SECTION 4

Model Development

This section of the report describes the development of the hydraulic model which included the following steps:

- Water distribution facility inspections
- Model construction
- Field testing and steady state model calibration
- Extended period simulation model calibration

Prior to this study, the Town of Cary selected the Wallingford InfoWorks WS software platform. This software platform uses an enhanced version of the WesNet engine. Prior to building the model, most of the water system facilities were visited to ensure accurate representation in the hydraulic model. The model was constructed based on the Town's water system GIS layers and the information gathered from the facility site visits and record collection. Field testing was also performed in order to calibrate the steady state and extended period simulation (EPS) models.

4.1 Water Distribution Facility Inspections

Prior to constructing the hydraulic model most of the Town's water distribution facilities, including pumping stations, control valves, master meters, and elevated tanks, were visited to ensure accurate representation in the hydraulic model. Table 4-1 lists the facilities visited on April 2 and 3, 2008. A worksheet for each facility was prepared and provided to the Town for review. A CD of these worksheets is included in Appendix A.

TABLE 4-1
Water System Facility Inspections

Facility Name[a]		
Cary/Apex WTP High Service Station	Ridgeview Elevated Tank	Weston Master Meter
Davis Drive Booster Station	Old Apex Ground Storage Tank	Evans Master Meter
Trinity Road Booster Station	Field Street Elevated Tank	Highway 54 Master Meter
Penny Road Booster Station / Meter	Davis Drive Pressure Reducing Valve	Lake Crabtree Master Meter
Carpenter Elevated Tank	Kildaire Farm Road Control Valve	Holiday Inn Master Meter
Harrison Elevated Tank	Cary Parkway Control Valve	National Guard Master Meter
Maynard Elevated Tank	Lake Pine Master Meter	RDU Airport Master Meter

[a] The following water distribution facilities were not inspected: Jenks Control Valve, Green Level Control Valve, and McCrimmon Master Meter.

4.2 Model Construction

The Town of Cary's previous hydraulic model was created in the Bentley/Haestad Methods WaterCAD software but did not include all pipes down to 6-inch in diameter. For this study, a completely new "full-pipe" model was created using the Wallingford InfoWorks WS v9.5 software which includes all pipes down to 6-inches in diameter.

Physical elements were incorporated into the model using the Town's GIS, record drawings, and facility worksheets. These elements include: pumps, control valves, tanks, reservoirs, junctions, and pipes. The model construction process was completed by adding the necessary elevations, demands, and controls to the model.

4.2.1 Pipes and Junctions

The hydraulic model network primarily consists of pipes and junction elements. Rather than adding the necessary grid main piping to the WaterCAD model network, a completely new InfoWorks WS model network was created using the Town's water distribution system GIS. Table 4.1 describes the data layers obtained from the Town's water distribution system geo-database including the layer name, source, content, and action required to incorporate the GIS data into the InfoWorks WS model.

TABLE 4-2
GIS Data Layers Used During Model Construction

GIS Data Layer	Data Source	Content and Action
Cary water lines	Layer from the Town of Cary Water System Geo-database (March 2008)	GIS layer contained pipes as small as 2-inch and included all hydrant laterals. CH2M HILL removed all hydrant laterals and pipes smaller than 6-inch. The layer differentiated between existing and proposed pipes.
Cary water symbols	Layer from the Town of Cary Water System Geo-database (March 2008)	GIS layer contained the following water system components: valves, hydrants, air release valves (ARVs), blowoffs, plugs, reducers, etc. Tees and cross fittings were not included in the Geo-database. For this reason, CH2M HILL created junctions using automatic functions in the InfoWorks WS software.
CaryTopoAll1999_polyline	NCDOT (March 2008)	Elevation contour data was provided at 2 foot intervals. Elevations were assigned to the model using automatic functions in the InfoWorks WS software.
2007 Meter Locations	Town of Cary (March 2008)	Data layer contained all of the Cary water service meter locations, within the urban service area, current through 2007. This data also contained the monthly and yearly consumption statistics summarized for each meter location. Using automatic functions in the InfoWorks WS software, demands were assigned to the nearest pipe which automatically allocated flow to the connecting model junctions. (The InfoWorks WS software leaves a permanent line from the meter point to the model pipe so the user can manage demand allocations.)

TABLE 4-2
GIS Data Layers Used During Model Construction

GIS Data Layer	Data Source	Content and Action
Pressure Zone	Town of Cary (March 2008)	Approximate pressure zone boundaries were used to verify with the Town which pipes should be closed in the model to form pressure zone boundaries. The pressure zone boundary layer cannot accurately differentiate between the WPZ and the CPZ in the Morrisville area. The InfoWorks WS software has a tracing function that was used to highlight which pipes and junctions are in a particular pressure zone.
Aerial Photography	Town of Cary (March 2008)	Aerial photography was utilized to verify new subdivision development

After the GIS data were verified and compiled, the GIS files were imported into Wallingford WS using the model import tool included with the software package. Data attributes, such as pipe and junction ID, pipe diameter, and material were included in the data import process. Service connections and hydrant lines were not included in the model. Elevations were automatically assigned to the model using 2-ft elevation contours provided by the Town. Once the basic data was imported into the model, the network connectivity was examined and verified with Town staff.

4.2.2 Demand Allocation

Demand allocation is an automated process of spatially assigning existing and future water demands to the model. Demand allocation consist of three parts: geo-coded customer billing data, non-revenue generated water, and future demand projections (Section 2).

4.2.2.1 Customer Billing Data

The Town of Cary provided 2007 water billing data which included all customer accounts including irrigation meters. The average day water demand (ADD) for each user account was summarized and assigned to a corresponding water meter point in GIS. Using this meter point GIS layer, water demand was allocated to the nearest model junction using the Static Demand Allocation tool in InfoWorks WS. The allocation process assigns the demand to the nearest pipe, which is assigned the closest node along that pipe. Additionally, rules can be set to ensure that only desired pipes are selected for demand assignment. The demands can be easily re-allocated in the future since InfoWorks WS displays a line from the demand point to the assigned pipe. Once the allocation process is complete the demand is referred to a customer point.

4.2.2.2 Non-Revenue Generated Water

Non-revenue water is the difference between water produced and water billed. Non-revenue water can be caused by:

- Physical losses due to leakage in the system

- Administrative losses due to illegal connections and under registration of the water meters
- Activities such as hydrant flushing, fire training, etc.

The Town of Cary has previously estimated that the system-wide non-revenue water is 9 percent. The non-revenue water was assumed to occur uniformly throughout the day. As a result, these demands were applied evenly, without any peaking over a 24-hour period.

4.2.2.3 Future Demand Projections

The allocation process of each future year was completed in the same manner as the 2007 demands, using the Static Demand Allocation Tool and assigning demand points to the nearest pipe. Furthermore, future demands for 2010, 2015, 2025 and build-out were imported into the model individually ensuring each future year was accurately allocated and assigned to the nearest pipe. Then, each future year was setup as an Alternate demand using the Alternate Demand Tool. This process created four separate demand files representing each individual future year.

4.2.3 Pump Curves

The Town of Cary provided manufacturer pump curves for the high service station, and all Booster pump stations. These curves were analyzed and transferred into a spreadsheet in order to determine key points representing head and flow along the pump curves. The key points (head and flow) were added to model for each pump to provide a good characterization of the curve. Additionally, pump specifics were added to model. None of the pumps were field tested to verify the manufacturer curves.

4.2.4 Tank Geometry

The Cary System has several different types of tanks with different geometries including: spheroid, fluted pillar, double ellipsoid, and ground storage (cylinder). Tank geometry was incorporated into the model for each tank by establishing a height to depth ratio at 1 foot increments. This physical information had not been incorporated into the previous WaterCAD model such that tanks were being simulated as cylinders with constant diameter along the height of the tank.). The addition of individual tank geometry provided a more accurate EPS model as described in more detail in Section 4.4.

4.2.5 Control Valves

The model was setup to include four control valves, which were Kildaire Farm Road OCV, Cary Parkway OCV, Davis Drive PRV, and Old Apex Tank fill valve. Green Level and Jenks control valves were both simulated as simple junctions with an associated demand based on customer billing records and a diurnal demand pattern based on observed SCADA flow data which varied widely from day to day operation.

After building the model using the Town's GIS, assigning existing demands from the customer billing data, incorporating the necessary facilities and preliminary controls, the model was ready for calibration which consisted of a two-step process: 1) steady state model calibration and 2) extended period simulation calibration.

4.3 Field Testing and Steady State Model Calibration

Calibration is the process making incremental adjustments to the model input data file (physical and operational settings) until the model output accurately reflects field conditions (pressure and flow). In essence, calibration is the process of eliminating model input data errors. Operational adjustments may include adjustments to boundary conditions such as tank water levels, pump "on-off" status, and control valve settings. Physical adjustments may include changing the pipe connectivity, pipe diameter, and finally pipe roughness as the last step in the steady state calibration process. Extensive field testing was performed prior to the model calibration task to ensure that the model would be calibrated and could accurately simulate the water distribution system under a wide range of flow and pressure conditions.

4.3.1 Field Testing Plan

A field test plan was prepared that suited the age, configuration, size, and condition of the Town of Cary system (Appendix B). Test sites were selected after evaluating the 2000 Master Plan report so as not to duplicate test type and location.

Two types of tests were conducted to perform the steady state calibration: system HGL tests and fire hydrant flow tests. In most cases, system HGL tests are used to determine the head variation along the larger trunk mains in a system, 16-inch and larger, and are often conducted in a linear path from a supply source to an elevated tank or to the end of a pressure zone. In other cases, a system HGL is conducted across pressure zone boundaries to determine the head/flow relationship of control valves or pumping stations. Fire hydrant flow tests are typically used to calibrate the grid system, 12-inch and smaller. Performing fire hydrant flow tests on larger mains usually require that more than one hydrant be flowed to achieve an adequate pressure drop (usually 10 psi or greater) which is necessary to produce accurate and reliable data that can be used for calibration.

Four system HGL tests were conducted on May 14-19, 2008 as shown in Figures 4-3 through 4-6. The second stage of testing included twenty-nine (29) hydrant flow tests performed from August 5-14, 2008 as shown in Figures 4-1 and 4-2.

4.3.2 Hydraulic Grade Line Testing

Hydraulic grade line testing was used to adjust the Hazen-Williams coefficient (C-factor) on the larger transmission mains in the Town of Cary system. Additionally, HGL testing was used to manual adjust the local losses associated with control valves in the system, such as the Davis Drive PRV, the Kildaire Farm Road OCV, and the Cary Parkway OCV. Four HGL tests were performed across the Cary System:

- HGL A (WPZ): Cary/Apex WTP to Carpenter Tank to Davis Drive PS
- HGL B (CPZ to WPZ): Cary/Apex WTP to Davis Drive PRV to Carpenter Tank
- HGL C (CPZ): Cary/Apex WTP to Davis Drive PRV to Morrisville to RDU Airport
- HGL D (CPZ to SPZ): Ridgeview Tank to Plumtree Way Tank to Southern extent of SPZ

Digital pressure recorders were strategically installed on hydrants at the locations described in Table 4-2. The digital recorders collected continuous pressure data (1 minute interval) for an entire day in order to capture the maximum and minimum hydraulic grade line. The pressure data obtained during the HGL tests was converted to head and used to make adjustments to the trunk mains in the hydraulic model.

4.3.2.1 Hydraulic Grade Line A (WPZ)

As shown in Figure 4-1, a system HGL test (HGL A) was conducted across the WPZ from the Cary/Apex WTP HSPS, east on Jenks Road (30″), north on Highway 55 (30″, 24″, 20″) to the Carpenter Elevated Tank, east along Morrisville Carpenter Road (16″), north along Davis Drive (16″) to the Davis Drive Pump Station at the north end of the WPZ.

Results of the field test and model calibration are shown in Figure 4-3. A slightly elevated grade line can be seen at the Cary/Apex WTP HSPS and along the 30-inch transmission main to the Carpenter tank. A significant drop in the grade line occurred north of the tank along Morrisville Carpenter Road and Davis Drive. Even though the digital pressure recorder at hydrant #3 malfunctioned such that a pressure data point was not obtained at the intersection of Morrisville Carpenter Road and Davis Drive Road, the modeling analysis indicated that during peak flows, the section of 16-inch main along Morrisville Carpenter Road was stressed resulting in a majority of the head loss between the Carpenter Elevated Tank and Davis Drive Pump Station.

4.3.2.2 Hydraulic Grade Line B (CPZ to WPZ)

As shown in Figure 4-1, a system HGL test (HGL B) was conducted from the CPZ to the WPZ through the Davis Drive PRV. HGL B was conducted from the Cary/Apex WTP HSPS, east on Jenks Road (30″), north on Jenks Carpenter Road (30″) to the Davis Drive PRV, north along Davis Drive (16″) into the WPZ, west along Morrisville Carpenter Road (16″), and south along Highway 55 (24″, 20″) to the Carpenter Elevated Tank.

Results of the field test and model calibration are shown in Figure 4-4 with the Davis Drive PRV opened by SCADA command. The grade line indicates that the valve pressure setting is approximately 78 psi (570-ft msl). based on a ground elevation of 390-ft. The grade line from the Davis Drive PRV to the Carpenter Elevated Tank dropped approximately 35-ft from 570-ft to 535-ft msl. The model calibration results were in very close agreement with the field test results.

4.3.2.3 Hydraulic Grade Line C (CPZ)

As shown in Figure 4-1, a system HGL test (HGL C) was conducted through the CPZ to Morrisville and the RDU Airport. HGL C was conducted from the Cary/Apex WTP HSPS, east on Jenks Road (30″), north on Jenks Carpenter Road (30″) to the upstream side of Davis Drive PRV, northeast along Cary Parkway to Chapel Hill Road (30″, 24″), north west along Chapel Hill Road to Aviation Parkway (16″), northeast along Aviation Parkway (16″) to the RDU Airport, southwest along Airport Boulevard (16″), and terminating at Pleasant Grove Church Road at the north end of CPZ. (Due to the previous boundary configuration between Morrisville and the Town of Cary, the 24-inch and 16-inch mains at the intersection of Cary Parkway and Chapel Hill Road are not connected so that flow still travels through the Highway 54 and Weston Parkway Master Meters.)

Results of the field test and model calibration are shown in Figure 4-5. The grade line across the system starts at approximately 670-ft at the Cary/Apex WTP HSPS to approximately 605-ft at the RDU Airport location. Similarly, the Raleigh water system north of the RDU Airport is a 605-ft pressure zone. Review of the piping configuration in the Raleigh-Durham-Cary water distribution model and record drawings indicate that the RDU Airport may also be connected to the Raleigh 605 pressure zone.

4.3.2.4 Hydraulic Grade Line D (CPZ to SPZ)

As shown in Figure 4-1, a system HGL test (HGL D) was conducted from the CPZ, through the Kildaire Farm Road OCV, and to the end of the SPZ. HGL D was conducted from the Ridgeview Elevated Tank, south along Kildaire Farm Road (12", 16") through the Kildaire Farm Road OCV into the SPZ, south along Kildaire Farm Road (12") to Ten-Ten Road, southeast along Ten-Ten Road (20") to the Plumtree Way Elevated Tank, southeast along Ten-Ten Road to West Lake Road (20", 16"), south along West Lake Road to Optimist Farm Road (16"). Data from site HGL D Hydrant #15 was not used since there was a malfunction with the digital recorder.

Results of the field test and model calibration are shown in Figure 4-6 with the Kildaire Farm Road OCV opened by SCADA command. A consistent drop in the hydraulic grade line was observed from the Ridgeview Elevated Tank (617-ft msl) to the Plumtree Way Elevated Tank (588-ft msl) with very little head loss occurring across the control valve itself because the valve is a operated at full-open position. From the Plumtree Way Elevated Tank to the south end of the SPZ, the model head matched the field within 5 feet.

TABLE 4-3
Hydrant Pressure Test & Hydraulic Grade Line Test Locations

Grade Line	Hydrant # or SCADA	Location	Ground Elevation (feet)	Max HGL (feet)	Min HGL (feet)
A	SCADA	Cary/Apex WTP 30" SCADA Pressure	330	546	522
	1	1905 Highway 55 ~700 N of Jenks Road	433	539	517
	2	Green Level & Highway 55	395	534	515
	SCADA	Carpenter Elevated Tank SCADA Level	391	532	525
	3	1115 Morrisville Carpenter Rd *Note: Logger malfunctioned and was not used in calibration.*	N/A	N/A	N/A
	4	Between Little Drive & Kitt Creek Road	292	505	494
B	SCADA	Cary/Apex WTP 42" SCADA Pressure	330	645	N/A
	5	Along Collins ~ 300' E of Jenks Carpenter	419	622	N/A
	6	Davis Drive & High House Road	394	573	N/A
	7	Along Davis Rd between Caviston Way & Preston Village	372	568	N/A
	SCADA	Carpenter Elevated Tank SCADA Level	391	537	N/A
C	SCADA	Cary/Apex WTP 42" SCADA Pressure	330	669	651
	5	Along Collins ~ 300' E of Jenks Carpenter	419	642	629
	8	High House Road & Cavendish Road	436	638	628
	9	Maynard Road & Chapel Hill Road	470	628	623
	10	Morrisville Parkway & Chapel Hill Road	405	608	603
	11	10012 Chapel Hill Road	298	606	602
	12	1015 Aviation Parkway	303	605	595
	13	2800 Pleasant Grove Church Road	329	610	601
D	SCADA	Ridgeview Elevated Tank SCADA Level	474	621	617
	SCADA	Kildaire Farm Road CV SCADA US Pressure	462	605	605
	SCADA	Kildaire Farm Road CV SCADA DS Pressure	462	607	603
	14	Kildaire Farm Road and Penny Road	459	600	598
	SCADA	Plumtree Way Elevated Tank SCADA Level	469	588	576
	15	Intersection of Ten Ten Road & West Lake Road *Note: Logger malfunctioned and was not used in calibration.*	N/A	N/A	N/A
	16	Westlake ~500' N of Optimist Farm Road	391	589	583

N/A = Information not available

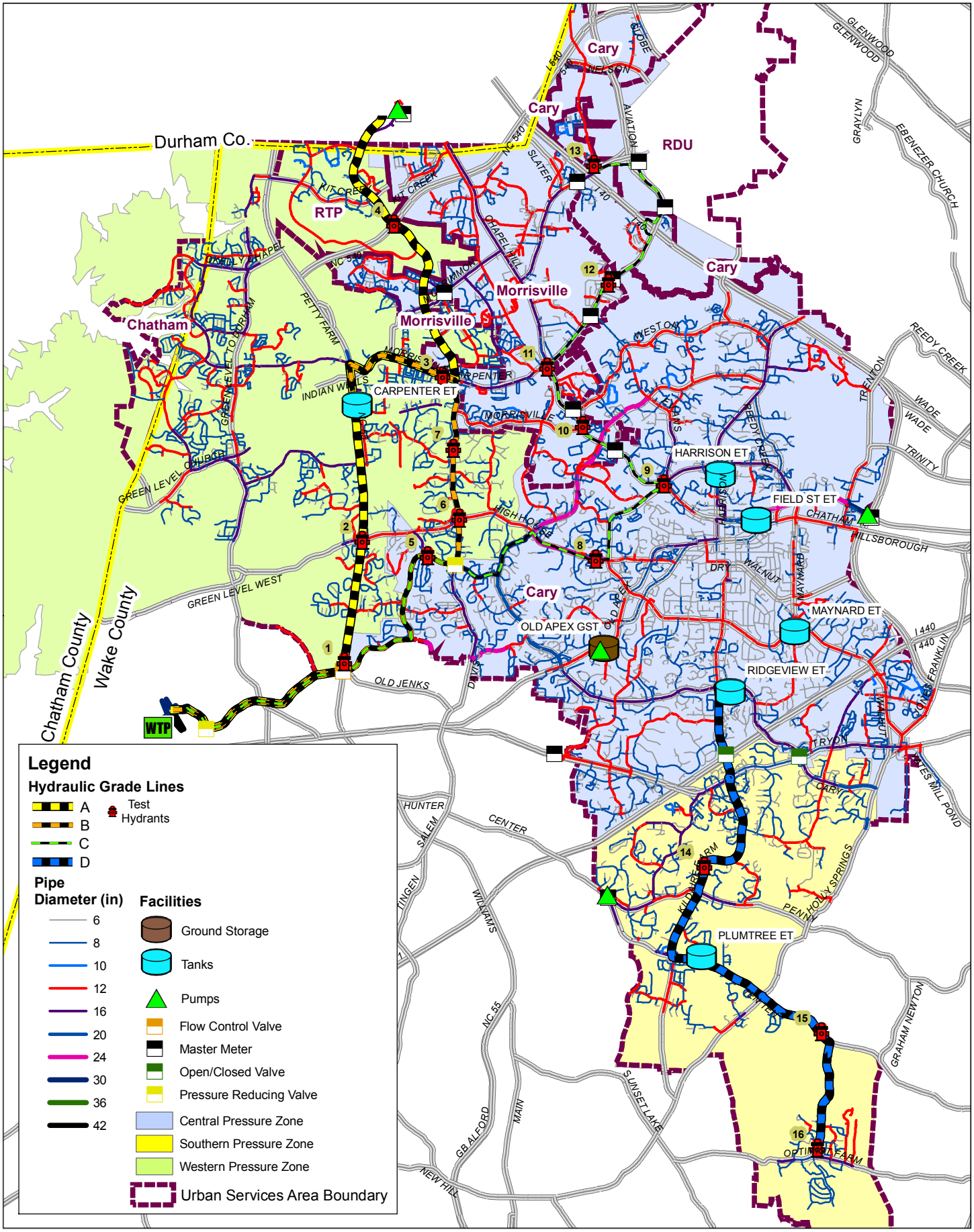
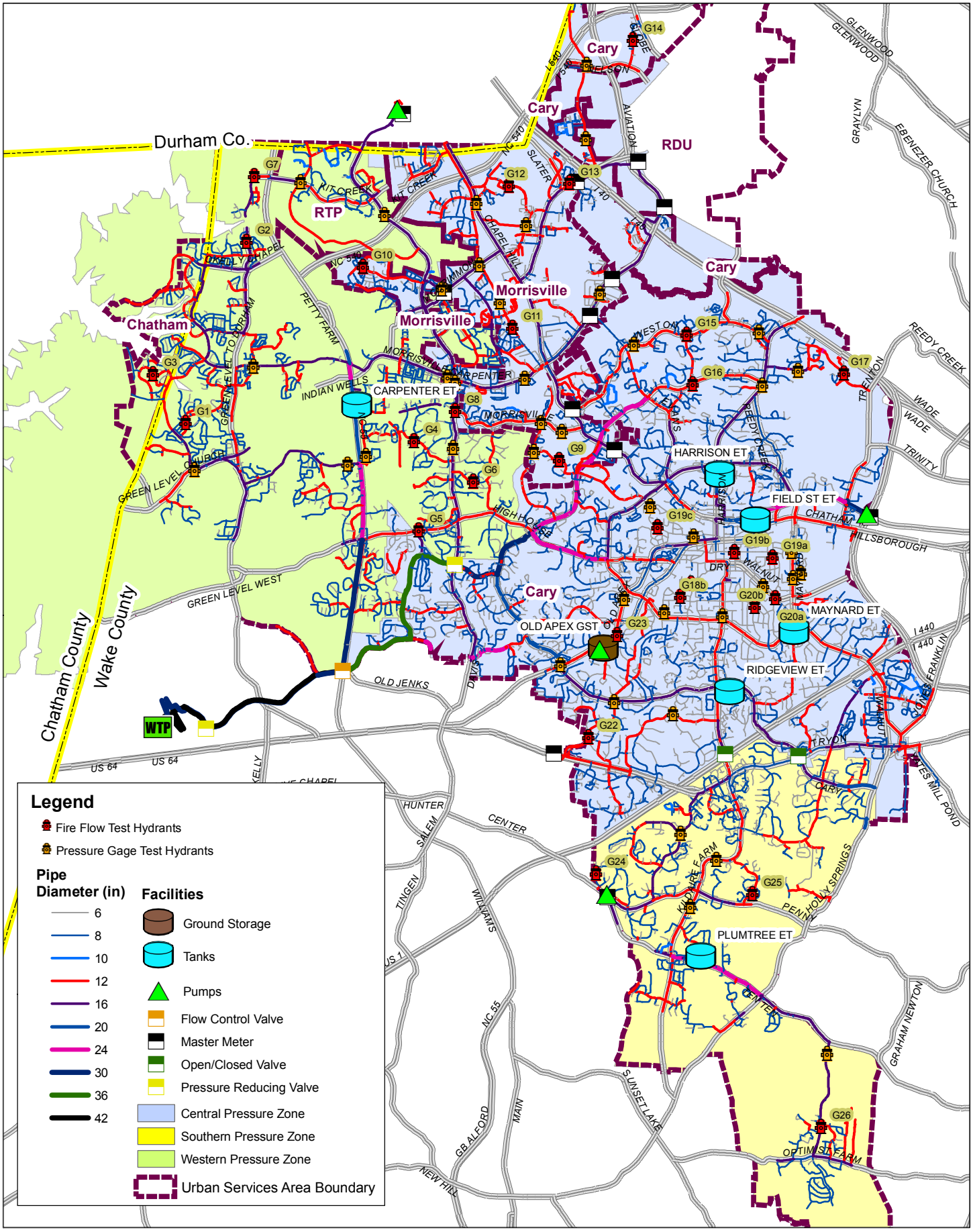


FIGURE 4-1
HGL and Pressure Hydrant Test Locations

CH2MHILL



N

0 1 2 3 Miles

FIGURE 4-2
Fire Flow and Pressure Hydrant Test Locations

CH2MHILL

FIGURE 4-3
Hydraulic Grade Line Test A (WPZ)

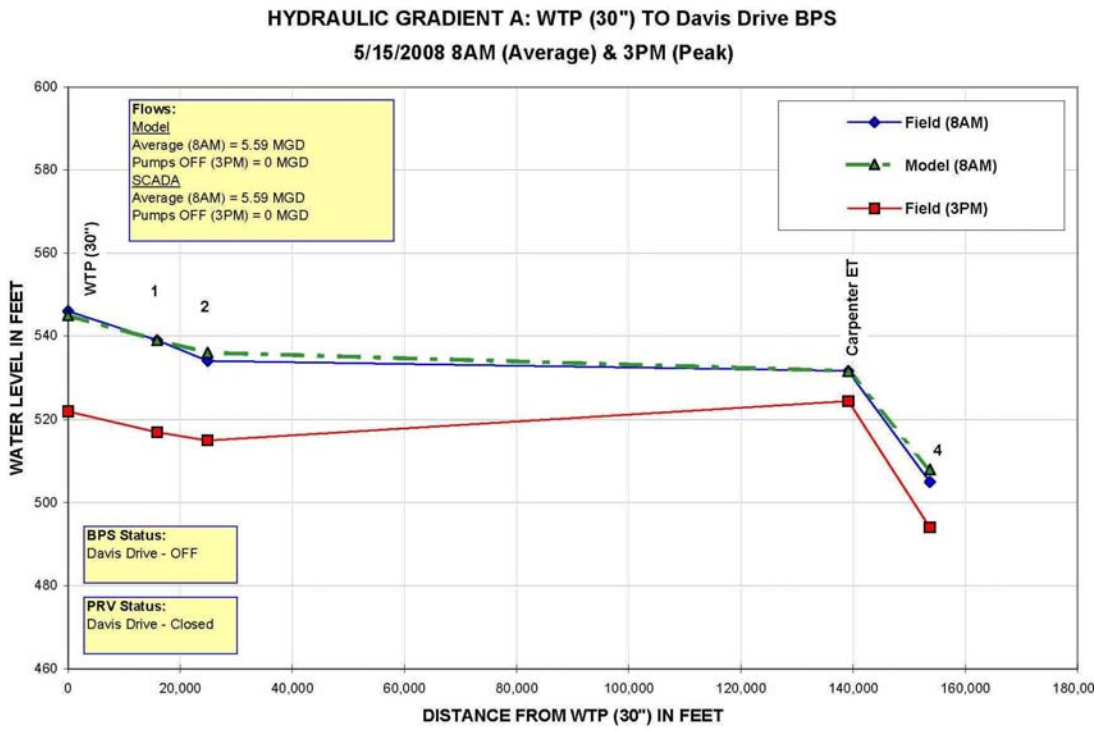


FIGURE 4-4
Hydraulic Grade Line Test B (CPZ to WPZ)

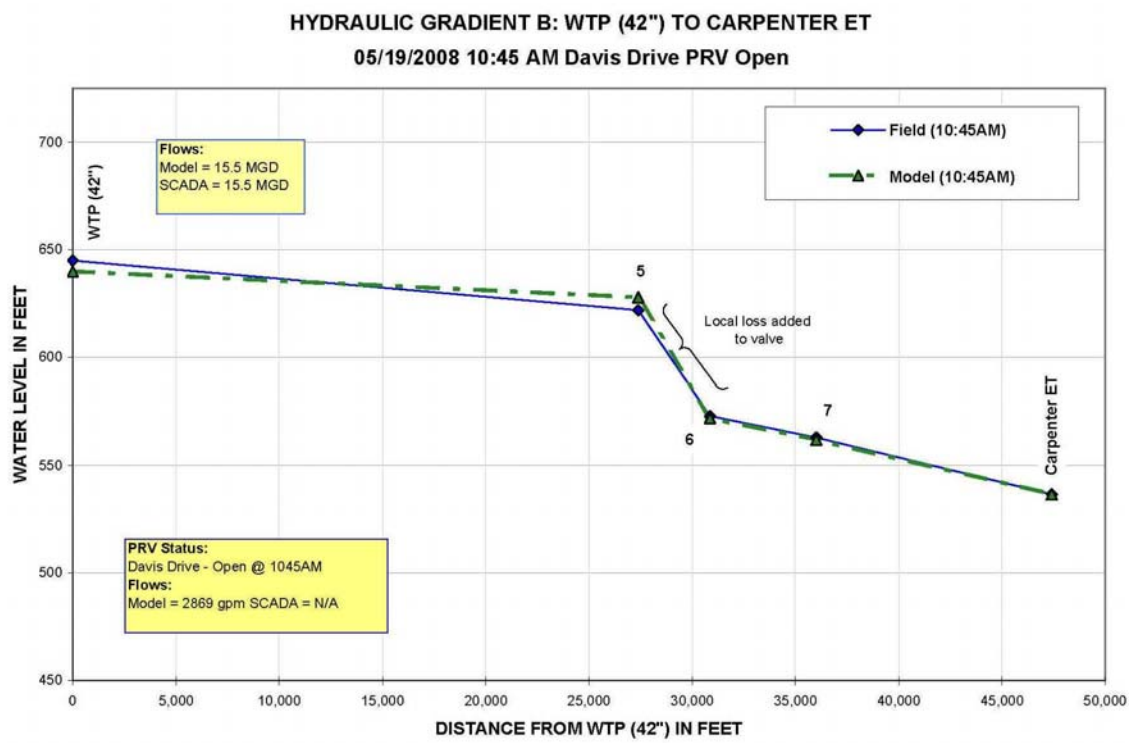


FIGURE 4-5
Hydraulic Grade Line Test C (CPZ)

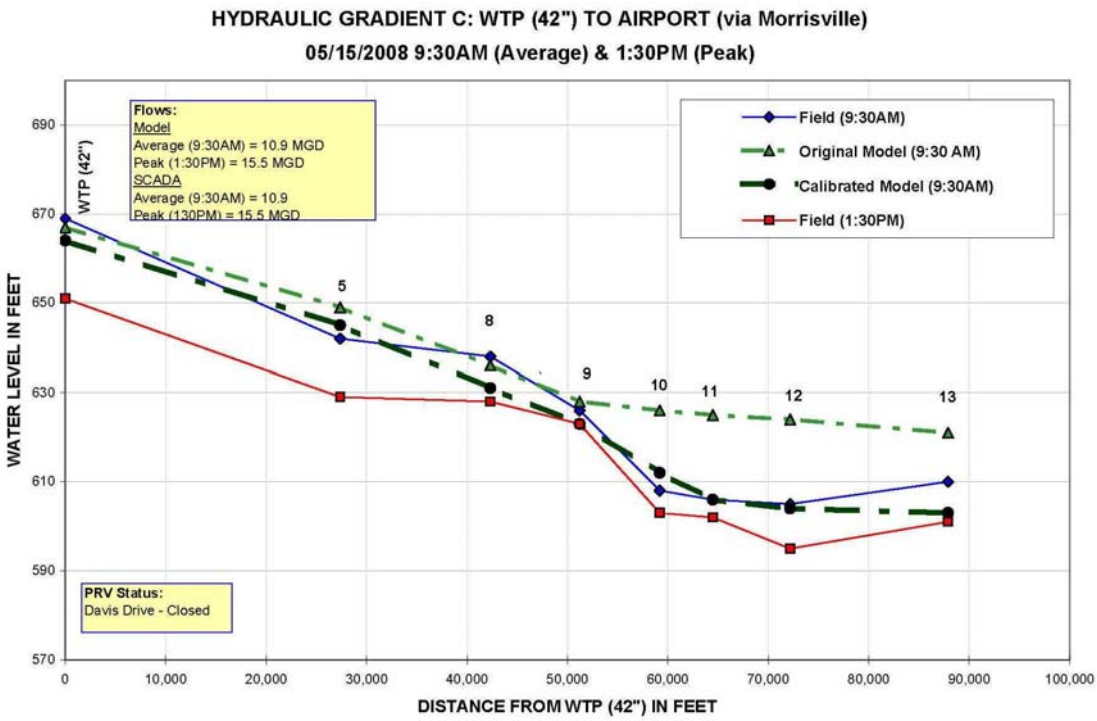
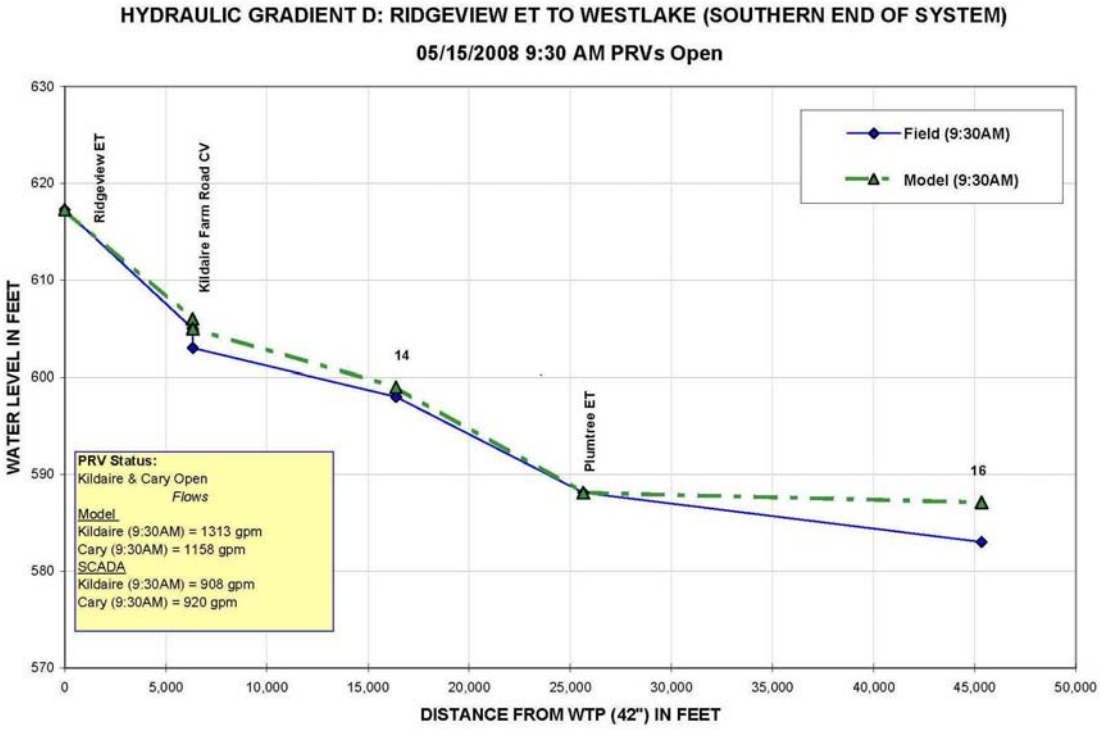


FIGURE 4-6
Hydraulic Grade Line Test D (CPZ to SPZ)



4.3.3 Hydrant Flow Testing

Hydrant flow tests are the most common method used to calibrate the network piping in hydraulic computer models. During hydrant flow tests local piping is stressed resulting in pressure drops that can used to identify closed or partially closed valves in the system, pipe connectivity discrepancies, and/or those pipes where adjustments to the Hazen-Williams C-factor is necessary.

Traditional fire flow tests consist of a single "flow" hydrant and "test" hydrant. For larger mains (12-inch and larger), more than one "flow" hydrant may be required to induce enough pressure drop in the system. Pressure is measured at the "test" hydrant prior to and during the flow event to determine the static and residual pressures. Pressure is also measured at the "flow" hydrant using a pitot tube device which is converted to flow using a hydrant flow equation. With the advent of digital pressure recording devices in recent years, multiple "test" hydrants can be monitored at one time without the need for additional field staff. The digital pressure recorders can be strategically placed in a linear path so that a "static" and "residual" hydraulic grade line can be plotted and compared to the hydraulic model. This modified hydrant flow test is called a fire flow hydraulic profile test.

4.3.3.1 Fire Flow Test Locations

From August 5-14, 2008, twenty-nine (29) fire flow hydraulic profile tests were conducted across the Cary water distribution system. While the model contains all pipes down to 6-inches, test sites were chosen so that pipes 12-inch and larger in the model could be calibrated for master planning purposes. After the tests were conducted, pressure data from the digital recorders was used to create the hydraulic profiles shown in Appendix C. Operating information such as pump flow rates and tank levels obtained from the Town's SCADA system was used to set the boundary conditions in the model. Through trial-and-error, the model was adjusted until a high level of calibration accuracy was obtained for a majority of the tests.

4.3.3.2 Calibration Confidence Criteria

The fire flow hydraulic profile test is robust and powerful tool for calibrating hydraulic models. Experience has shown that a high level of calibration accuracy can be obtained when using this methodology. Four "levels of confidence" criteria developed by CH2M HILL for both static and residual pressures were adopted for this study as shown in Table 4-3. If both the static and residual model vs. field measurements were less than 7 feet, the level of confidence in the model calibration at the particular test site was considered 'very high', from 7 to 12 feet difference was considered 'high', from 12 to 25 feet was considered 'medium', and more than 25 feet difference was considered as 'low'.

Table 4-4 provides the fire flow test ID # which corresponds with the fire flow test map shown in Appendix C, the pressure zone and street location, the static and residual model error in feet, the "level of confidence" criteria rating as described above, and notes regarding the potential cause of model error. Out of 29 fire flow profile tests, fifteen (15) were rated as "very high", six (6) as "high", three (3) as "medium", and five (5) as "low". For the five tests that resulted in a "low" level of confidence criteria rating, the following notes were provided to explain the potential cause of the error:

- Note 1 - suspected closed or partially closed valve and
- Note 2 - potential inaccuracies in diurnal demands

Some tests resulted in a "high" level of confidence after simulating suspected closed valves or adjusting the local diurnal demands in the model. These tests are identified in Table 4-4 as well.

TABLE 4-4
Calibration Results Level of Confidence Criteria: Field Testing and Model Calibration

Level of Confidence	Field vs. Model Pressures (Static & Residual)
Very High	Less than 7 feet
High	7 to 12 feet
Medium	12 to 25 feet
Low	More than 25 feet

TABLE 4-5
Hydrant Flow Test Model Calibration Summary

Test ID	Pressure Zone	Street Location	Test Hydrant Average Error		Calibration Level of Confidence				Notes[c]
			Static (feet)	Residual (feet)	Very High (0-7 ft)	High (7-12 ft)	Medium (12-25 ft)	Low (>25 ft)	
1	WPZ	Cary Glenn	2.1	5.1	x				
2	WPZ	Green Level to Durham & O'Kelly Chapel	3.3	1.3	x				1
3	WPZ	Bosworth	-5.0	-0.8	x				1
4	WPZ	Preston Village & Walcott	-5.4	54.0				x	1 or 2
5	WPZ	Upchurch & High House	0.3	-1.8	x				2
6	WPZ	FireCrest	1.8	18.1			x		2
7	WPZ	Kitt Creek	20.9	64.1				x	2
8	CPZ - M[a]	Morrisville Parkway & Davis	1.2	5.4	x				2
9	CPZ - M	Preston Grande & Trelling Wood	-0.3	-0.9	x				2
10	CPZ - M	Parkside Valley	9.2	1.7		x			2
11	CPZ - M	Downing Glen & Church	1.2	-1.1	x				2
12	CPZ - M	Paramount Park	0.7	4.3	x				2
13	CPZ - M	Airport Blvd	-0.1	5.5	x				2
14	CPZ - M	Kitty Hawk	0	1.7	x				2
15	CPZ	Weston	-5.5	-30.1				x	2
16	CPZ	Cary & Norwell	-1.5	-23.2			x		1 or 2
17	CPZ	Research (SAS)	-5.3	-11.7		x			2
18a	CPZ - ML[b]	Grifis & Church Parking Lot	0.7	6.9		x			
18b	CPZ - ML	Normandy & Union	4.3	8.1		x			
19a	CPZ - ML	Holtz & Melanie	-4.1	-0.2	x				
19b	CPZ - ML	Park & Walker	-2.5	-4.3	x				
19c	CPZ - ML	Beech & Madison	-0.1	34.3				x	1
20a	CPZ - ML	Tanglewood & Walnut	-6.0	-33				x	1
20b	CPZ - ML	E Cornwall & Ralph	-4.9	-11		x			
22	CPZ	Versailles & Lake Pine	4.9	-3.8	x				
23	CPZ	Old Apex	-1.0	-8.0		x			
24	SPZ	Hasselwood & Crowin Forest	-0.2	-20.0			x		
25	SPZ	Lochhighlands & Piperwood	4.5	-3.5	x				
26	SPZ	West Lake & Wolfs Bane	-2.3	1.7	x				
				Total	**15**	**6**	**3**	**5**	

[a] Morrisville Area.

[b] Maynard Road Loop Area.

[c] 1 = Potential closed valve or piping connectivity error; 2 = Difference attributed to diurnal demand.

4.3.4 Steady State Model Calibration Discrepancies

During the calibration process, multiple adjustments are often made to the hydraulic model until simulation results produce similar pressure drops to those observed in the field. Field testing can identify errors in the computer model input data, or it may reveal an unknown condition in the field; for example, valves that should normally be open might actually be closed (or vice versa), or an error in pipe size or connectivity may be present. The following summarizes the changes made to the model for some of the test sites in which considerable engineering judgment was required to replicate conditions observed in the field. This list provides additional information for future study efforts and designs at which time these assumptions can be field verified. The following list references the system HGL and fire flow hydraulic profile tests shown in Table 4-2 and 4-4:

- HGL C: There is a large drop in the HGL along Chapel Hill Road between gauging point 9 and 10 on one of the 16-inch mains that supplies Morrisville. Because of this drop (of more than 20 feet), there was a need for diurnal demand pattern adjustments for the Morrisville and RDU Airport areas. Therefore, a commercial diurnal demand pattern assigned to this area which produced a more closely calibrated HGL C. As well, a potential partially closed valve between gauging points 9 and 10 should not be ruled out.
- HGL D: During Fire Flow testing it was discussed that the remote southern end of the SPZ undergoes regular flushing at a rate of 300 gpm. Since, HGL D displays a discrepancy at gauging point 16, there is a need to assign the flushing demand in order to more accurately calibrate to the location of gauging point 16.
- FF Test 2: Three pipes in the vicinity of gauging point 2 were open during the initial fire flow run analysis. It was determined these three particular pipes were in fact developer undesignated and closed for successful calibration of Test 2.
- FF Test 3: Gauging point 3 was located within a new subdivision currently under construction. An existing pipe in the development was closed and the 12" main along Yates Store Road was closed to achieve the 'very high' match. It is recommended that a future fire flow profile test be conducted along Yates Store Road with closer spacing of digital pressure recorders in order to determine the location of the potential closed valve.
- FF Test 4 and 6: The small area within the WPZ east of NC-55 and south of Morris-Carpenter Road exhibited the need for diurnal demand pattern adjustments. A sensitivity analysis involving several adjustments to the diurnal demand pattern was modeled for this small area within the WPZ. However, the diurnal demand pattern adjustments were not successful. This reflects the need for more accurate diurnal demand patterns for the WPZ. Additionally, this area may have a partially closed or closed valve, which is impacting the calibration. It is recommended that this area be re-tested near gauging points 4 and 6 after more refined diurnal demand patterns are developed for this area.
- FF Test 5: Gauging point 5 was located in the same small area of the WPZ as gauging points 4 and 6. It should be noted that adjustments to the diurnal demand pattern successfully calibrated this flow test.

- FF Test 7: Gauging point 7 was located in the Research Triangle Park area, which consists of many commercial developments. There were notable adjustments to the diurnal demand pattern in this area. Additionally, there are known large users in this area. Therefore, there is a need for more accurate diurnal demand patterns for this area of the WPZ.
- FF Tests 8-14: Tests 8-14 were located within the Morrisville and RDU Airport Area of the CPZ. A standard diurnal curve was initially used for the entire CPZ and it was observed very early in the modeling process that the Morrisville and RDU Airport Area needed an adjusted diurnal demand curve to more accurate calibrate the model to the field tests. Therefore, a commercial diurnal demand pattern was assigned to this area of the CPZ.
- FF Test 15 and 16: Gauging points 15 and 16 were located just south of Morrisville and exhibited the need for diurnal demand pattern adjustments. A standard commercial diurnal demand pattern was assigned to all commercial parcels in the CPZ. However, this adjustment did not achieve successful calibration of Test 15 and 16. It is suspected there is a need for a more individualized diurnal demand pattern near Weston Master Meter.
- FF Test 17: Gauging point 17 was located in the vicinity of FF Tests 15 and 16. Although diurnal demand adjustments did not impact Tests 15 and 16 greatly, the assignment of a commercial diurnal demand pattern to the parcels achieved a successful calibration of Test 17.
- FF Test 19c: Gauging point 19c revealed some potential piping connectivity errors between existing 8" and 16" Old Apex Road in the vicinity of Murphy Drive and Falcon Parkway. It is recommended this area be visited to determine pipe connectivity in the area.
- FF Test 20a: Gauging point 20a was located within the Maynard Loop area and it was thought that a potential closed valve or partially closed valve in the vicinity of Gage 20a may exist. Since there is an upcoming pipe replacement project in the area, it is recommended that this area be investigated for valve closures as well.
- FF Test 24: A pipe connectivity error near gauging point 24 was resolved. Two pipes appeared to be connected; however, were not actually connected in the model. These pipes were connected and the measurement at gauging point 24 improved considerably. It should be noted that the Kildaire Farm Road OCV pressure was not matched well during calibration, which continued throughout the test. A closer match of the Kildaire Farm Road OCV should result in an overall more successful calibration of Test 24. Additional calibration efforts were completed for the Kildaire Farm Road and Cary Parkway OCV during extended simulation period runs.

4.4 Extended Period Simulation (EPS) Model Calibration

After the model was calibrated for steady-state conditions, the next step was to calibrate the EPS aspect of the model. Unlike steady-state calibration, which matches field data taken from a snapshot in time, EPS calibration verifies that the model accurately simulates the

distribution system over a period of 24 hours or more. The EPS calibration ensures that the operational controls and diurnal demands are accurately incorporated into the hydraulic model.

4.4.1 Diurnal Demand Patterns

A daily diurnal demand pattern reflects the variations in water usage over a 24-hour period. This pattern depends on the type of demands that the water distribution system supplies. Commonly used demand types include commercial, industrial, and residential. After a diurnal demand pattern has been established, a clear correlation between demand magnitude and the time of day can be noted, demonstrating the maximum and minimum demand periods throughout a typical day.

4.4.1.1 Diurnal Demands By Pressure Zone

Diurnal demand patterns were developed for the WPZ, CPZ, and SPZs using SCADA historical trend data for July 23-24, 2008. A flow balance was performed using the following SCADA trend points:

- WPZ - Cary/Apex WTP HSPS flow and Carpenter ET (the Davis Drive PRV and Davis Drive BPS were off-line)
- CPZ - Cary/Apex WTP HSPS flow, Maynard ET, Ridgeview ET, Harrison ET, Field Street ET, Kildaire Farm Road OCV, and the Cary Parkway OCV (the Davis Drive PRV was and Trinity Road BPS were off-line)
- SPZ - Plumtree Way ET, Kildaire Farm Road OCV, and the Cary Parkway OCV (the Penny Road BPS and Lake Pine Master Meters were off-line)

The diurnal pattern includes peaks at varying times over the 24-hour period based on the predominant land use for the particular pressure zone or area. It should be noted that some localized areas both in the WPZ (Research Triangle Park - RTP) and CPZ (Morrisville/ Airport) required adjustments in order to achieve EPS calibration. The primary diurnal patterns used in the hydraulic model are shown in Figures 4-9, 4-10, and 4-11. The Y-axis is the pattern multiplier, which is defined as hourly demand divided by average demand for a particular day.

4.4.1.2 Equalization Requirements By Pressure Zone

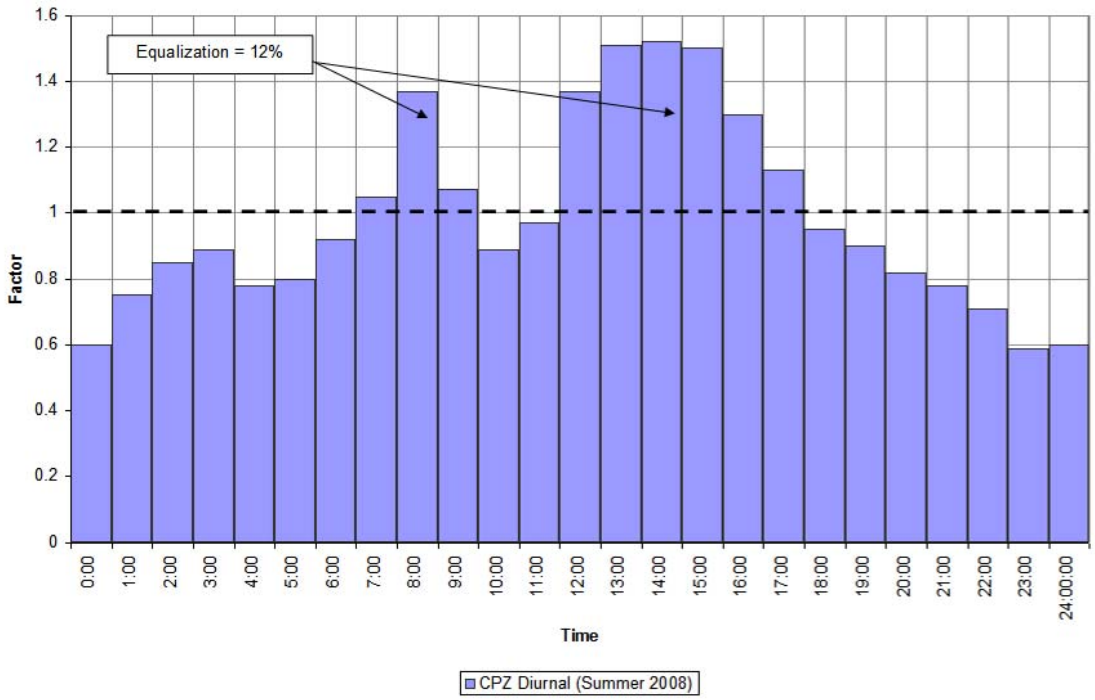
While production facilities are typically sized to satisfy maximum day demand requirements, storage tanks are sized to supply the volume of water in excess of the maximum day demand. This volume is called the operational volume or equalization component of storage. Equalization is calculated by evaluating the diurnal demand pattern for a particular pressure zone or district. An equalization factor is determined by summing the volume above the average demand or the % above the diurnal demand factor of 1.0.

Figures 4-7, 4-8, and 4-9 show the diurnal demand patterns derived for the CPZ, WPZ, and SPZs during this study. The following equalization factors were determined: CPZ (12%), WPZ (16%), and SPZ (24%).

A conservative equalization factor of 30% was utilized during the 2000 Master Plan for sizing all future storage tanks. This factor was derived from a district measurement event

conducted on the SPZ in 1998. For most water systems, equalization factors range from 10% to 15%, while small systems or systems in arid climates may have equalization factors as high as 30%[1]. For this study, the equalization percentages derived for each pressure zone are recommended for sizing future storage tanks. By studying diurnal demand patterns using smaller areas or districts within each pressure zone, additional water conservation strategies could be developed and implemented to minimize the peak hour consumption and further reduce the Town's storage equalization requirements.

FIGURE 4-7
CPZ Summer Diurnal Demand Pattern



[1] AWWA M32, Computer Modeling of Water Distribution Systems, p. 72

FIGURE 4-8
WPZ Diurnal Demand Pattern

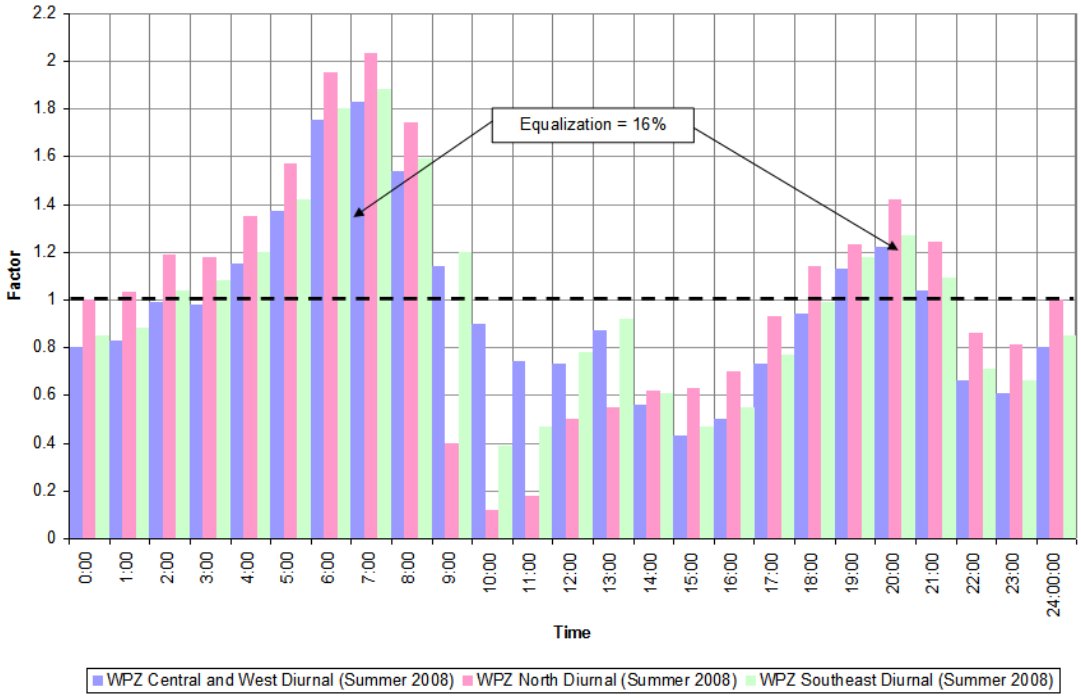
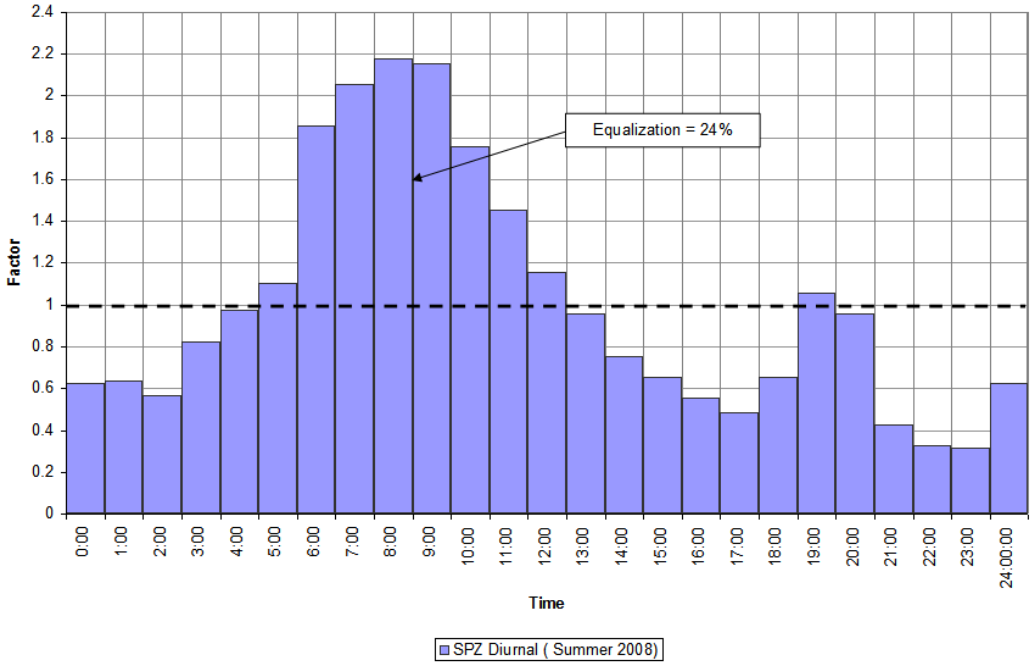


FIGURE 4-9
SPZ Diurnal Demand Pattern



4.4.2 EPS Calibration Results

The EPS calibration was performed using historical SCADA trend data from July 23-24, 2008. The Cary/Apex WTP HSPS and the Kildaire Farm Road and Cary Parkway OCVs are manually controlled. For this reason, a time-based control was entered into the model to match those that occurred on July 23-24, 2008.

Both the CPZ and WPZ flow meters at the HSPS were reported to be calibrated during the week of May 12, 2008. For this reason, the SCADA trend data provided by the Town was assumed to be accurate and suitable for calibration.

Four factors were used to evaluate the accuracy of the EPS calibration: elevated tank levels, HSPS flows, HSPS pressures, and control valve flows. In most cases, the model corresponded well with the provided SCADA data after minor refinements to the model. The average difference between the model and field hourly tank level data was typically within four feet. Figures 4-10 through 4-12 display the EPS calibration results for the elevated tank level comparisons (tank level converted to head in msl).

4.4.2.1 EPS Calibration (WPZ)

A small discrepancy between the model and SCADA data was observed for the Cary/Apex WTP HSPS WPZ header flow and pressure. For this reason, the WPZ pump curve was slightly de-rated to provide a better match between the model and SCADA data. As shown in Figure 4-10, the simulated tank level for the Carpenter Elevated Tank was within 1-ft of the SCADA trend data during most of the second day of calibration. At hour 40, only a 3-ft difference in water levels existed.

It is recommended that the Town perform a desktop analysis of the WPZ high service pump curves by downloading a years worth of hourly SCADA data for the following trend points: WPZ discharge header pressure, WPZ discharge header flow, and clear-well level. Using the elevations for the bottom of clear-well and the discharge header pressure indicated transmitter (PIT), the hourly pump head can be plotted for a years worth of SCADA data which will define the actual profiles of the two WPZ high service pumps.

4.4.2.2 EPS Calibration (CPZ)

A discrepancy was not observed between the model and SCADA data for the CPZ pumps. The model and SCADA flow and pressure data at the Cary/Apex HSPS CPZ header were in close agreement.

As shown in Figure 4-11, the elevated tank level data from SCADA was converted to head based on the estimated bottom of bowl elevations. On July 24, 2008, it appears that the Harrison Elevated Tank operated on average 5-ft higher than the Field Street and Maynard Elevated Tanks and 12-ft higher than the Ridgeview Elevated Tank. The Harrison Elevated Tank modeled head was within 2-3 feet of the SCADA data. The Field Street Elevated Tank modeled head was on average 2-6 feet higher than the SCADA data. The Maynard Elevated Tank modeled head was 2-6 feet lower than the SCADA data. And the Ridgeview Elevated Tank modeled head was on average 2 feet higher than the SCADA data. More importantly the Maynard and Ridgeview modeled head was identical while there was a 6-7 foot separation in the SCADA head values.

There are three plausible reasons why there is no separation in the Maynard and Ridgeview SCADA modeled head values while a 6-7 foot separation results from the SCADA data: 1) inaccurate bottom of bowl elevation for the Maynard Elevated Tank (built in 1966), 2) closed or partially closed valve on a key trunk main, and 3) error in the diurnal demand for this area of the model. Closing a 12-inch main in the model along Kildaire Farm Road resulted in some separation in the Maynard and Ridgeview Elevated Tank but the results were not conclusive. The assumed model error in the Maynard Elevated Tank head values was considered acceptable this master planning effort because they were lower than the SCADA data which would add a level of conservatism in the model simulations. However, further refinement of the district diurnal curves and verifying the bottom of bowl elevation for the Maynard Elevated Tank is recommended. As well, record drawings for the Field Street Elevated Tank should be reviewed to ensure that the yard piping matches the model configuration.

4.4.2.3 EPS Calibration (SPZ)

During the initial EPS calibration for the SPZ, it appeared that the Cary Parkway flowmeter data from SCADA did not match model simulations. Discussion with Town staff indicated that the Cary Parkway flow meter was malfunctioning on July 23-24, 2008. For this reason, the Town provided additional flow data after the meter was repaired. Comparing the model and SCADA flow and pressure data for both the Kildaire Farm Road and Cary Parkway OCVs revealed a close match. As shown in Figure 4-12, the model and SCADA tank head values were in good agreement with only a 2-3 feet difference.

FIGURE 4-10
Model vs. Field Tank Level Comparison (WPZ)

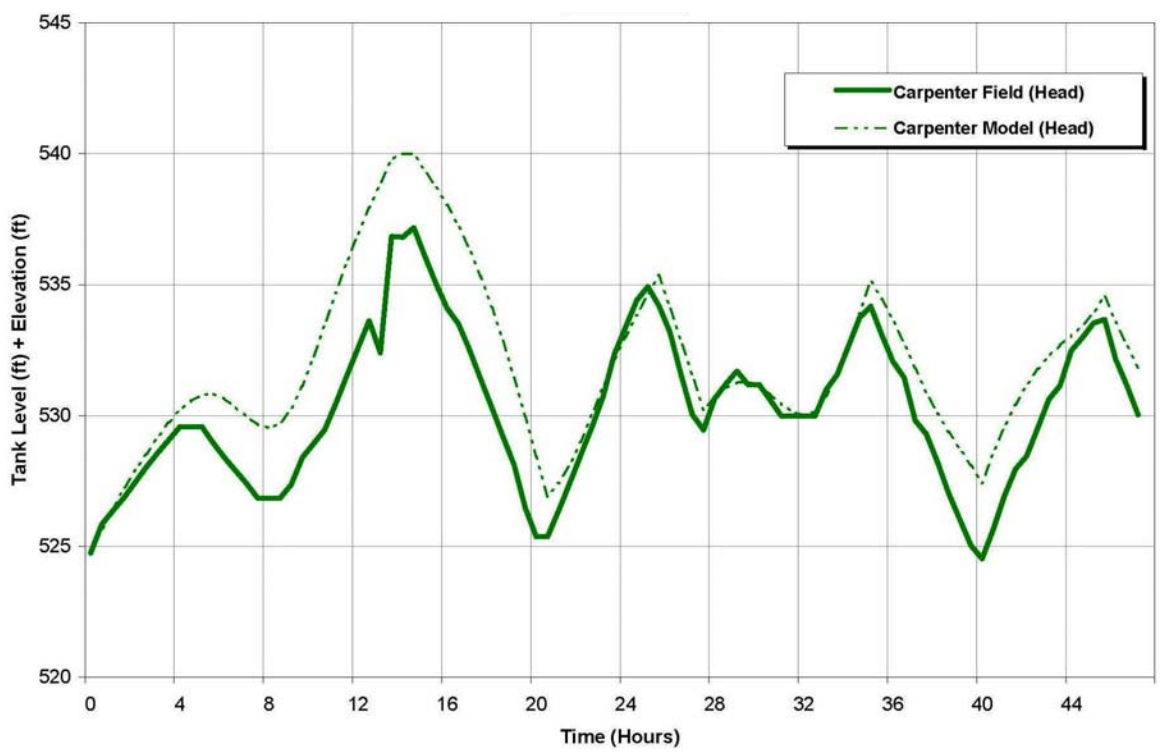


FIGURE 4-11
Model vs. Field Tank Level Comparison (CPZ)

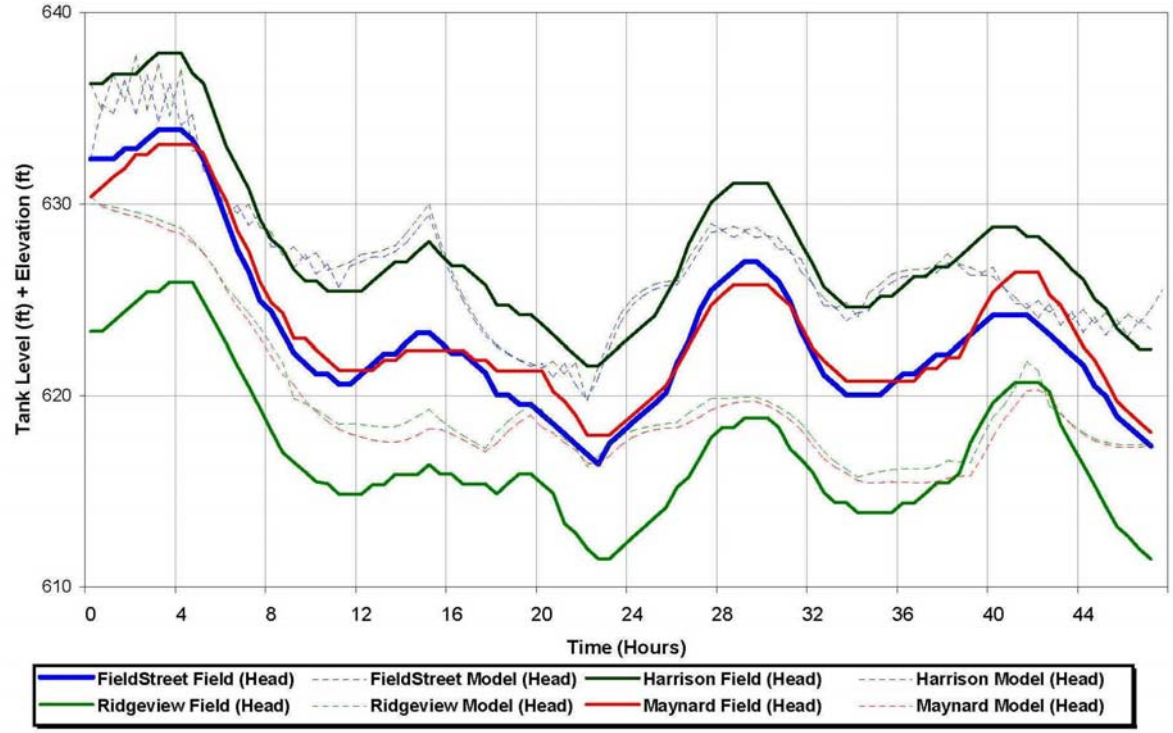
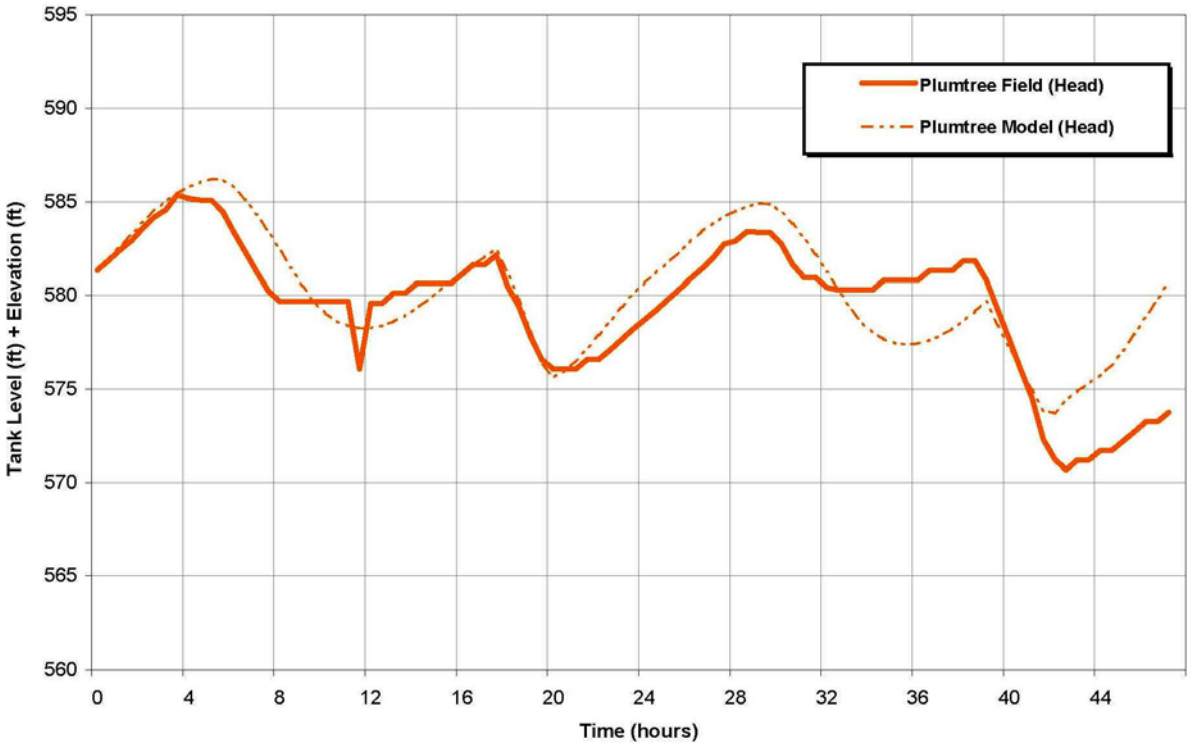



FIGURE 4-12
Model vs. Field Tank Level Comparison (SPZ)