24		3:00	0.53	1.67	2.24
4:00		2.17	0.68	2.47	2.33		4:00	0.68	1.91	2.47
5:00		2.69	1.07	3.52	3.05		5:00	1.07	2.58	3.52
6:00		2.39	2.19	3.60	3.77		6:00	2.19	2.99	3.77
7:00		2.11	3.40	3.67	3.81		7:00	2.11	3.25	3.81
8:00		2.38	3.31	3.18	2.42		8:00	2.38	2.82	3.31
9:00	3.08	3.42	2.95	2.77	1.42		9:00	1.42	2.73	3.42
10:00	2.85	2.88	2.83	3.05			10:00	2.83	2.90	3.05
11:00	2.77	2.74	2.69	2.48			11:00	2.48	2.67	2.77
12:00	2.46	2.50	3.35	2.40			12:00	2.40	2.68	3.35
13:00	2.29	2.38	3.08	2.35			13:00	2.29	2.52	3.08
14:00	2.22	2.20	2.30	2.25			14:00	2.20	2.24	2.30
15:00	2.17	1.96	2.14	1.98			15:00	1.96	2.06	2.17
16:00	2.12	2.10	2.16	2.04			16:00	2.04	2.11	2.16
17:00	2.11	2.23	2.31	2.16			17:00	2.11	2.20	2.31
18:00	2.13	2.28	2.43	2.35			18:00	2.13	2.30	2.43
19:00	2.09	2.32	2.31	2.41			19:00	2.09	2.28	2.41
20:00	2.18	2.52	2.34	2.63			20:00	2.18	2.42	2.63
21:00	2.17	2.39	2.02	2.42			21:00	2.02	2.25	2.42
22:00	1.96	1.89	1.74	2.07			22:00	1.74	1.91	2.07
23:00	1.74	1.27	1.28	1.72			23:00	1.27	1.50	1.74

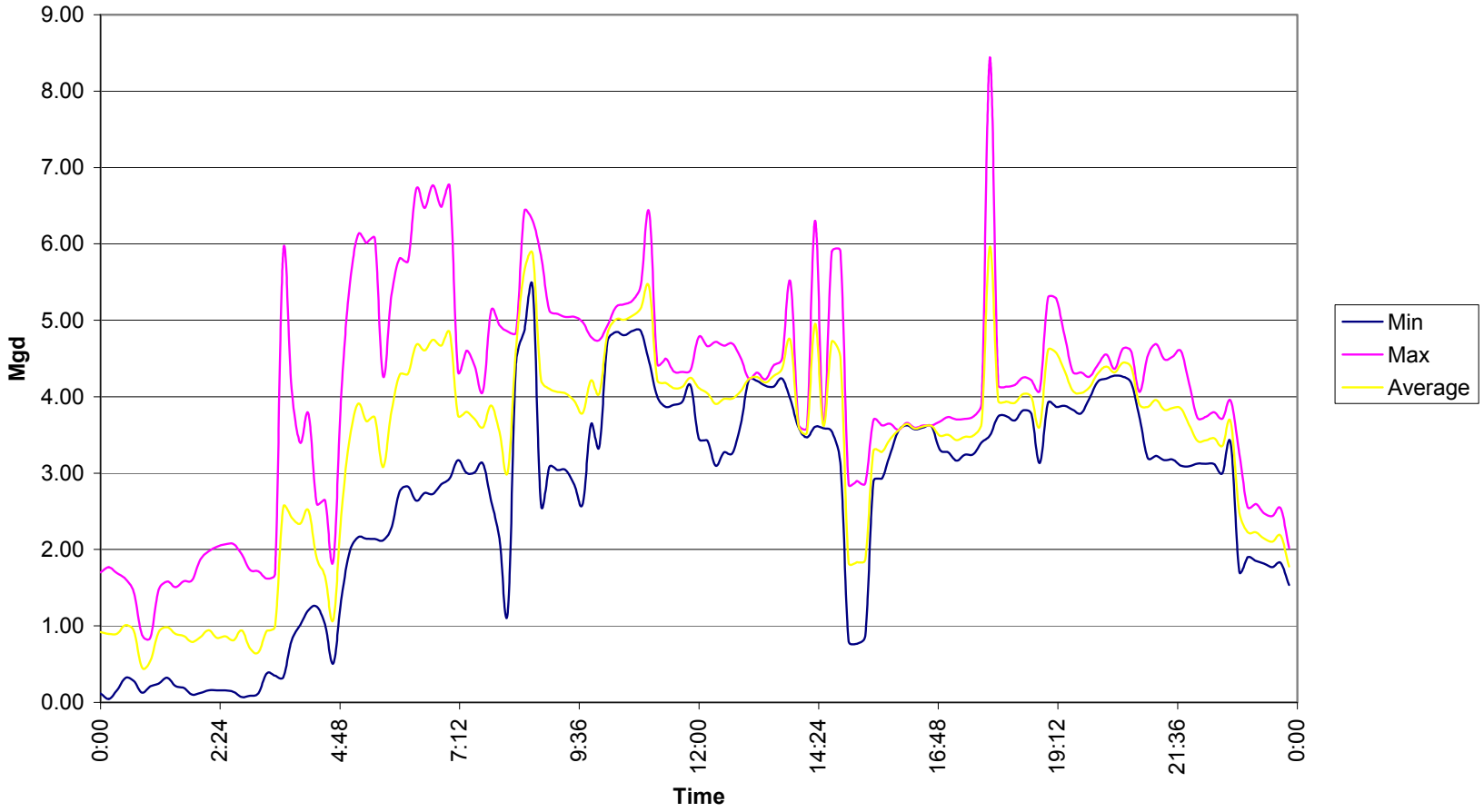

Cary, NC District Measurements
Central Pressure Zone, Morrisville District (CPZ MD)
Average Day, Max Day, Min Day
June 20 to June 22, 2009
Mgd
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0:00
2:24
4:48
7:12
9:36
12:00
14:24
16:48
19:12
21:36
0:00
Time
Min
Max
Ave

Cary NC District Measurements
Central Pressure Zone, Morrisville District (CPZ MD)
Average Day, Maximum Day, and Minimum Day
June 20 - June 24, 2008

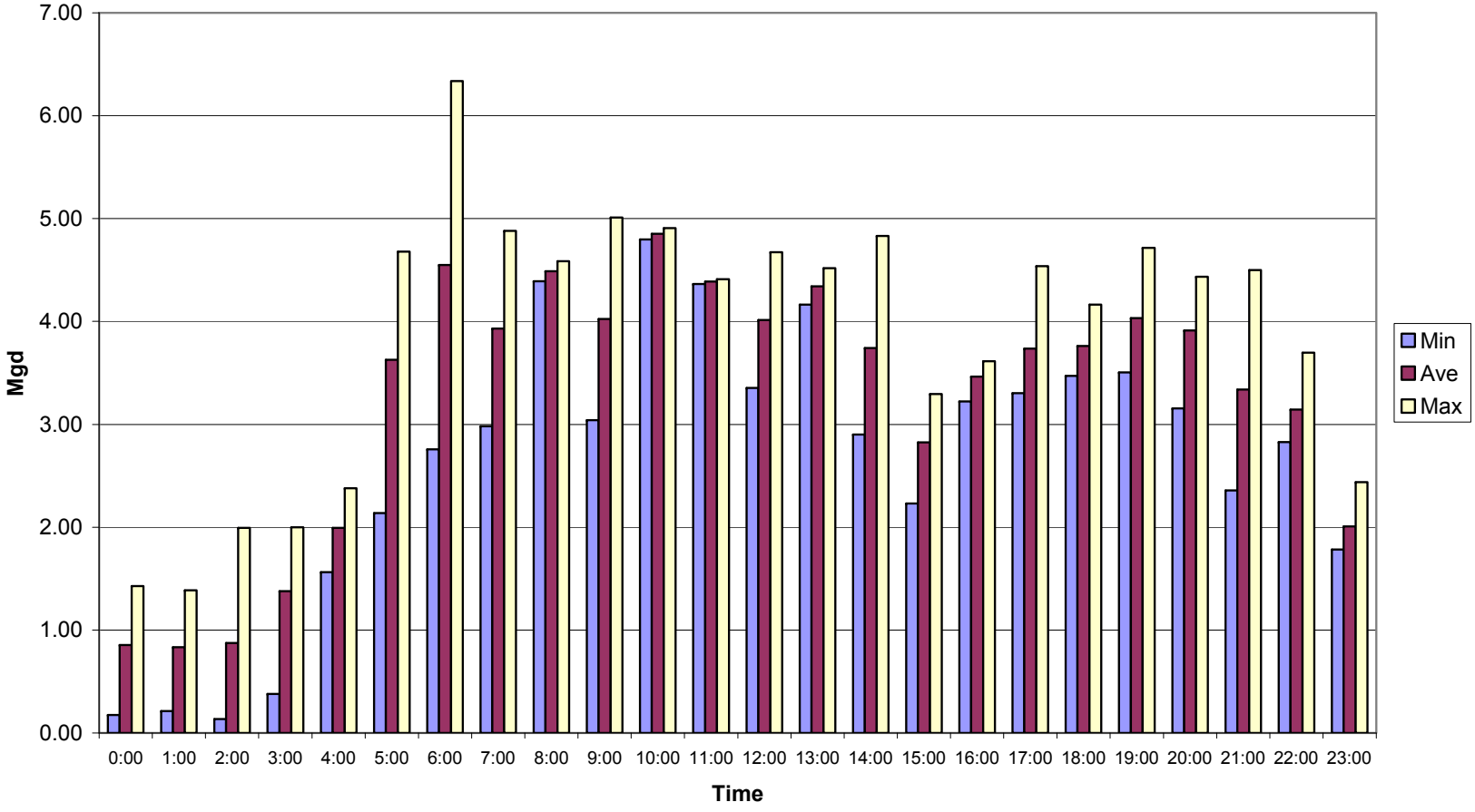


Cary NC, District Measurements Central Pressure Zone Southern District (CPZ SD)											
Daily Hourly Averages (Mgd)								Hourly Minimums, Averages, and Maximums (Mgd)			
	6/19/2009	6/20/2009	6/21/2009	6/22/2009	6/23/2009	6/24/2009			Min	Ave	Max
0:00		1.43			0.17	0.96		0:00	0.17	0.85	1.43
1:00		1.39			0.21	0.90		1:00	0.21	0.83	1.39
2:00		1.99			0.13	0.50		2:00	0.13	0.88	1.99
3:00		1.75			2.00	0.38		3:00	0.38	1.38	2.00
4:00		2.04			2.38	1.56		4:00	1.56	1.99	2.38
5:00		2.14			4.68	4.06		5:00	2.14	3.63	4.68
6:00		2.76			6.34			6:00	2.76	4.55	6.34
7:00		2.98			4.88			7:00	2.98	3.93	4.88
8:00		4.39			4.59			8:00	4.39	4.49	4.59
9:00		5.01			3.04			9:00	3.04	4.03	5.01
10:00		4.91			4.80			10:00	4.80	4.85	4.91
11:00		4.41			4.36			11:00	4.36	4.39	4.41
12:00		4.67			3.35			12:00	3.35	4.01	4.67
13:00		4.52			4.16			13:00	4.16	4.34	4.52
14:00	2.90	4.83			3.49			14:00	2.90	3.74	4.83
15:00	3.30	2.23			2.95			15:00	2.23	2.82	3.30
16:00	3.22	3.55			3.61			16:00	3.22	3.46	3.61
17:00	3.37	3.30			4.54			17:00	3.30	3.74	4.54
18:00	3.47	3.65			4.16			18:00	3.47	3.76	4.16
19:00	3.50	4.71			3.88			19:00	3.50	4.03	4.71
20:00	3.15	4.15			4.44			20:00	3.15	3.91	4.44
21:00	2.36	3.16			4.50			21:00	2.36	3.34	4.50
22:00	2.83	2.91			3.70			22:00	2.83	3.14	3.70
23:00	1.80	1.78			2.44			23:00	1.78	2.01	2.44

Cary NC, District Measurements
Central Pressure Zone Southern District (CPZ SD)
Average Day, Maximum Day, and Average Day
June 19 - June 24, 2009

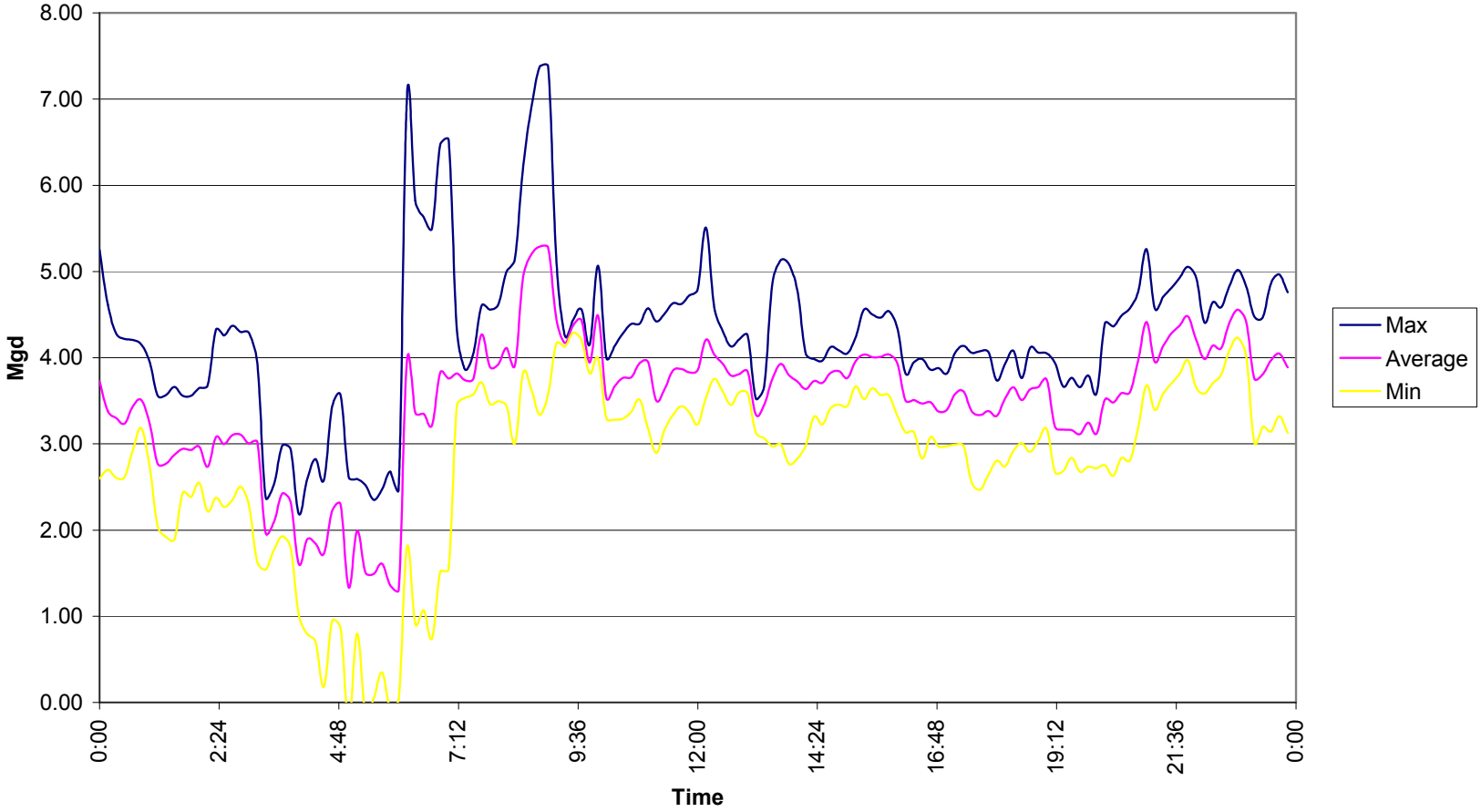


Cary NC, District Measurements
Southern Pressure Zone District, Hourly Averages (CPZ SD)
Average Day, Maximum Day, and Minimum Day
June 19 - June 24, 2009

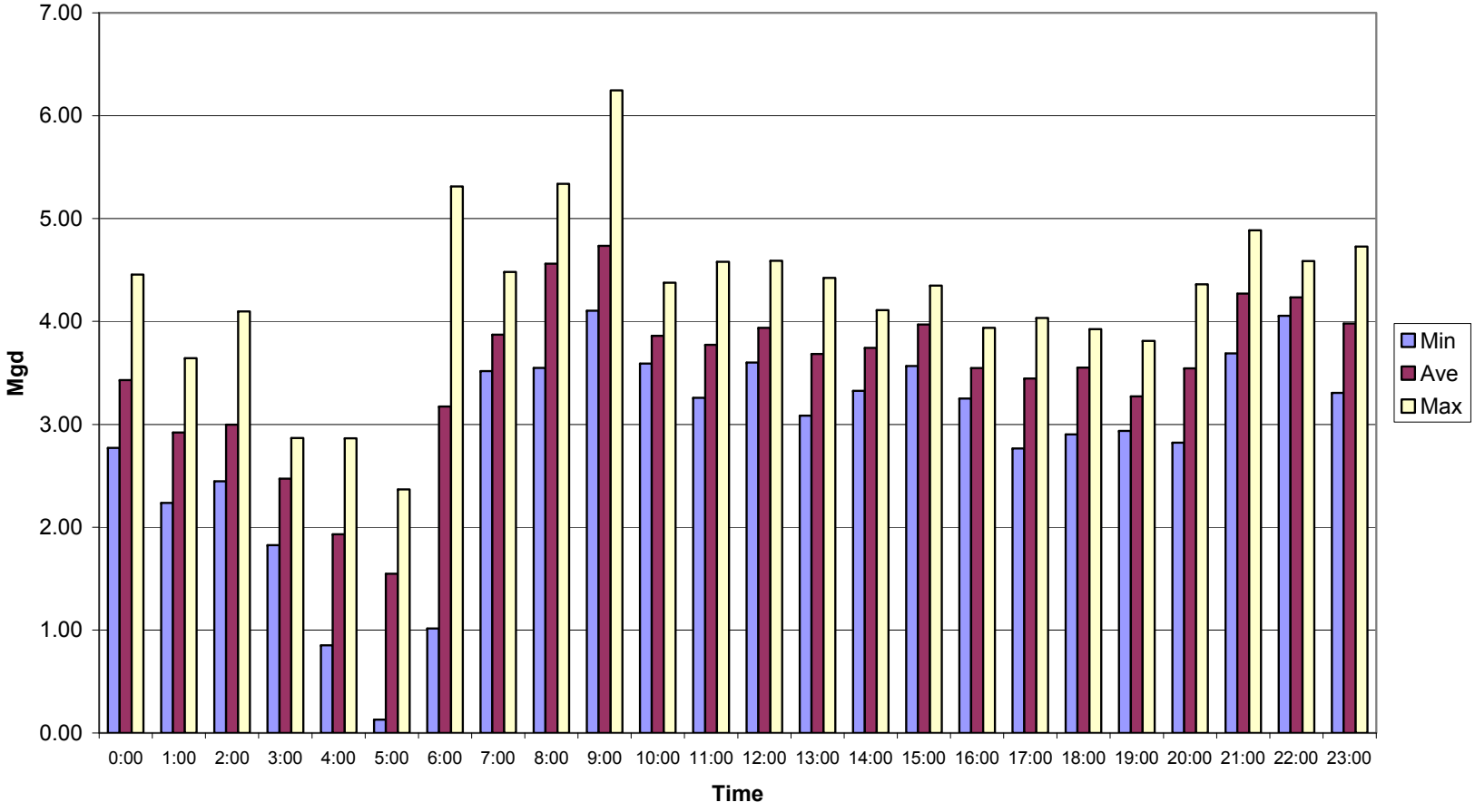


Cary NC, District Measurements, Central Pressure Zone, Northern District (CPZ ND)										
Daily Hourly Averages (Mgd)							Hourly Minimums, Averages, and Maximums (Mgd)			
Time	6/20/2009	6/21/2009	6/22/2009	6/23/2009	6/24/2009		Time	Min	Ave	Max
0:00	3.07			4.45	2.77		0:00	2.77	3.43	4.45
1:00	2.89			3.64	2.24		1:00	2.24	2.92	3.64
2:00	2.45			4.10	2.45		2:00	2.45	3.00	4.10
3:00	1.83			2.73	2.87		3:00	1.83	2.47	2.87
4:00	2.08			0.85	2.86		4:00	0.85	1.93	2.86
5:00	2.37			0.13	2.15		5:00	0.13	1.55	2.37
6:00	3.19			1.01	5.31		6:00	1.01	3.17	5.31
7:00	3.62			3.52	4.48		7:00	3.52	3.87	4.48
8:00	4.80			3.55	5.34		8:00	3.55	4.56	5.34
9:00	4.29		4.31	4.11	6.25		9:00	4.11	4.74	6.25
10:00	3.61		4.38	3.59			10:00	3.59	3.86	4.38
11:00	3.26		4.58	3.48			11:00	3.26	3.77	4.58
12:00	3.62		4.59	3.60			12:00	3.60	3.94	4.59
13:00	3.09		4.42	3.55			13:00	3.09	3.69	4.42
14:00	3.80		4.11	3.33			14:00	3.33	3.74	4.11
15:00	3.99		4.35	3.57			15:00	3.57	3.97	4.35
16:00	3.94		3.25	3.45			16:00	3.25	3.55	3.94
17:00	4.03		2.77	3.54			17:00	2.77	3.45	4.03
18:00	3.93		2.90	3.83			18:00	2.90	3.55	3.93
19:00	2.94		3.07	3.81			19:00	2.94	3.27	3.81
20:00	2.82		3.45	4.36			20:00	2.82	3.54	4.36
21:00	3.69		4.24	4.89			21:00	3.69	4.27	4.89
22:00	4.06		4.59	4.06			22:00	4.06	4.23	4.59
23:00	3.91		4.73	3.31			23:00	3.31	3.98	4.73

Cary NC, District Mesurements
Central Pressure Zone, Northern District (CPZ ND)
Average Day, Maximum Day, and Minimum Day
June 20 to June 24, 2009



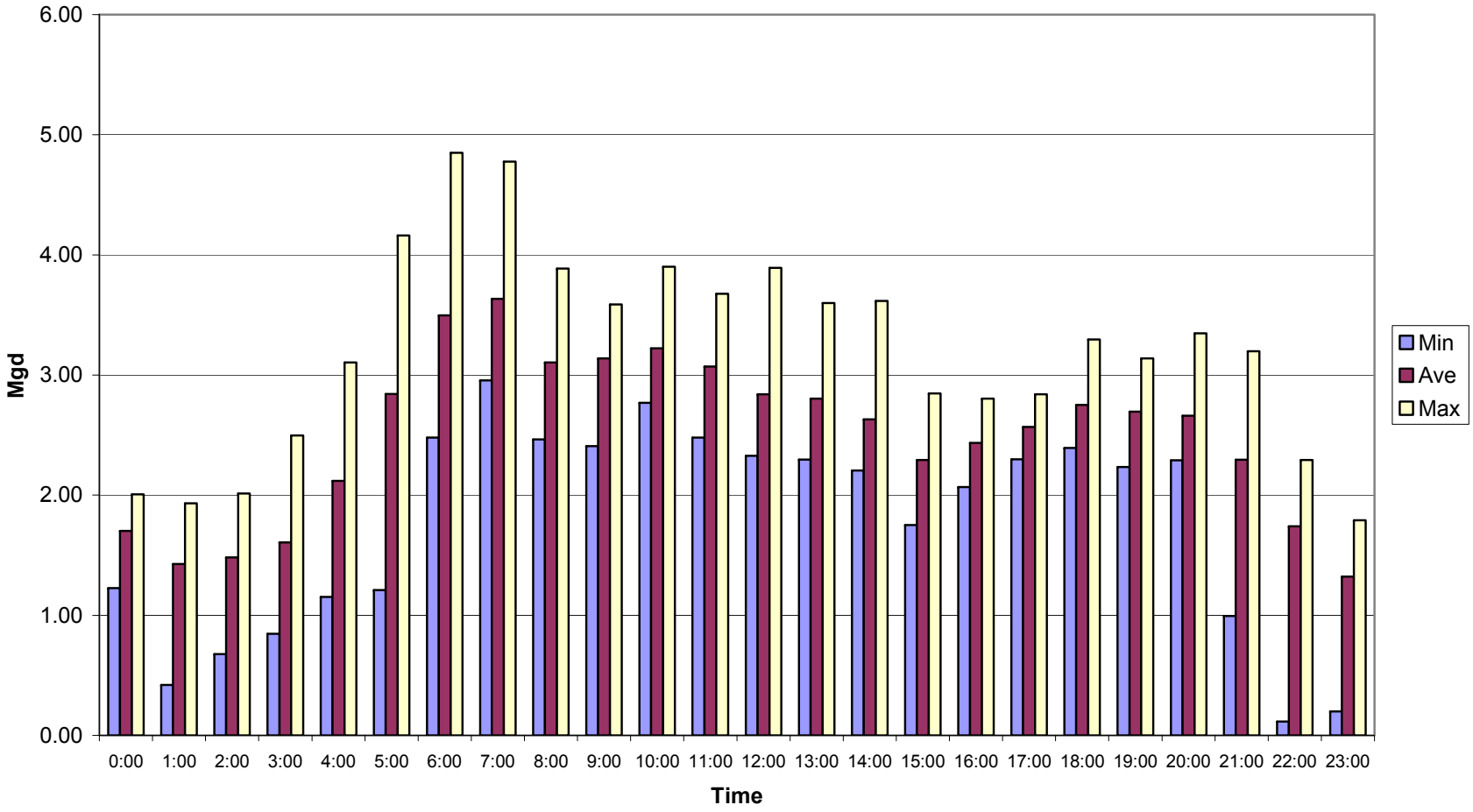
Cary NC, District Measurement
Central Pressure Zone, Northern District Hourly Averages (CPZ ND)
Average Day, Maximum Day, and Minimum Day
June 20 - June 24, 2008



Cary NC, District Measurements, Southern Pressure Zone (SPZ)												
	Daily Hourly Averages (Mgd)								Hourly Minimum, Average, and Maximum (Mgd)			
Time	6/18/2009	6/19/2009	6/20/2009	6/21/2009	6/22/2009	6/23/2009	6/24/2009		Time	Min	Ave	Max
0:00	1.57	2.01	1.23	1.75	1.76	1.83	1.76		0:00	1.23	1.70	2.01
1:00	1.30	1.01	1.84	1.80	0.42	1.68	1.93		1:00	0.42	1.43	1.93
2:00	1.17	1.74	1.72	1.47	0.68	1.59	2.01		2:00	0.68	1.48	2.01
3:00	1.09	1.46	1.63	2.31	0.85	1.41	2.50		3:00	0.85	1.61	2.50
4:00	1.15	1.70	2.28	2.46	1.47	2.66	3.10		4:00	1.15	2.12	3.10
5:00	1.64	2.62	3.21	3.47	1.21	3.59	4.16		5:00	1.21	2.84	4.16
6:00	2.60	3.67	3.19	3.88	2.48	3.81	4.85		6:00	2.48	3.50	4.85
7:00	2.95	2.96	3.17	3.45	3.89	4.24	4.78		7:00	2.95	3.63	4.78
8:00	2.46	3.03	2.69	3.42	3.89	2.93	3.31		8:00	2.46	3.11	3.89
9:00	2.70	2.41	3.54	3.45	3.59	3.12	3.16		9:00	2.41	3.14	3.59
10:00	2.87	2.77	2.92	3.36	3.90	3.54	3.20		10:00	2.77	3.22	3.90
11:00	2.51	2.93	3.32	2.48	3.40	3.68	3.19		11:00	2.48	3.07	3.68
12:00	2.53	3.89	2.43	2.77	2.33	3.10			12:00	2.33	2.84	3.89
13:00	2.52	3.60	2.98	2.81	2.62	2.30			13:00	2.30	2.80	3.60
14:00	2.23	3.62	2.44	2.82	2.47	2.21			14:00	2.21	2.63	3.62
15:00	2.19	2.85	2.44	2.41	1.75	2.11			15:00	1.75	2.29	2.85
16:00	2.28	2.35	2.80	2.47	2.63	2.07			16:00	2.07	2.43	2.80
17:00	2.32	2.81	2.36	2.79	2.84	2.30			17:00	2.30	2.57	2.84
18:00	2.40	2.61	2.74	3.30	3.06	2.39			18:00	2.39	2.75	3.30
19:00	2.41	2.24	2.86	2.97	3.14	2.56			19:00	2.24	2.69	3.14
20:00	2.29	2.56	2.57	2.90	3.35	2.30			20:00	2.29	2.66	3.35
21:00	2.52	2.07	2.14	3.20	0.99	2.86			21:00	0.99	2.29	3.20
22:00	2.26	1.62	1.91	2.29	0.11	2.24			22:00	0.11	1.74	2.29
23:00	1.31	1.72	1.42	1.48	0.20	1.79			23:00	0.20	1.32	1.79

Cary, NC
Southern Pressure Zone District Measurement (SPZ)
Average Day, Maximum Day, and Minimum Day
June 18, to June 24, 2009

Cary NC, District Measurements
Southern Pressure Zone District (SPZ)
Average Day, Maximum Day, and Minimum Day
June 18 - June 24, 2008



Gauging Points

The following is a table of the gauging point location information.

Gauging Point No.	Location Type	Location:	Main Size	VF
R1	Air Valve Manhole	20 ft. north of NCL of Carpenter Fire Station Rd 3000 ft. east of ECL of NC Hwy 55	16	0.852
M1	Meter Vault	30 ft. north of the NCL of NC Hwy 54 100 ft. south of SCL of Wilson St.	16	0.837
R2	Air Valve Manhole	7 ft. east of ECL of Cary Parkway 45 ft. north of NCL of James Jackson Ave	24	0.895
R3	Air Valve Manhole	2 ft. north of NCL of West Chatham St. 30 ft. west of WCL of Dixon Ave.	16	0.856
R4	Air Valve Manhole	1200 ft. east of ECL of Cary Parkway 260 ft. south of SCL of Rt. 1	16	0.918

Summary

The purpose of the seven district measurements conducted in the Cary water system over a multi-day period was to develop information to calibrate a computer model of the water distribution system. The measurements were conducted over a weekend period and also during normal business hours. The flows into and out of districts was merged to show the normal diurnal pattern of consumption for the 24 hour period. The flow rates into and out of the elevated tanks was determined by the level changes in each tank using the Town of Cary's SCADA system and pressures measured with data loggers.

The data collected in 1 minute intervals was summarized in data spreadsheets and submitted for review at the end of the field work. The field data was collected using a Pitometer rod inserted into the water main and logged using a Pitometer Computer Recorder. Prior to the measurements, the pipe's inside diameter was measured. Also recorded was a velocity profile of the pipe's cross-section.

A summary of the data collected at each of the districts is submitted in this report.

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Appendix B

Bulk Decay Testing Results

TABLE B-1
Warm-Weather Bulk Decay Testing Results –Cary WTP
Water Quality Model Development

Sample No.	Target Hours Elapsed	Analysis Date & Time	Actual Hours Elapsed	Temperature C	Cl_2 Residual Measurement No. 1	Cl_2 Residual Measurement No. 2	Cl_2 Residual Measurement No. 3	Average Measurement	Ln Cl_2/ Initial Cl_2
1	0	7/10/09 9:00 AM	0	26.1	4.60	4.90	4.60	4.7	0.00
2	12	7/10/09 9:00 PM	12	24.1	4.40	4.40	4.30	4.4	-0.07
3	24	7/11/09 9:00 AM	24	23.9	4.30	4.10	4.10	4.2	-0.12
4	36	7/11/09 9:00 PM	36	23.8	4.20	4.10	4.10	4.1	-0.13
5	48	7/12/09 9:00 AM	48	23.8	4.10	4.00	4.10	4.1	-0.14
6	72	7/13/09 9:00 AM	72	23.9	3.70	3.90	4.00	3.9	-0.20
7	96	7/14/09 9:00 AM	96	24.1	3.80	3.80	3.70	3.8	-0.22
8	120	7/15/09 6:00 AM	120	24.1	3.60	3.40	3.80	3.6	-0.27
9	144	7/16/09 9:00 AM	144	23.6	3.40	3.40	3.30	3.4	-0.33
10	168	7/17/09 9:00 AM	168	23.9	3.40	3.40	3.40	3.4	-0.32
11	192	7/18/09 9:00 AM	192	23.8	3.30	3.40	3.50	3.4	-0.32
12	216	7/19/09 9:00 AM	216	23.4	3.30	3.20	3.40	3.3	-0.35
			Avg Temp	**24.0**					
			Max Temp	**26.1**					
			Min Temp	**23.4**					

TABLE B-2
Cold-Weather Bulk Decay Testing Results – Cary WTP
Water Quality Model Development

Sample No.	Target Hours Elapsed	Analysis Date & Time	Actual Hours Elapsed	Temperature C	Cl_2 Residual Measurement No. 1	Cl_2 Residual Measurement No. 2	Cl_2 Residual Measurement No. 3	Average Measurement	Ln Cl_2/ Initial Cl_2
1	0	2/3/09 9:00 AM	0	9	4.4	4.4	4.5	4.43	0.00
2	12	2/3/09 9:00 PM	12	9	4.3	4.5	4.4	4.40	-0.01
3	24	2/4/09 9:00 AM	24	8	4.4	4.4	4.4	4.40	-0.01
4	36	2/4/09 9:00 PM	36	7	4	4	3.8	3.93	-0.12
5	48	2/5/09 11:00 AM	50	7	4.1	4.2	4.1	4.13	-0.07
6	72	2/6/09 9:00 AM	72	6	3.8	4.1	4.1	4.00	-0.10
7	96	2/7/09 9:00 AM	96	5	3.9	3.9	4	3.93	-0.12
8	120	2/8/09 9:00 AM	120	5	3.9	3.9	4	3.93	-0.12
9	144	2/9/09 9:00 AM	144	5	3.9	4	4.1	4.00	-0.10
10	168	2/10/09 9:00 AM	168	5	4	4.1	4	4.03	-0.09
11	192	2/11/09 9:00 AM	192	6	3.8	3.8	3.7	3.77	-0.16
12	216	2/12/09 9:00 AM	216	7	3.7	3.8	3.7	3.73	-0.17
			Avg Temp	**6.6**					
			Max Temp	**9**					
			Min Temp	**5**					

Appendix C

Model Results

Figure C1 (Appendix C)
Modeling Results of Western PZ Tank Levels and High Service Pumping Station Flow
Year 2010 Maximum Day Design Conditions With New Diurnals

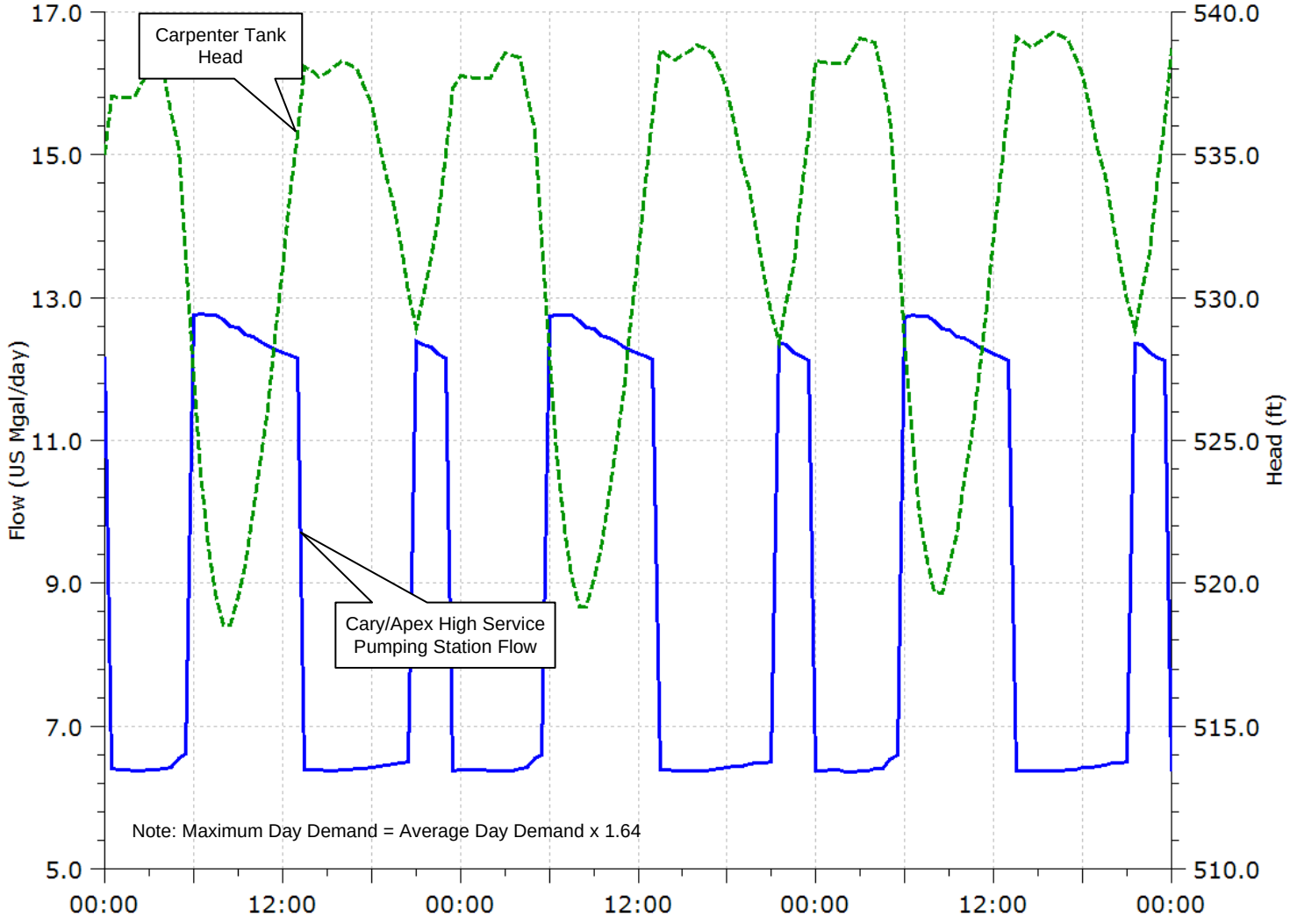


Figure C2 (Appendix C)
Modeling Results of Central PZ Tank Levels and High Service Pumping Station Flow
Year 2010 Maximum Day Design Conditions With New Diurnals

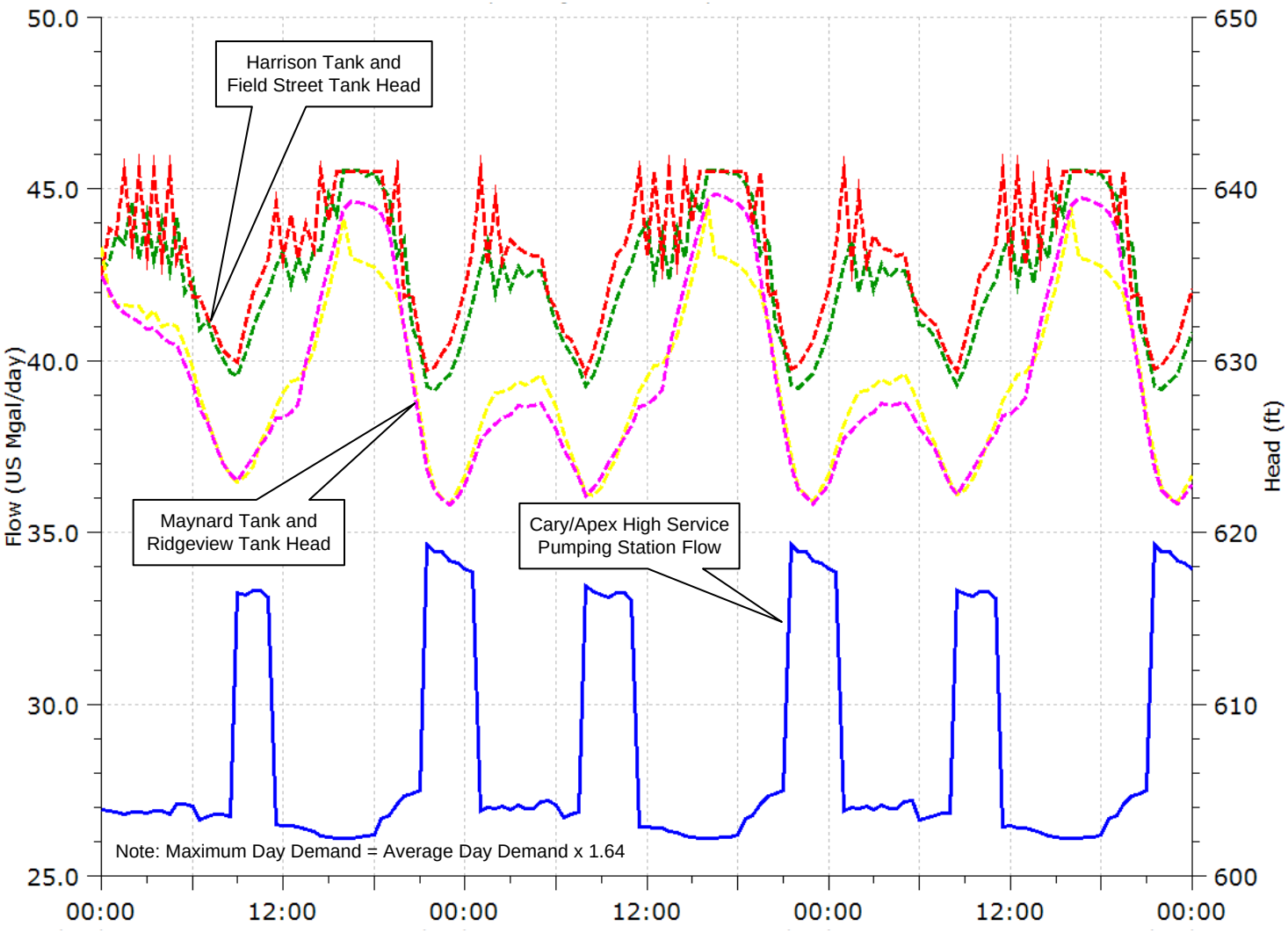


Figure C3 (Appendix C)
Modeling Results of Southern PZ Tank Level and Control Valve Flows
Year 2010 Maximum Day Design Conditions With New Diurnals

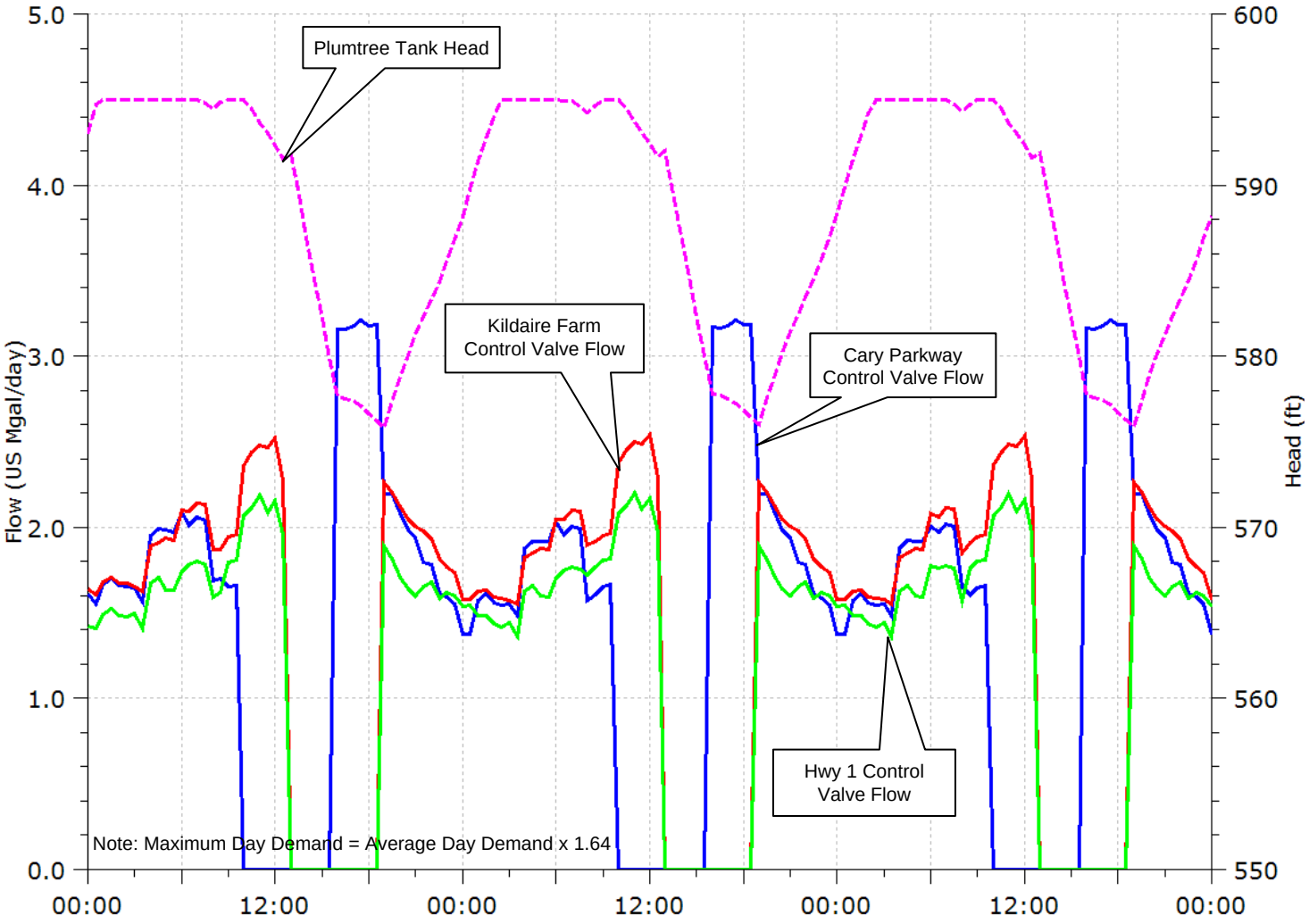


Figure C4 (Appendix C)
Modeling Results of Western PZ Tank Levels and High Service Pumping Station Flow
Year 2015 Maximum Day Design Conditions With New Diurnals

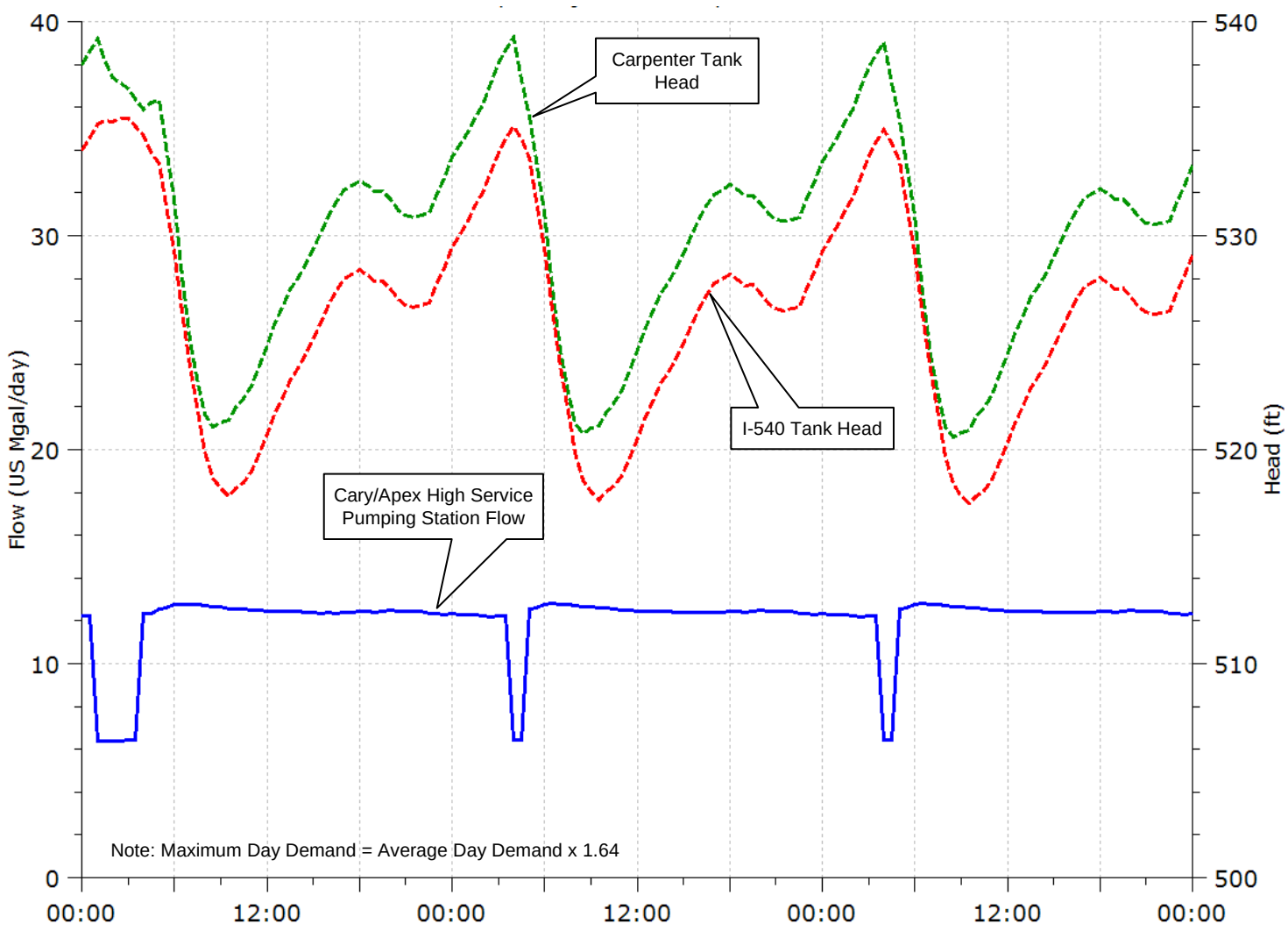


Figure C5 (Appendix C)
Modeling Results of Central PZ Tank Levels and High Service Pumping Station Flow
Year 2015 Maximum Day Design Conditions With New Diurnals

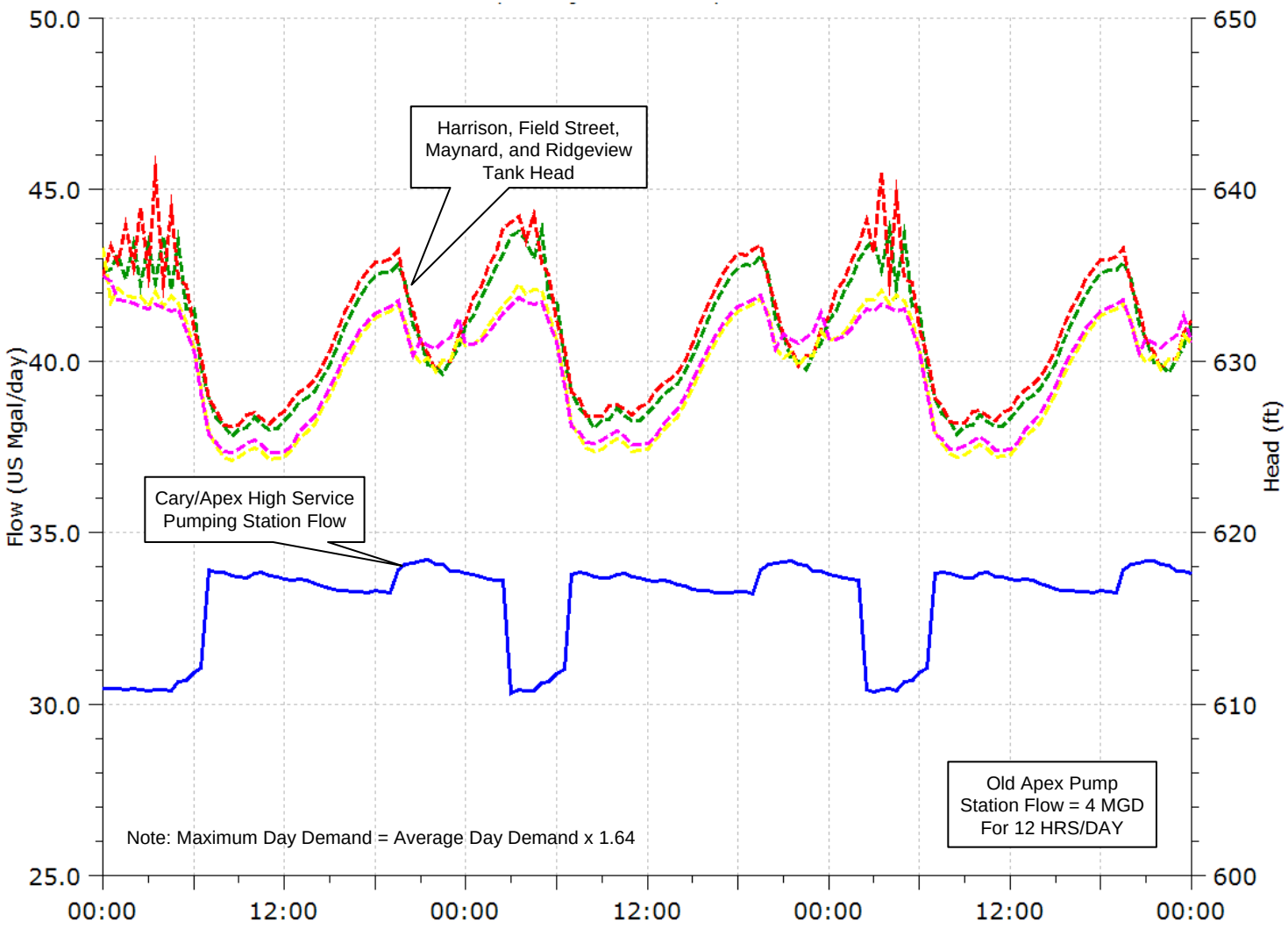


Figure C6 (Appendix C)
Modeling Results of Southern PZ Tank Level and Control Valve Flows
Year 2015 Maximum Day Design Conditions With New Diurnals

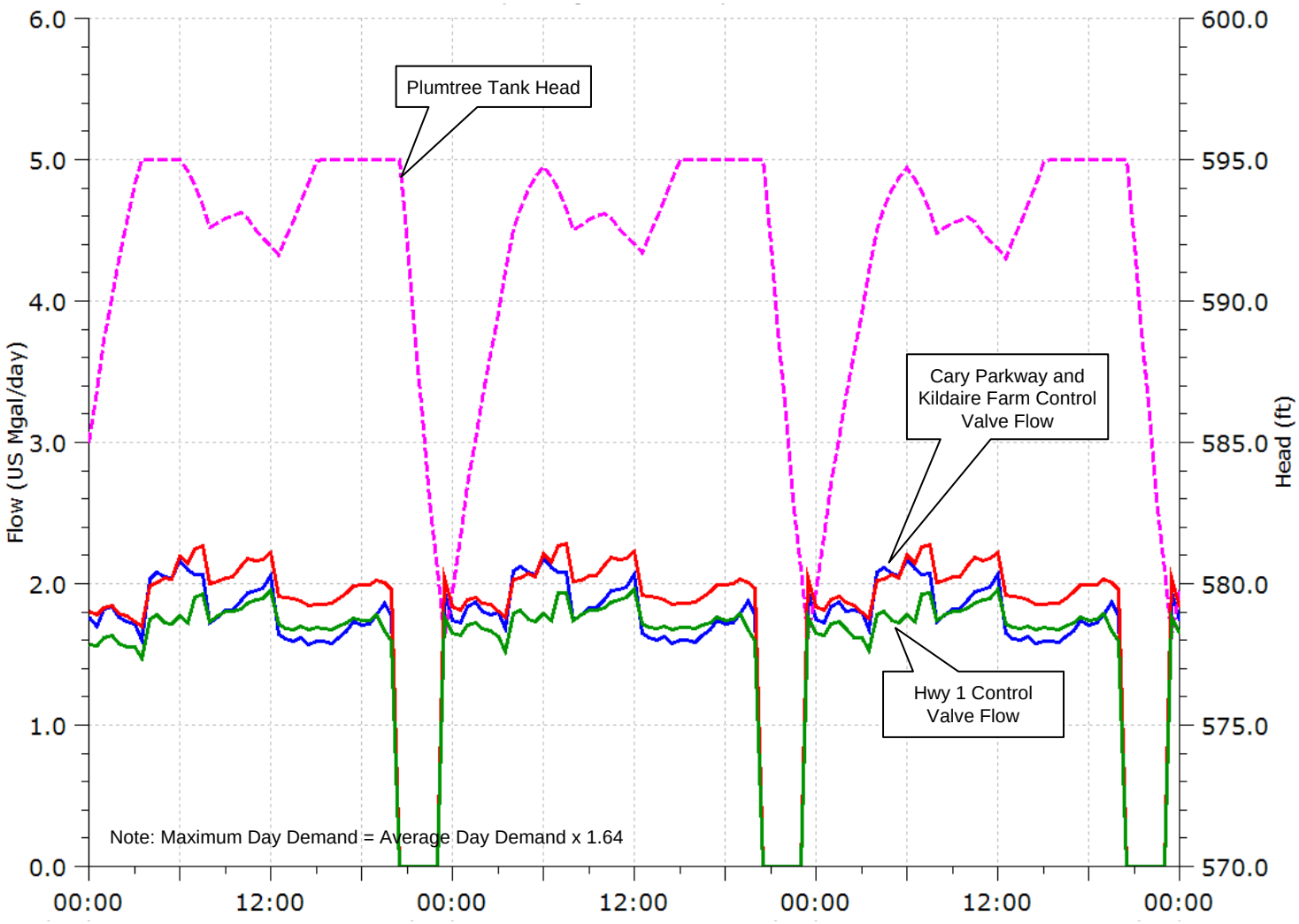


Figure C7 (Appendix C)
Modeling Results of Western PZ Tank Levels and High Service Pumping Station Flow
Year 2025 Maximum Day Design Conditions With New Diurnals

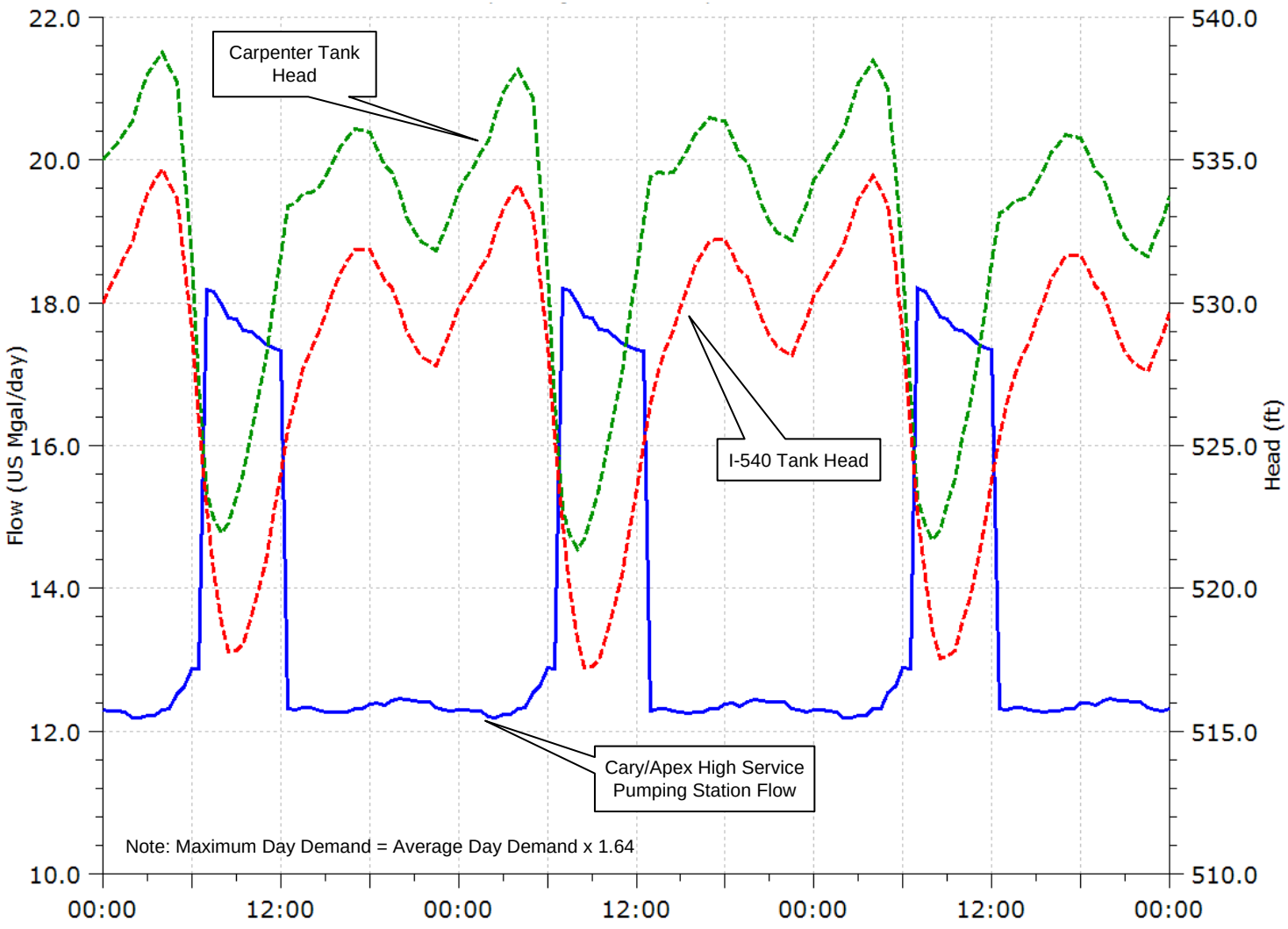


Figure C8 (Appendix C)
Modeling Results of Central PZ Tank Levels and High Service Pumping Station Flow
Year 2025 Maximum Day Design Conditions With New Diurnals

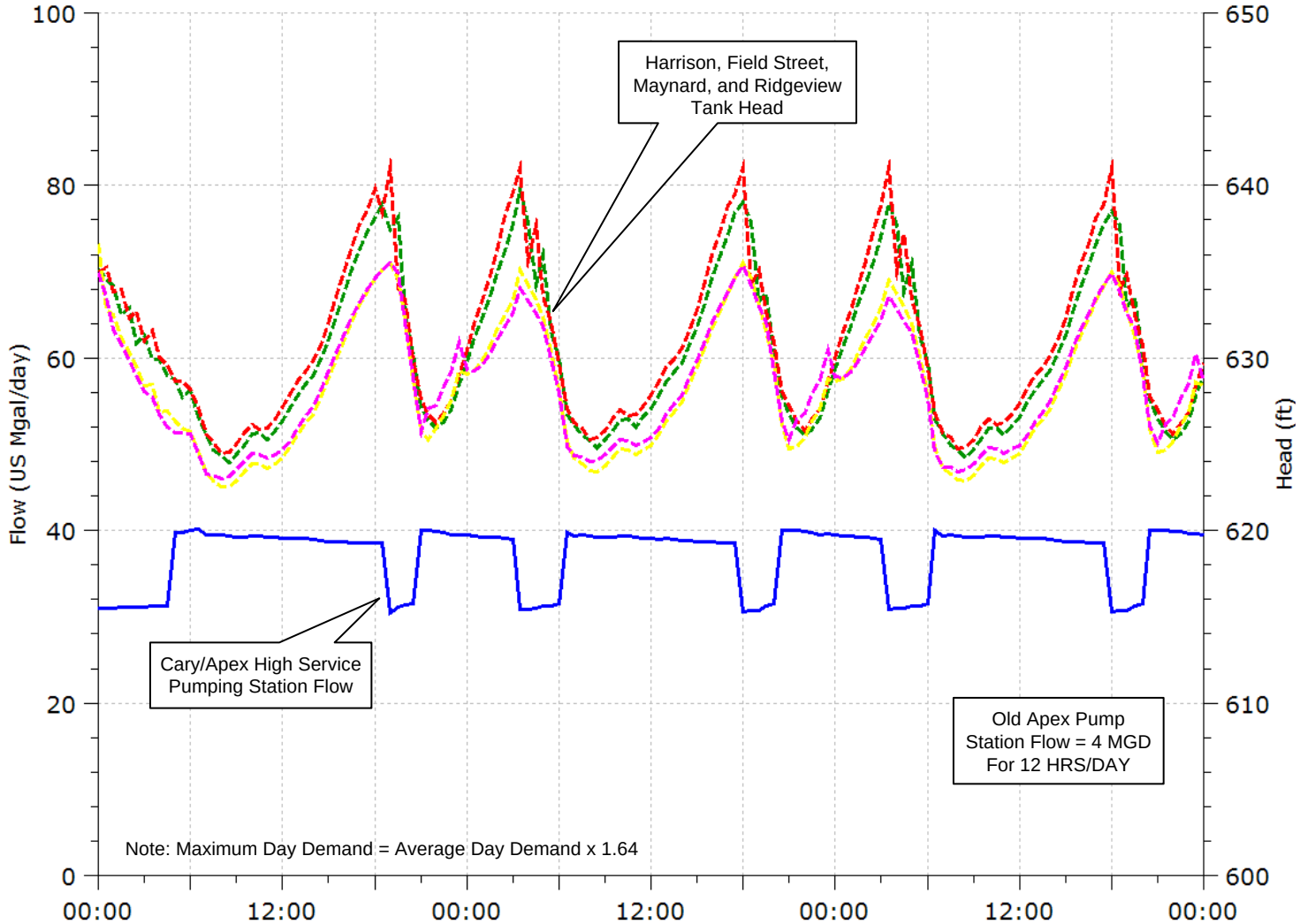


Figure C9 (Appendix C)
Modeling Results of Southern PZ Tank Level and Control Valve Flows
Year 2025 Maximum Day Design Conditions With New Diurnals

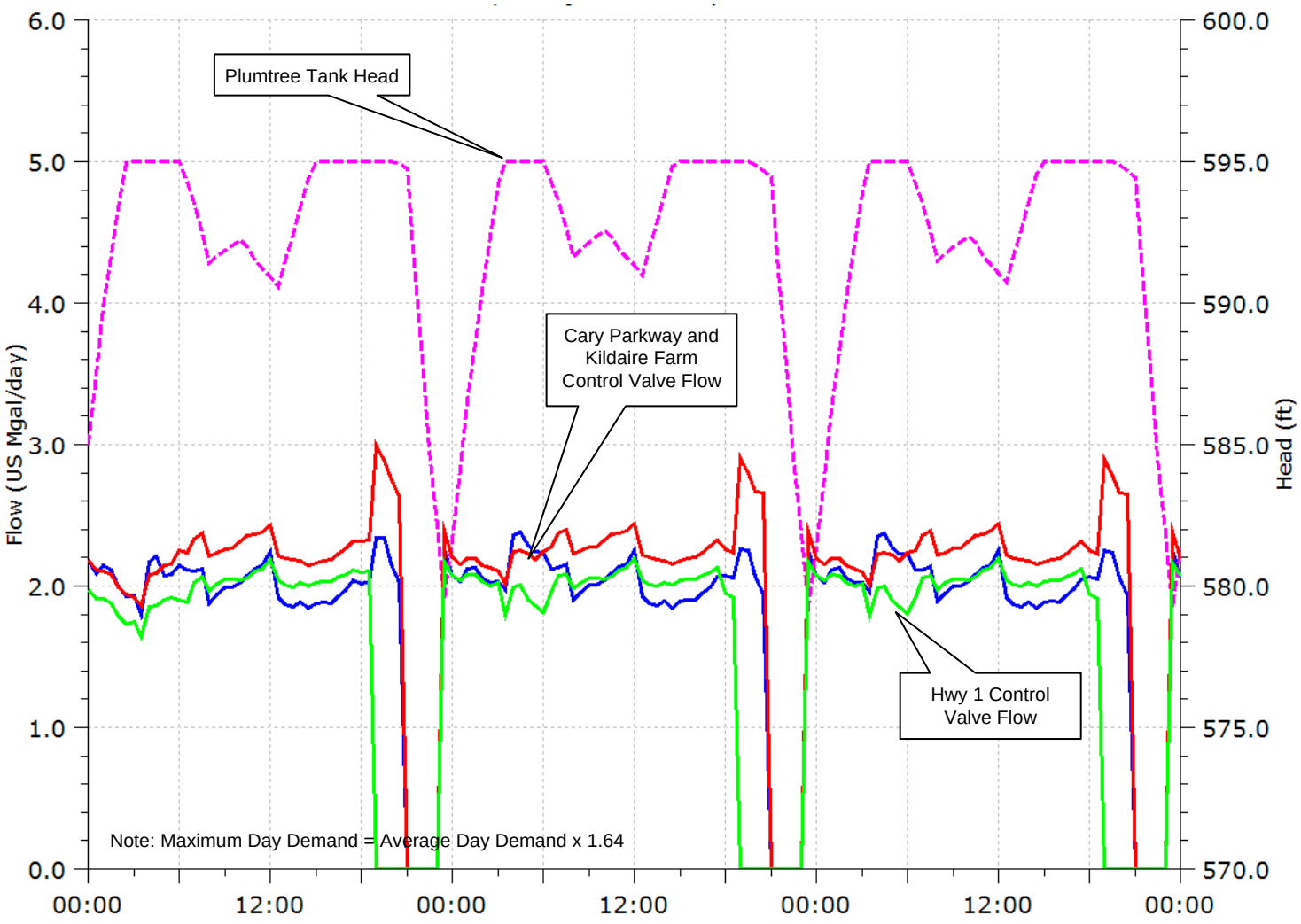


Figure C10 (Appendix C)
Modeling Results of Western PZ Tank Levels, HSPS Flow, and Davis Drive PRV Flow
Buildout Maximum Day Design Condition With New Diurnals

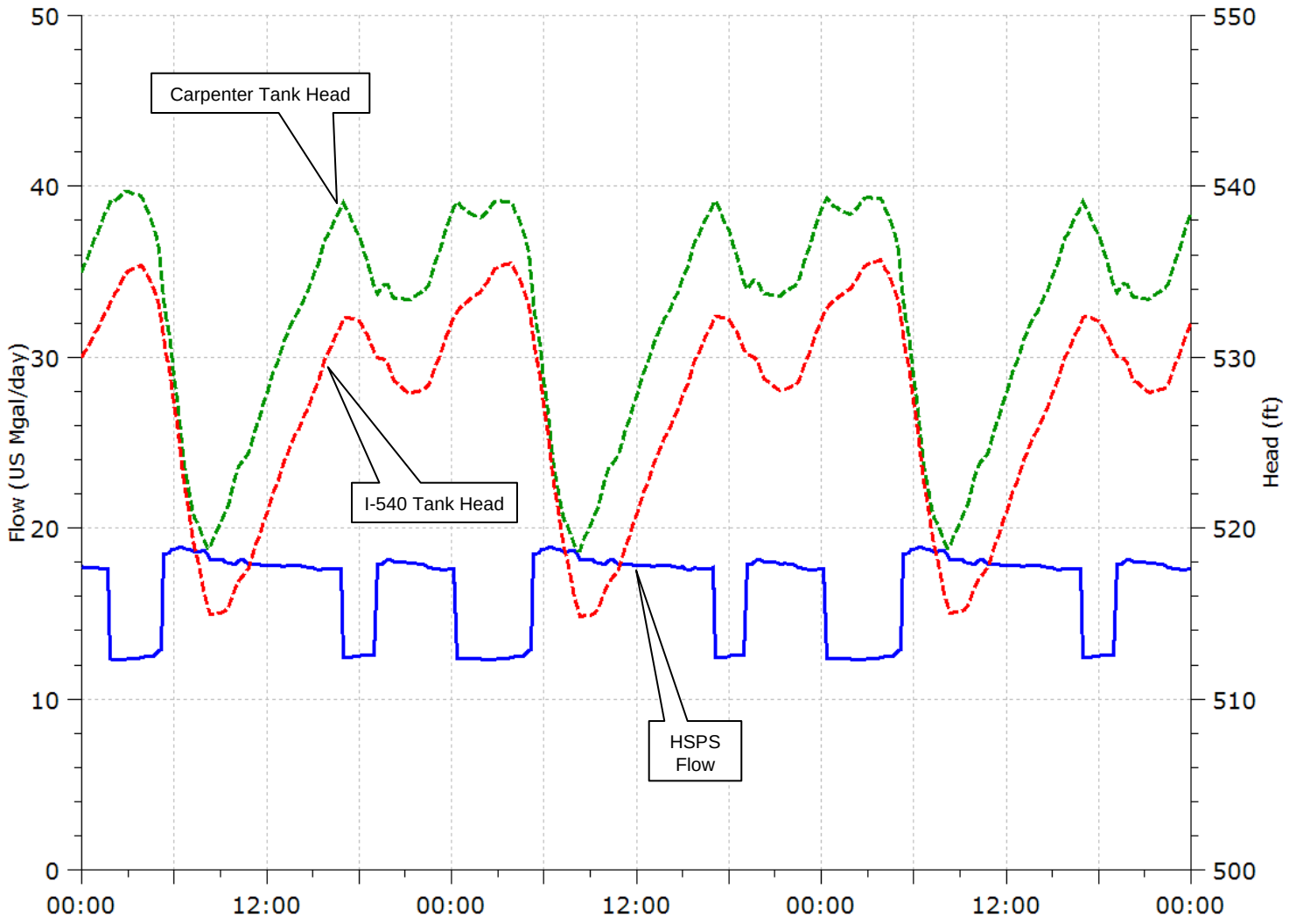


Figure C11 (Appendix C)
Modeling Results of Central PZ Tank Levels, High Service Pumping Station Flow
Buildout Maximum Day Design Condition With New Diurnals

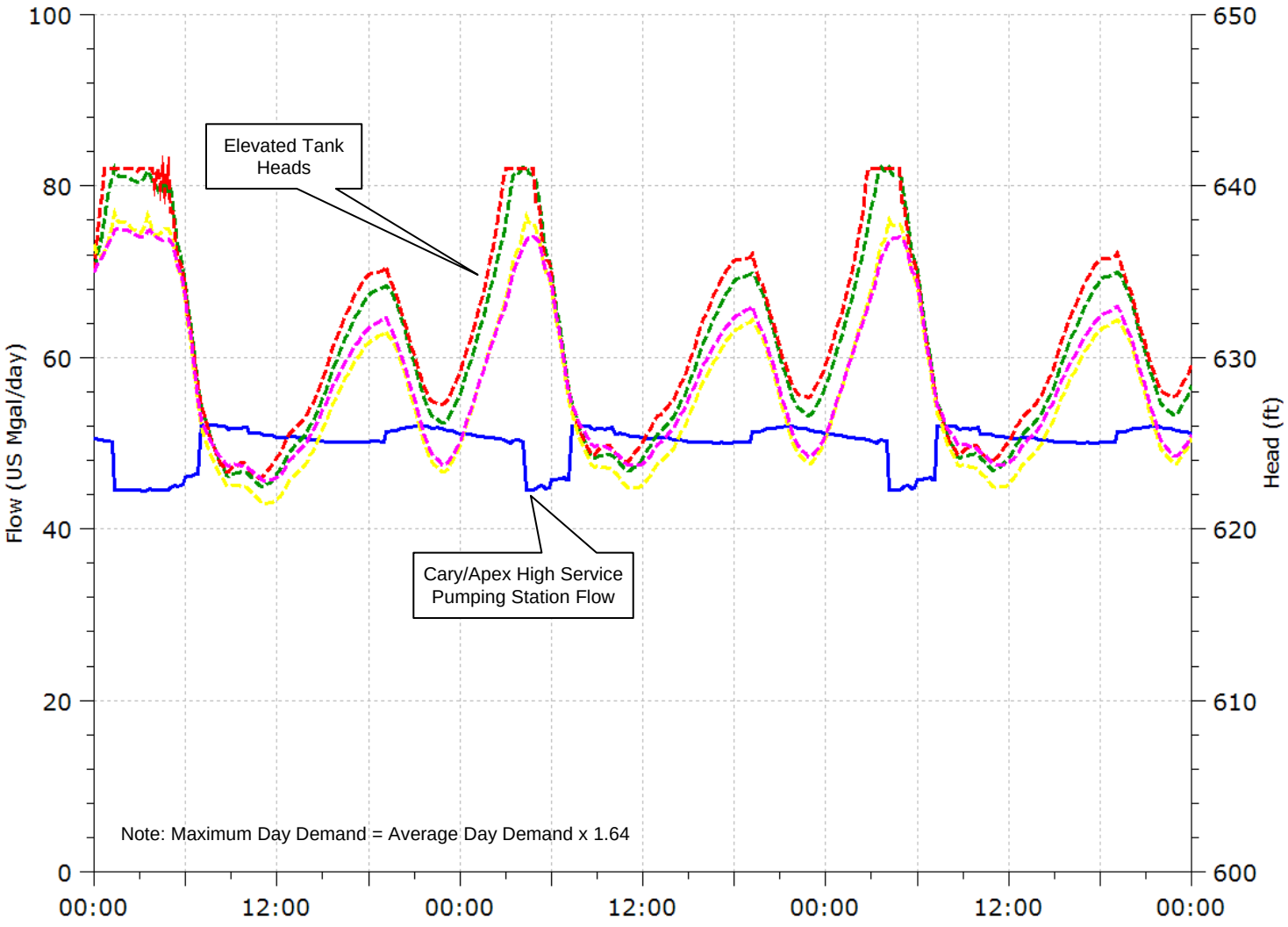
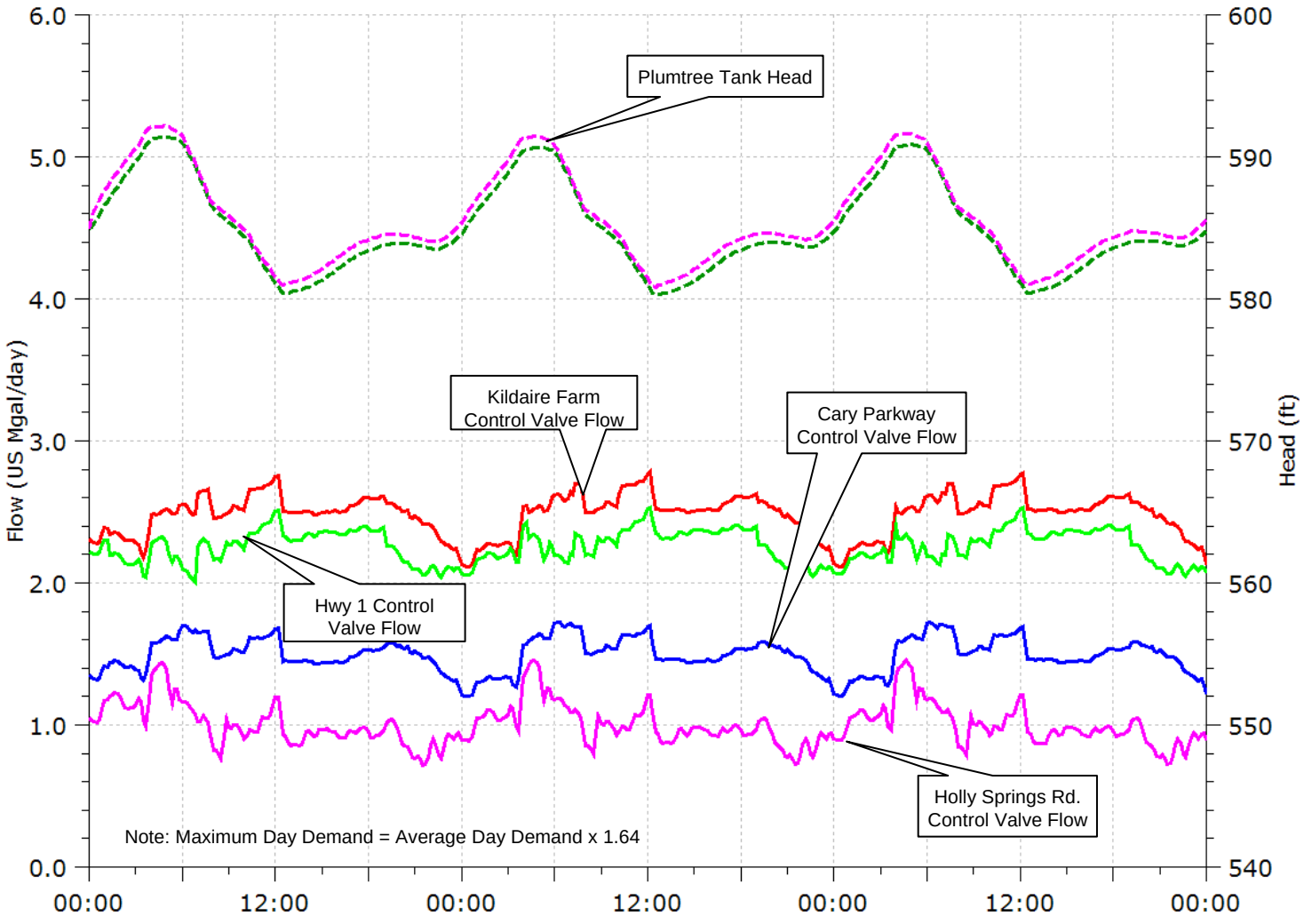


Figure C12 (Appendix C)
Modeling Results of Southern PZ Tank Level and Control Valve Flows
Buildout Maximum Day Design Conditions With New Diurnals

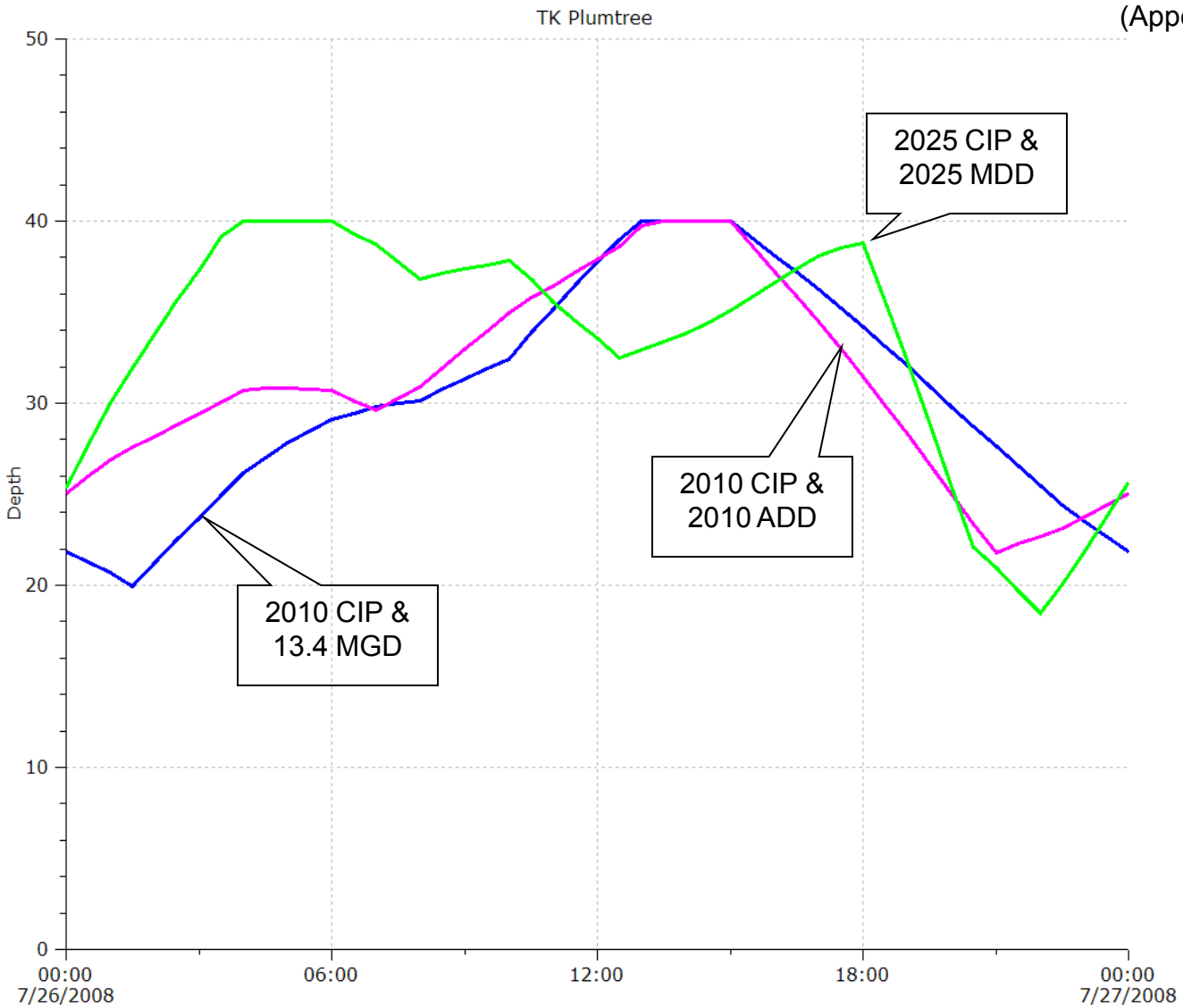


Appendix D

Southern Pressure Zone Model Results

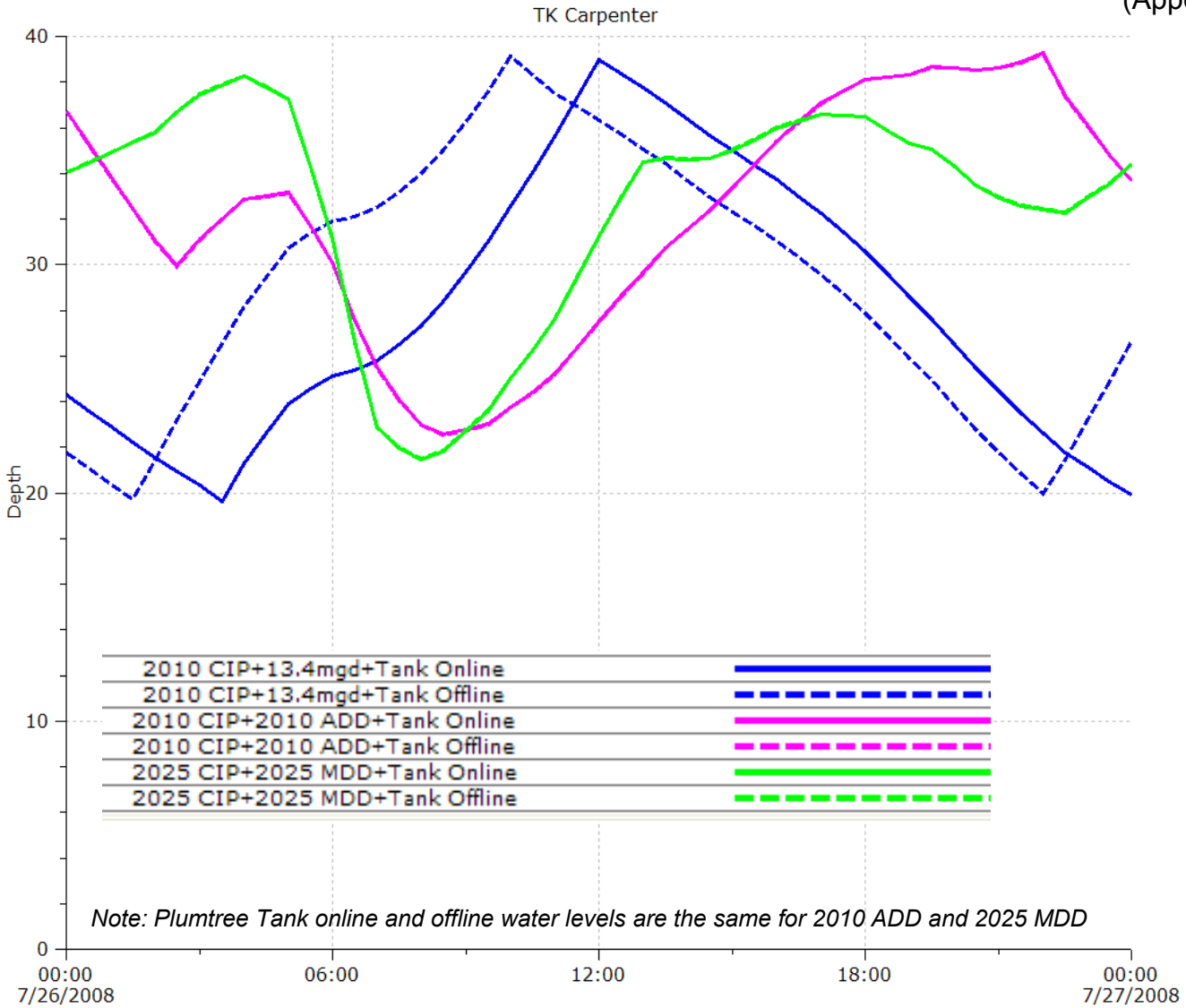
Plumtree Tank

(Appendix D)



Carpenter Tank

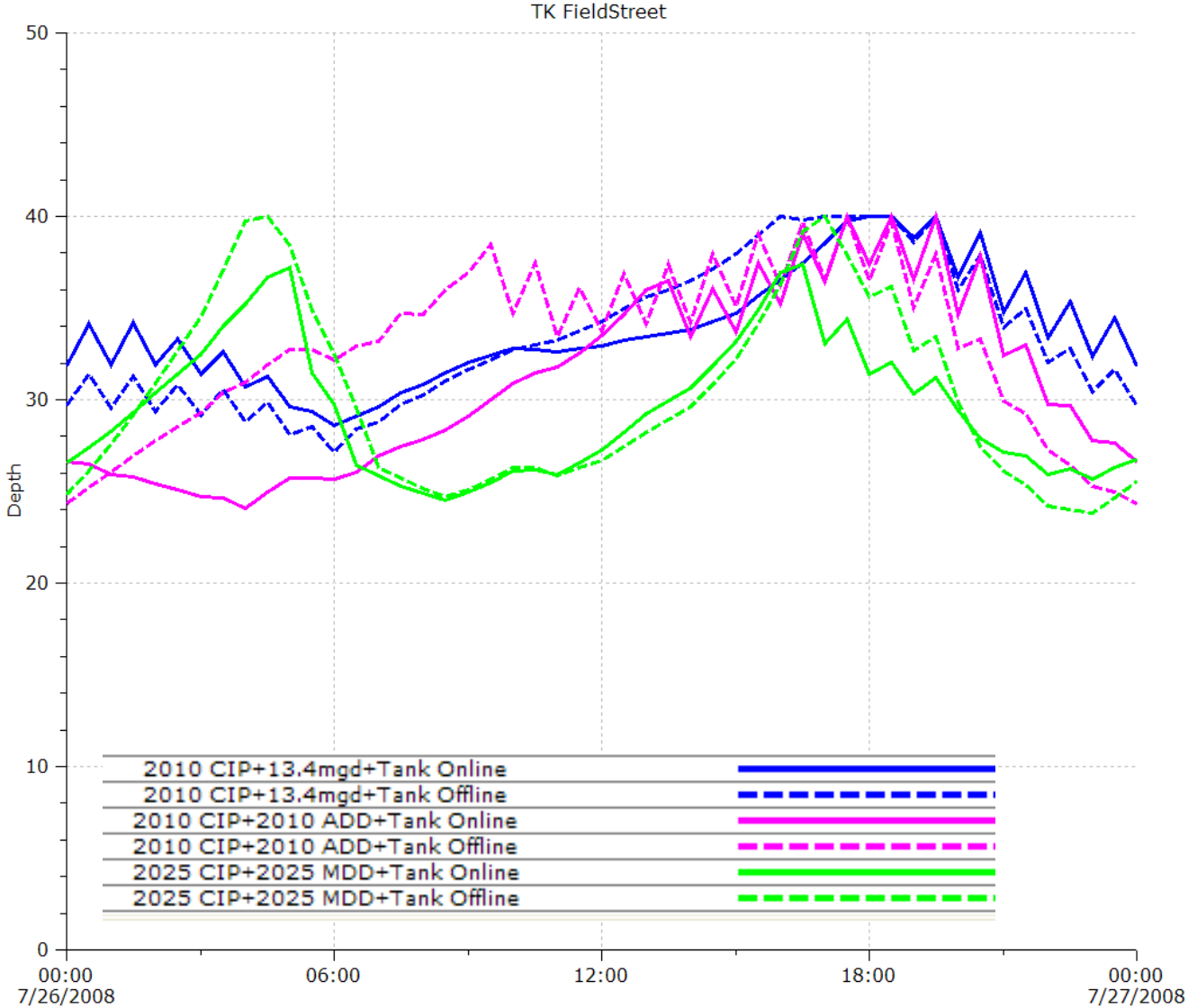
(Appendix D)



Note: Plumtree Tank online and offline water levels are the same for 2010 ADD and 2025 MDD

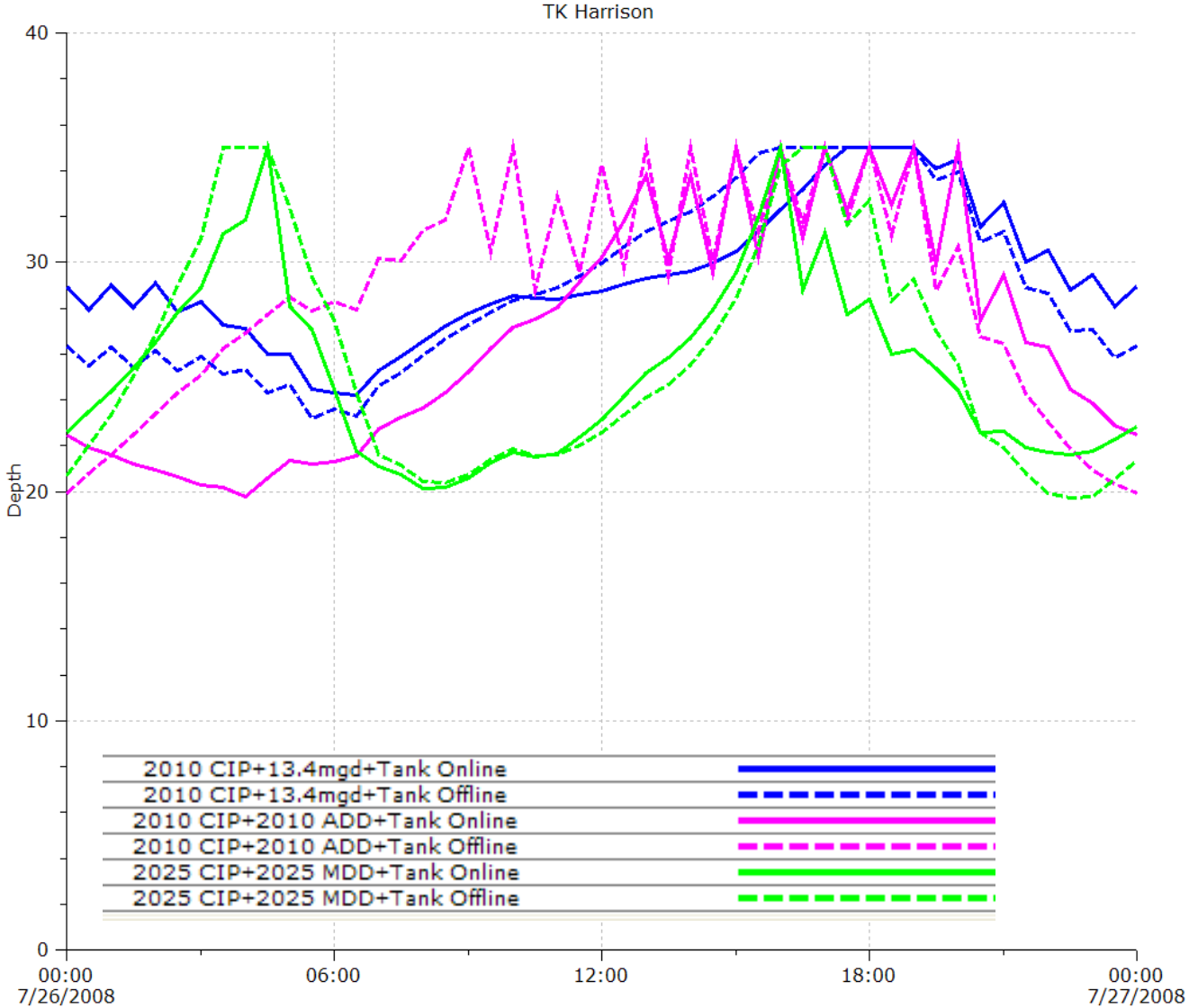
Field Street Tank

(Appendix D)



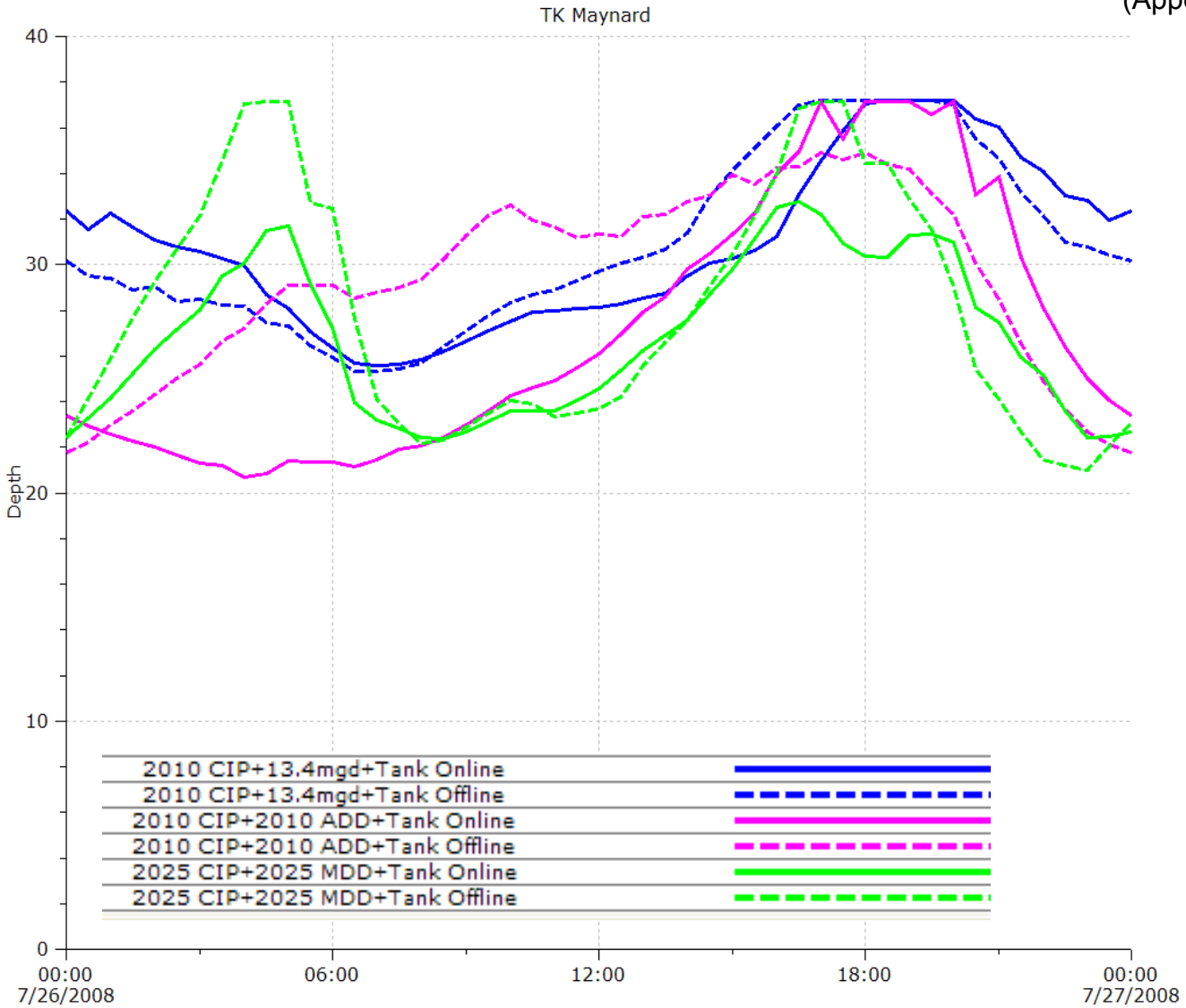
Harrison Tank

(Appendix D)



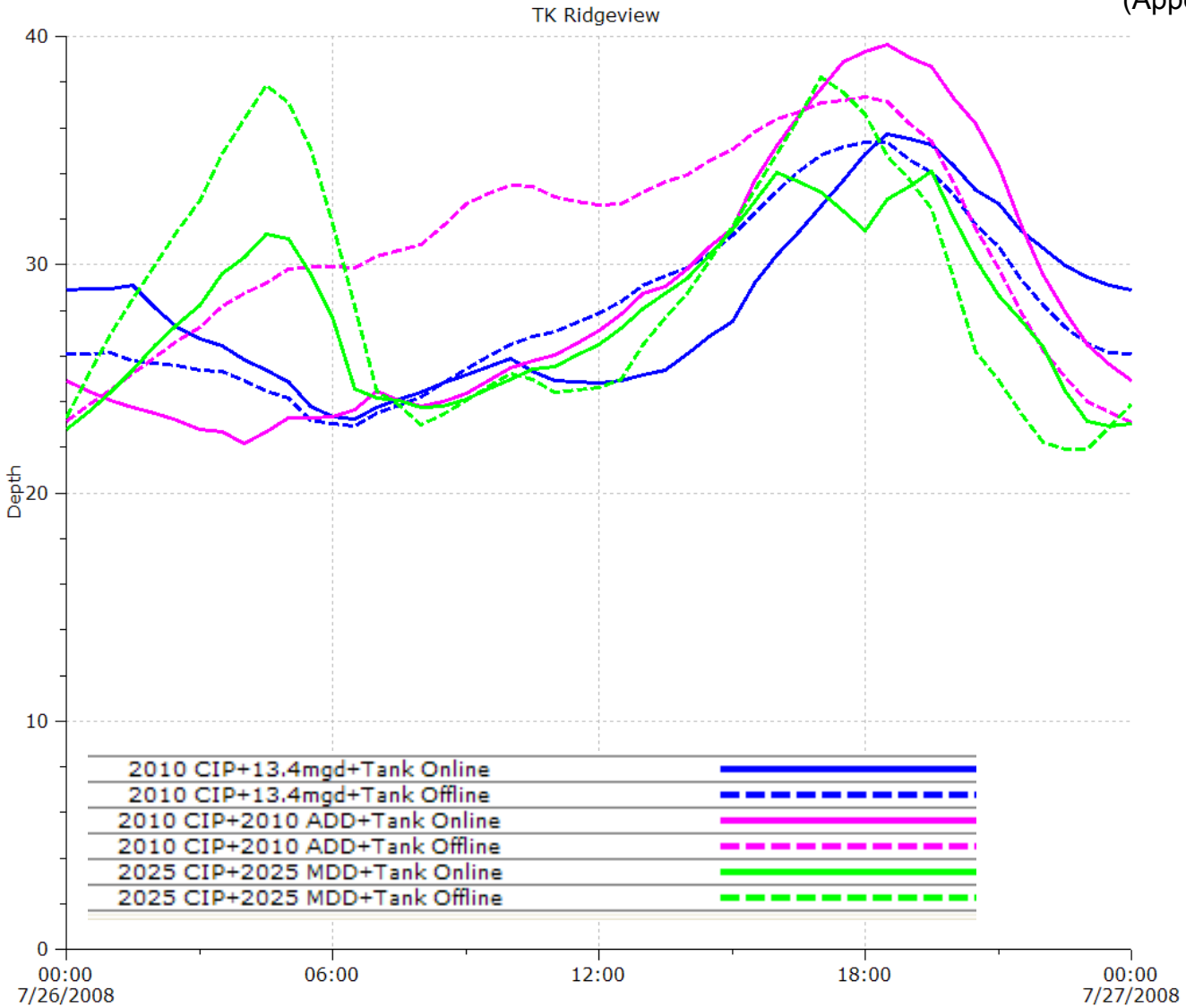
Maynard Tank

(Appendix D)



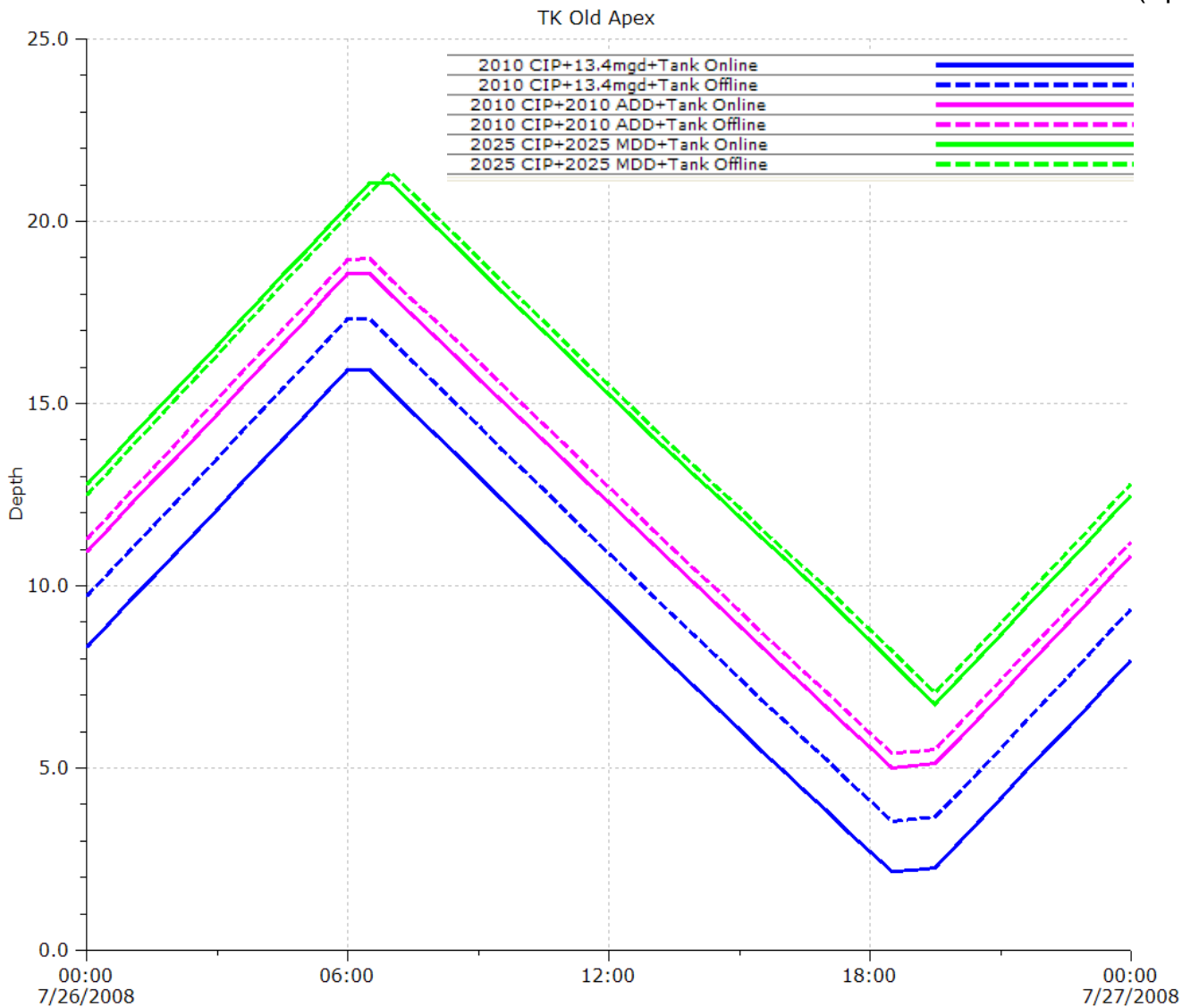
Ridgeview Tank

(Appendix D)



Old Apex Tank

(Appendix D)



Appendix E

Water Quality Addendum Review Comments and Responses

CH2MHILL Water Business Group Quality Review Form	
Client/Project: Cary Water Distribution System Master Plan and Model	
Project No.: 371661	
Phase:	Comments on Sept. 22, 2009 Draft Water Quality Report and Review of Report in Meeting with the Town on Oct. 20, 2009
Work Product:	Information to complete CH2M HILL responses to comments on Draft Water Quality Report
Date: November 19, 2009	

Comment Number	Review Comment	Response	Action
1	District Measurement graphs – Please remove/explain 0-depth data points. It appears there was a communication glitch just before 10AM and Bobby Fann indicates that Ridgeview 0-depth data point at 9:30 was likely due to taking sample.	We will remove the 0-depth data points from the graphs as they are most likely communication dropouts as confirmed by Bobby Fann at the meeting. The revised graphs will be in the final version of the report.	Revised Figures 1.7, 1.10, and 1.13-16 are in attached file RevCalibrationFigures.ppt; Figures will be included in final report.
2	Figure 1.19 – Can you show a "Model Closed Valves" line on this graph like you did for Fig 1.20 – 1.23? It looks like the "Model" line is similar to the "Model_no Closed Valves" line in the other graphs.	A "Model_no Closed Valves" line will be added to Figure 1.19 and to Figure 1.18 also and will be in the final version of the report.	Revised Figures 1.18 and 1.19 are in attached file RevCalibrationFigures.ppt; Figures will be included in final report.
3	Why proceed with such a poor R-square value for cold weather, instead of getting more data?	The data showed a good downward trend as expected although 3 data points are questionable as they showed the residual increasing over time. Kelvin explained that the residuals are measured in their lab on bench-top equipment that is calibrated every day. There is actually little difference between a 3.8 and a 4.0 when measured this way on bench-top equipment. The difference between 3.7 and 4.4 is not considered a large difference. There was considerable discussion about the slow rate of chloramine decay. CH2M HILL will re-run the cold weather K_b calculations dropping out the 3 data points that are outliers (at hours 36, 144 and 168) to determine the effect of excluding these data points, will provide the findings and include the	CH2M HILL re-ran the cold weather K_b calculations without the 3 data points. The slope changed from -0.0006 to -0.0008. The R-square increased from 0.622 to 0.883. The small difference in K_b does not change the original findings. Revised Figure 2.3 is in attached file Rev Fig 2.3.pdf and will be included in final report.

		revised graph and information in the final version of the report. The Town will repeat the cold weather bulk decay tests in Feb. 2010 just to provide additional data for later comparison with the 2009 cold weather decay rates. There was discussion about whether to incubate the cold weather samples for a longer period of time.	
4	Why adjust Kb for warm weather to -0.0025, which is nearly double what the data shows?	It is standard practice to adjust values in the model, based on the starting K_b developed through the jar tests. The adjustment made is within the accepted range of adjustments to K_b..	No Action
5	Why not calibrate model so that samples from more outlying areas match?	We selected locations to provide a good cross-section of water ages and follow IDSE sampling procedures, and did use many of the IDSE sites for calibration. Model was calibrated to June 2009 data. The Town will provide sampling data for July–Sept. 2009 from the approximately 120 sites that are sampled monthly at the same locations. CH2M HILL will review the data to determine if the calibration of outlying locations could be improved using nearby data points (note that the new data form Cary is all monthly data).	CH2M HILL reviewed the new data and did a comparison at 9 outlying locations, where the 2008 field average was outside the model data range (see attached file Calib Check with July 2009 data.pdf). The 2009 data are all monthly data, and the July data was used for comparison because the model calibration was run for July. For daily sampling sites 5, 8, 9, 11, and 13, nearby monthly data points were used. The results show some improvements at site 5, 8, 15, 16, 21, 23. There is still a gap at sites 9 and 13 due to the impact of tank operation and closed valves at Evans Master Meter.

6	Was CDM's Tracer Study data used in water age component?	For an actual comparison the model would need significant changes to match with the old sampling data. Also, many times, unknown closed valves can create issues with tracer studies, especially since this was performed in 2006, and much of the piping has been updated in the model. The Town stated that the demands are similar and there have been no significant changes in operations since that study. CH2M HILL will compare the water age data from the 2006 tracer study to the model to determine if the two studies show roughly the same areas of concern.	CH2M HILL compared the water age data from the year 2006 tracer study to the model (see attached file CDM Tracer Study Comparison.pdf for results). The two studies show roughly the same areas of concern with the highest water age at Plumtree. The average water age results are very close at most of the locations. The difference at Old Apex Tank is caused by the pump operation.
7	Is there other data available to confirm where the model shows poor water quality?	The answers to Comment Nos. 5 and 6 will answer this question. We used the Town's provided chlorine and DBP sampling data.	Same Action as for Comment Nos. 5 and 6 above
8	Why use MDD instead of ADD when concerned with addressing poor water quality?	The CIP was developed using MDD as is the industry standard and as recommended in the EPA's water quality modeling guidance documents. For Cary, the Max Month or average summer demand is only slightly less than the MDD. Kelvin commented that they experience most water quality problems in the transition period from spring to summer because the water temperature can increase very quickly but there is still relatively low demand. Cary does not allow irrigation on Mondays and the demand on Mondays in the summer is 15-17 mgd. All agreed that under Contract Amendment No. 2 SPZ additional WQ analysis, a scenario of 15 mgd Cary demand to represent an average summer day will be run in place of the proposed warm weather existing MDD scenario	CH2M HILL to complete under Amendment No. 2

9	Table 2-3 – Provide range of values for Field data, not just avg.	We discussed that a range is seen because the model is using diurnal curves which causes different demand patterns at the same location and also models the tanks as they fill and drain. We will modify Table 2-3 to show the average of the modeled conditions for the daily samples only. Some of the monthly sites had only one data point and monthly averages will not be shown on the table.	CH2M HILL modified Table 2-3 to add the range of values for field data for the daily sampling sites It follows the same trends as the average value comparison. The file Revised Table 2-3.pdf is attached.
10	Section 3.2 – The chlorine source of 4.7 mg/L is beyond the high end of the typical range of 4 - 4.5 mg/L.	This was the initial value shown in the data provided to CH2M HILL for the warm weather samples. Kelvin commented that the typical range is between 4 – 4.5 mg/l. At the meeting, the exact value to use was not agreed upon. CH2M HILL proposes to use an initial value of 4.25 mg/l and requests the Town's approval before initiating work. All agreed that this work will be in Contract Amendment No. 2 SPZ additional WQ analysis.	Town of Cary approved use of 4.25 mg/l as initial source concentration by email on 11/16/09
11	Comments on figures in general – Provide a legend complete enough to convey the important points in the figure. For example, my understanding is that not all pipes shown the figures are actually open in some of the modeling scenarios.	The figures and legends will be revised and will be in the final version of the report.	The figures and legend will be clarified in the final version of the report
12	Fig 3.3 and 3.4 have same title.	Figure 3.3 shows water age and Figure 3.4 shows chlorine residual. The figures and legend will be clarified in the final version of the report.	The figures and legend will be clarified in the final version of the report
13	Are there any benefits provided by tank mixing?	In the model, the tanks are evaluated as complete mix. CFD modeling and field data can be used to evaluate mixing scenarios if desired by the Town.	No Action