CHAPTER 6

WATER SYSTEM HYDRAULIC ANALYSIS

INTRODUCTION

The operation of the District's municipal water system involves a variety of interactions among various water system components, including source, storage, transmission, and distribution system facilities. These interactions and their effect on the level of service provided to the District's customers are dependent on the distribution and magnitude of water demands within the system and the performance characteristics of the water system. In addition to normal diurnal demands, infrequent demand events, such as fire flows, can create significant stress on the water system. Such factors must be considered in analyzing the ability of the water system to meet future demands while maintaining the minimum system pressure required by the Department of Health.

The development of a computer hydraulic model, which can simulate the response of a water system under a variety of conditions, has become an increasingly important element in the planning, design, and analysis of municipal water systems. WAC 246-290 requires hydraulic modeling as a component of water system comprehensive plans. This chapter presents the development and use of a computer hydraulic model for the District's water system.

HYDRAULIC MODELING PROGRAM

The hydraulic mode of the District's water system was constructed using Innovyze's H_2ONet hydraulic modeling software, which operates in an AutoCAD computer-aided design and drafting environment. The H_2ONet model is configured with a graphical user interface. Each model element, including pipes, valves, pumps, and tanks, is assigned a unique graphical representation within the program. Each element is also assigned a number of attributes specific to its function and representation. Element attributes include spatial coordinates, elevation, water demand, pipe length, diameter, and pipe status, as well as pump and tank characteristics. Model input is accomplished through the creation and manipulation of these objects and their attributes. The H_2ONet modeling package also includes a number of tools that facilitate the presentation of model results. The results for a given simulation can be presented either graphically or in a tabular report format to indicate flow, demand, pressure, headloss, and hydraulic grade for various system elements.

The hydraulic model can be utilized to simulate two primary types of scenarios. A steady state analysis can be used to evaluate the conditions in the system instantaneously, or an extended period analysis can be run to simulate the changing conditions of the system over time. The steady state analysis determines pipe flows and system pressures according to a specified system demand, configuration, and operational conditions. The steady state analysis is a useful tool for looking at how the system responds to high-demand events, such as analyzing the available fire flow in the system.

The extended period analysis models the water system's continuous response and performance over a defined period of time and simulates the water system's response according to real time variations in demands and operation. As system conditions and demands change within the District during the extended period analysis, the SPU connections and booster pumps are activated and deactivated according to predetermined set points. Storage facilities respond by filling or emptying as required.

HYDRAULIC MODEL DEVELOPMENT

The District's model realistically represents the current water system and includes elements representing reservoirs, pipes, pumps, valves, master meter connections, and junction nodes, which establish points of connection between pipes. Input information for each of these elements must be as accurate as possible in order to develop a realistic representation of the water system as a whole.

MODEL LAYOUT AND CONSTRUCTION

The District's model was developed in 1999 and has been periodically updated as the District and developers complete projects. The following sections provide a description of how each type of facility is modeled. District operations staff provided the operational settings for the master meters, booster stations, and pressure reducing valve stations. Model element elevations are based on the contour maps and record drawings provided by the District.

Water Supply

The District has seven physical connections to the SPU transmission system. These seven connections to SPU are modeled in H_2O Net as infinite supply, fixed-head tanks with flow control valves in place to limit the flow rates into the District's system. Flow control valves are located at Master Meters No. 5A and 5B; one directs flows to the 380 Zone (Westhill Standpipe), and the other directs flows to the 537 Zone (Inglemoor Reservoirs).

The SPU connections are modeled with a constant hydraulic grade within each alternative. Two SPU connection alternatives are included in the model, one for the average day hydraulic grade and the other for the maximum day hydraulic grade. Table 6-1 provides the hydraulic grade for each master meter connection and the flow setting to the District.

TABLE 6-1

Master Meter Settings and SPU Hydraulic Grade

Metered Site Names	Master Meter	Zone Supplied	Flow Setting (gpm)	Tolt Pipeline HGL(1)(2) (ft) 2014 Avg. Day	Tolt Pipeline HGL(1)(2) (ft) 2014 Max Day
TESSL	No. 1	446 (451)	500-1,000	690	661
119th Avenue NE	No. 2	446 (451)	2,500	698	584
112th Avenue NE	No. 3	451	2,000-2,500	705	626
104th Avenue NE	No. 4	601	1,000-1,500	692	602
Westhill Standpipe	No. 5A	380	2,500	708	607
Westhill ING	No. 5B	537	3,000-3,500	708	607
NE 185th Street	No. 6	473	500	Not Measured	Not Measured
LFP	No. 7	530	2,500	705	603

(1) Datum is NAVD 88.
(2) Average HGL in SPU system as measured in 2014. Maximum day HGL in SPU system as measured in 2014.

SPU has a contractual minimum for planning purposes. According to recent correspondence with SPU, the District can use the existing hydraulic grade for planning purposes.

Reservoirs and Standpipes

In H_2ONet, reservoirs and standpipes are modeled as cylindrical tanks using actual facility dimensions and elevations. All eight of the District's reservoirs are included in the model. Reservoir elevation and dimensions are included in Table 4-2.

Automatic Control Valves

Automatic control valves in H_2ONet are modeled as points that can provide a single function, such as a PRV, pressure sustaining valve, or flow control valve.

Most of the District's PRV stations have two or more PRVs in parallel. The smaller diameter PRVs are set to provide flow under normal operating conditions, and the larger PRVs are set to open during high-demand scenarios such as fire flow, when the smaller PRV can no longer meet the necessary pressure requirements. All PRVs are included in the model, but typically only the smaller PRVs operate. PRV settings included in the model are based on measured pressures at each PRV station.

Booster Stations

Pumps in H_2ONet are modeled by entering a pump curve and providing operational settings, such as on and off set points. The District's model includes the pumps for the Inglemoor, Norway Hill, and Lake Forest Park Booster Stations. Pump curves for all pumps have been included in the model. Operational set points in the model are based on the flow rates provided in Table 6-1 and the reservoir levels provided in Table 7-4. The Inglemoor Booster Station pumps are controlled by the level in the Inglemoor Standpipe per the Inglemoor pump matrix.

During normal operation, the Inglemoor and Lake Forest Park Booster Stations operate while the Norway Hill Booster Station does not operate.

SYSTEM DEMANDS

Several demand alternatives are included in the District's model in order to assess the water system at different conditions. These demand alternatives are based on the projected system demands as provided in Table 5-16, including average day, maximum day, and peak hour demands.

Existing System

For existing system modeling scenarios, historical records of actual customer consumption are used to spatially distribute domestic demands. Once distributed, demands are uniformly increased so that the total modeled demand equals the projected 2014 average day demand. This set of demands is considered the "baseline" for creating additional demand scenarios. For each model node, maximum day demand equals 2.0 times the average day demand, and peak hour demand equals 2.0 times the maximum day demand as established in Chapter 5.

Future Growth

Future demand scenarios for the 6-year, 20-year, and buildout planning periods are created by uniformly increasing the demands within each TAZ from the baseline demand to the future demand. This method distributes future demands within the actual area of the District that growth is predicted.

MODEL CALIBRATION

The calibration of a hydraulic model provides a measure of assurance that the model is an accurate and realistic representation of the actual system. The hydraulic model of the District's system has been calibrated using data obtained from 36 hydrant tests initially conducted on March 18-20, 2014, with the assistance of District staff. Additional testing of five hydrants in the 366 Zone was conducted August 28, 2014. During the tests, static and residual pressures were recorded as District staff opened hydrants and recorded the flow rates. Field results have been used to calibrate the hydraulic model through verification and adjustment of pipe type, sizes, roughness coefficients, PRV settings, and junction elevations.

System conditions during each hydrant test were recorded, including reservoir levels, master meter flow rates, and booster station status. Using the system conditions for each hydrant test, the hydraulic model has been used to generate static pressure and residual pressure at the measured flow rate. The domestic demands used during the calibration process are based on the actual flow rates as measured by the SCADA system during the two-day testing period. Model output has been generated at points in the model equivalent to the locations of the hydrants tested.

Static pressure results are generated by running the model with only average day domestic demands. Residual pressure results are generated by placing an additional demand at the location of the hydrant test equal to the measured flow.

The system pressures and pipe flow rates determined in the calibration process are highly dependent on the friction loss characteristics established for each pipe. The friction losses occurring in lengths of pipe, fittings, and isolation valves are accounted for in the hydraulic model. The friction factors for the model pipes are adjusted throughout the calibration process until the model output best approximates the measured values. Hazen-Williams C-factors (a measure of pipe friction) between 110 and 130 are used throughout the system. These friction factors are typical for most pipe types and are generally conservative. The friction factors for the pipe also compensate for system losses through valves and pipe fittings.

The model output has been produced for two data comparisons, static pressure and residual pressure. Table 6-2 provides the measured flow rates, static pressure and residual pressure, and the modeled static and residual pressure. Calibration of the hydraulic model produced results that vary from 0 to 5 psi of actual field test data for static pressure. Most modeled residual pressures are within 5 psi of the measured residual pressure, however four hydrants were outside of that range, but still within 9 psi of field results. Hydraulic models are recommended to be within 5 psi of measured pressure readings for long-range planning, according to the DOH, Water System Design Manual, Table 8-1. The four hydrants outside of this range are accepted for this calibration though. Two of these four hydrants registered a lower residual pressure in the model than what was recorded in the field, and are thus accepted as conservative data points. The other two hydrants that fall outside of the 5 psi range had residual pressures higher than field conditions, however they are each located in large zones in which multiple other hydrants were tested, indicating that the model inconsistencies are localized.

TABLE 6-2

Model Calibration Results

Zone	Flowing Hydrant Location	Static Pressure (psi)		Residual Pressure (psi)		Field Flow (gpm)	Δ Static, Field to Model, psi	Δ Resid., Field to Model, psi	Δ Resid., Field to Model, %	Pressure Node	Flow Node 1	Flow Node 2
		Field	Model	Field	Model							
342	NE 180th Street at 57th Avenue NE	108	112	97	98	1,472	-4	-1	1%	J6-320	J6-321	NA
342	81st Lane NE and NE 179th Place	127	133	118	122	1,678	-6	-4	3%	J116	J272	NA
366	Holmes Pt. Drive NE near O.O. Denny Park	130	136	113	114	1,635	-6	-1	1%	J13-3500	J13-989	NA
366	NE 126th Place west of 98th Avenue NE	118	121	109	114	1,453	-3	-5	4%	J13-510	J13-512	NA
366	105th Place NE and NE 125th Place	90	90	81	84	1,416	0	-3	3%	J13-322	J13-321	NA
366	NE 128th Street west of 109th Avenue NE	86	85	74	81	1,353	1	-7	9%	J13-460	J13-464	NA
366	NE 141st Place and 111th Avenue NE	89	88	71	66	1,061	1	5	7%	J13-843	J13-977	NA
380 N	NE 204th Street west of 77th Avenue NE	82	80	72	68	1,267	2	4	6%	J7-100	J7-270	NA
380 N	NE 193rd Street at 86th Place NE	44	46	38	41	957, 839	-2	-3	8%	J7-267	J7-158	J7-159
380 S	Dead end of Totem Lake Way	88	90	72	72	1,379	-2	0	1%	J22-116	J22-122	NA
405	64th Place NE and NE 153rd Street	70	70	48	49	1,061	0	-1	3%	J276	J9-142	NA
420	Dead end of 99th Place NE south of NE 151st Street	118	121	92	91	1,477	-3	1	1%	J13-1102	J13-1106	NA
425	81st Avenue NE b/w NE 115th and 114th Street	75	74	54	53	1,186	1	1	2%	J19-121	J19-110	NA
435	NE 192nd Street and 37th Avenue NE	86	82	71	70	1,300	4	1	1%	J1-135	J1-134	NA
440	NE 129th Street northeast of 64th Avenue NE (6430 NE 129th Street)	110	113	95	92	1,657	-3	3	3%	J17-112	J17-101	NA
446W	84th Avenue NE and NE 163rd Street	50	49	36	39	1,028	1	-3	7%	J12-117	J12-113	NA
446E	NE 140th Street and 121st Avenue NE	53	53	42	47	839	0	-5	11%	J16-239	J16-653	NA
446E	118th Avenue NE and NE 167th Street	52	53	42	46	993, 839	-1	-4	10%	J16-476	J16-477	J16-652
450	73rd Place NE south of NE 120th Street	110	112	95	89	1,547	-2	6	7%	J18-122	J18-118	NA
473	NE 198th Street and 64th Avenue NE	107	110	97	93	1,570	-3	4	5%	J5-158	J270	NA
485	Private drive at end of NE 151st Street	52	53	34	34	957	-1	0	0%	J10-110	J10-101	NA
495	NE 135th Lane and 94th Place NE	72	73	58	61	993	-1	-3	6%	J21-111	J21-107	NA
529	112th Place NE and NE 164th Place	123	118	106	106	1,635	5	0	0%	J15-114	J15-113	NA

TABLE 6-2 – (continued)

Model Calibration Results

Zone	Flowing Hydrant Location	Static Pressure (psi)		Residual Pressure (psi)		Field Flow (gpm)	Δ Static, Field to Model, psi	Δ Resid., Field to Model, psi	Δ Resid., Field to Model, %	Pressure Node	Flow Node 1	Flow Node 2
		Field	Model	Field	Model							
530 N	NE 200th Place east of 55th Avenue NE	100	104	80	76	1,482	-4	4	5%	J4-121	J4-123	NA
530 S	52nd Avenue NE and NE 190th Street	61	61	55	57	1,028, 1,028	0	-2	4%	J2-133	J2-134	J2-139
601E	NE 155th Place and 102nd Avenue NE	151	154	138	129	1,678, 1,609	-3	9	7%	J274	J14-105	J14-170
601W	75th Avenue NE and NE 153rd Place	66	66	59	59	1,186, 1,216	0	0	0%	J11-1370	J11-1290	J11-196
601W	NE 140th Street east of 75th Avenue NE	87	87	80	84	1,379	0	-4	5%	J280	J278	NA
601W	NE 137th Place and 87th Avenue NE	80	81	70	78	1,150, 993	-1	-8	11%	J11-531	J11-663	J11-661
601W	92nd Place NE and 92nd Court NE	80	82	73	76	1,379	-2	-3	4%	J11-260	J11-258	NA
601W	NE 125th Street and 80th Avenue NE	96	98	89	89	1,477, 1,353	-2	0	0%	J11-892	J11-893	J11-902

MODELED SCENARIOS AND RESULTS

The District's hydraulic model is used as a tool for assessing the hydraulic capacity of the transmission and distribution system. An analysis of the water system's ability to maintain adequate system pressure, provide fire flows, and operate during emergency conditions was conducted. The following sections describe the three types of analyses modeled and provide output results.

PEAK HOUR ANALYSIS

Water systems must maintain a minimum pressure of 30 psi in the distribution system under peak hour demand conditions in accordance with WAC 246-290-230(5). During peak hour analyses, all operational and equalizing storage is depleted from the District's reservoirs. Reservoir storage volumes are provided in Tables 7-10, 7-11, and 7-12. The hydraulic model has been used to evaluate the system's ability to provide adequate service pressure. The District's distribution system has been modeled with the peak hour demand conditions provided in Table 6-3.

TABLE 6-3

System Conditions during 2034 Peak Hour Analyses

Condition	Value
Domestic Demands	2034 Peak hour demands, per Table 5-16
Source Conditions	SPU Maximum day HGL, per Table 6-1. All master meters operating.
Booster Station Status	Inglemoor Booster Station ON, Lake Forest Park Booster Station ON Norway Hill Booster Station OFF
Inglemoor Standpipe Water Level	84.1 feet
Inglemoor Reservoirs Water Level	32.8 feet
Norway Hill Reservoir Water Level	25.0 feet
Kingsgate Standpipe Water Level	82.0 feet
Westhill Standpipe Water Level	110.0 feet
Lake Forest Park Reservoir Water Level	24.3 feet

(1) Reservoirs are depleted of operational and equalizing storage, per Tables 7-3 and 7-4.

Hydraulic deficiencies have been identified under 2034 peak hour conditions. Table 6-4 provides the minimum system pressure during peak hour for each pressure zone that is served directly by a reservoir or a booster station. The omitted pressure zones are served by pressure reducing valve stations and do not experience significant pressure fluctuations during peak hour scenarios.

TABLE 6-4

Minimum System Pressures During 2034 Peak Hour Analyses

Pressure Zone	2034
Inglemoor (601 Zone)	35
Norway Hill/Kingsgate (451 Zone)	32
Westhill (380 Zone)	42
Lake Forest Park (530 Zone)	46
Lake Forest Park (640 Zone)	56

FIRE FLOW ANALYSIS

The hydraulic model has been used to assess the availability of fire flows throughout the District. WAC 246-290-230 (6) requires systems providing fire flow to be designed to provide maximum daily demand plus the required fire flow, while maintaining minimum system-wide pressures of 20 psi. In addition, operational, equalizing, and fire-suppression storage are depleted from the District's reservoirs for these analyses. Reservoir storage volumes are provided in Tables 7-10, 7-11, and 7-12. Existing facilities and distribution mains have been modeled for future peak hour and fire flow scenarios. The District's distribution system has been modeled with the fire flow conditions provided in Table 6-5.

TABLE 6-5

System Conditions During Fire Flow Analyses

Condition	Value
Domestic Demands	2034 Maximum day demands, per Table 5-16
Source Conditions	SPU Maximum day HGL, per Table 6-1. All master meters operating.
Booster Station Status	Inglemoor Booster Station ON, Lake Forest Park Booster Station ON Norway Hill Booster Station OFF
Inglemoor Standpipe Water Level	76.9 feet
Inglemoor Reservoirs Water Level	30.0 feet
Norway Hill Reservoir Water Level	23.6 feet
Kingsgate Standpipe Water Level	66.7 feet
Westhill Standpipe Water Level	89.5 feet
Lake Forest Park Reservoir Water Level	20.7 feet

(1) Reservoirs are depleted of all operational, equalizing, and fire suppression storage, per Tables 7-3, 7-4 and 7-5.

In general, the existing water system has sufficient capacity to provide fire flows throughout the service area. Several areas of the District have fire flow requirements greater than 1,500 gpm. Table 6-6 provides the fire flow modeling results for areas that have a fire flow requirement greater than 1,500 gpm.

TABLE 6-6

Available Fire Flows at High Required Fire Flow Locations

Location	Junction Node	Zone	Required Flow (gpm)	Available Flow[(1)] (gpm)
Moorlands Elementary School	J11-217	601	4,000	>5,000
Inglemoor High School	J11-246	601	3,000	3,800
Inglewood Village Shopping Center	J11-620	601	3,500	>5,000
Thoreau Elementary School	J11-650	601	3,500	>5,000
Juanita Elementary School	J13-1006, J13-1003	366	4,900	>5,000
Juanita Village	J13-196	366	2,800	>5,000
Walgreens	J13-197	366	1,600	>5,000
Avalon-Juanita Village	J13-200	366	2,625	>5,000
Market Place	J13-211	366	3,000	>5,000
Holy Spirit Lutheran Church	J13-281	366	3,000	>5,000
Center 405 Office Building	J13-376	366	3,500	4,800
Marriott	J13-399	366	4,900	>5,000
Casa Lupita	J13-399	366	3,000	>5,000
Totem Lake West	J13-408	366	3,250	>5,000
Villa Bonita	J13-533	366	3,000	>5,000
Albertson's	J13-643	366	3,000	>5,000
Juanita Auto Rebuild	J13-689	366	3,000	>5,000
Safeway Store	J13-693	366	3,500	>5,000
Safeway	J13-707	366	2,250	>5,000
Eastside Four Square Church	J13-867	366	2,000	>5,000
Cedar Park High School	J15-101	529	2,500	>5,000
Evergreen Plaza	J16-105	446	2,600	4,200
Evergreen Heights Building	J16-131	446	2,500	4,200
EHMC ER Expansion	J16-141	446	2,625	4,200
Ream Office Building	J16-422	446	2,500	>5,000
Northshore Junior High School	J16-425	446	2,000	>5,000
Orcas Moon	J16-459	446	2,000	>5,000
Woodmoor Elementary School	J16-516	446	2,500	>5,000
Chelsea Court II	J22-106	380	2,500	4,100
Heritage 17 Unit Apartments	J6-220	342	3,500	>5,000
James Murphy Co.	J6-221	342	3,000	>5,000
Kenmore Apartments	J6-239	342	2,250	>5,000
Northshore House	J6-249	342	3,000	>5,000
Inglewood Square	J6-372	342	3,000	>5,000
Knoll Lumber	J6-386	342	5,000	>5,000
Kenmore Village Apts.	J6-413	342	3,000	>5,000
Bothell Public Storage	J6-423	342	2,500	>5,000
Bothell United Methodist Church	J7-199	380	3,000	>5,000
Bothell High School	J7-219	380	3,000	>5,000

(1) Available fire flow while maintaining 20 psi minimum system pressure. This does not reflect availability while applying a velocity limitation.

There are a number of hydrants in residential areas that do not meet the required fire flow. Within the City of Kirkland, the required minimum residential fire flow is 1,000 gpm. In the other jurisdictions served, including Lake Forest Park, Kenmore, and Bothell, the minimum residential fire flow requirement is 1,500 gpm. Table 6-7 summarizes the nodes that do not meet residential fire flow requirements. The majority of the deficient hydrants are located on dead end water mains.

TABLE 6-7

Residential Locations with Deficient Fire Flow

Location	Model Node	Zone	Req'd Flow (gpm)	Available Flow(1) (gpm)	Flow Deficiency (gpm)	Capital Improvement Project	2034 Flow w/CIPs (gpm)
NE 140th Street and 98th Avenue NE	J11-513	366	1,000	812	188	8-inch to hydrant	1,563
86th Avenue NE north of NE 190th Street	J7-165	380	1,500	1,114	386	8-inch to hydrant	2,327
89th Avenue NE north of NE 192nd Place	J7-211	380	1,500	1,466	34	8-inch to hydrant	2,204
NE 154th Street and 61st Place NE	J9-145	405	1,500	1,466	34	Adjust Zone HGL up by 15 psi	1,981
61st Place NE and NE 152nd Street	J9-146	405	1,500	1,328	172		1,785
NE 152nd Street and 62nd Avenue NE	J9-147	405	1,500	1,148	352		1,543
NE 194th Street east of 37th Avenue NE	J1-127	435	1,500	1,409	91	8-inch to hydrant	1,852
NE 141st Way and 125th Avenue NE	J16-357	451/ 446	1,000	813	187	8-inch to hydrant	1,150
NE 151st Street last hydrant	J10-101	485	1,500	1,394	106	Adjust Zone HGL up by 5 psi	1,534
NE 200th Place west of 55th Avenue NE	J4-125	530 N	1,500	1,103	397	8-inch to hydrant	1,539
NE 196th Court east of 40th Place NE	J2-119	530 S	1,500	691	809	8-inch to hydrant	2,902
NE 139th Street west of 70th Avenue NE	J11-963	601	1,000	907	93	8-inch to hydrant	1,595
NE 139th Street and 71st Place NE	J11-966	601	1,000	872	128	8-inch to hydrant	1,553

(1) Available flow while maintaining 20 psi minimum system pressure. This does not reflect availability while applying velocity limitations.

Capital improvement projects to address these deficiencies are included in Chapter 10.

A figure showing the available fire flow rates is provided in the back sleeve of the Plan, and full model results are included in Appendix I.

ADDITIONAL MODELING ANALYSES

The hydraulic model is a useful tool in evaluating system configuration changes or the system's vulnerability during emergency conditions. The following sections describe additional modeling that has occurred since the last WSP.

425-450 Zones PRV Analysis

The District had concerns about the condition of several PRV stations and water quality within the 425 and 450 Zones, which are located in the southwest part of the system, and are supplied by the 601 Zone and can supply the 366 Zone through PRVs. Modeling determined that the zones could be combined with little impact to service pressures, and that water age would decrease on average, thus reducing the potential for water quality problems.

451 Zone Regional Vault

The District is moving forward with relocating several control valve and master meter stations into a regional vault. The vault will be located at 112th Avenue NE north of the Tolt Pipeline and will include Master Meter No. 3, PRV Site 46 (Tolt, 451/446, and 529 Zones), and will be plumbed to include PRV Site 47 as well.

Alternate Inglemoor Transmission Main

An alternate transmission supply line to the Inglemoor Tank Farm Site has been investigated. Preliminary testing was conducted in August 2014 to serve the site from Master Meter No. 4 at 104th Avenue NE. Field testing and model verification indicate that this is an option, however some additional pipe may need to be installed to maintain looping and available flow capacity if piping needs to be isolated between 104th Avenue NE and Inglemoor.

SUMMARY OF HYDRAULIC CAPACITIES AND DEFICIENCIES

The District's water distribution system has sufficient capacity through the 20-year planning period to provide peak hour demands and fire flow demands while maintaining adequate service pressures throughout most of the system. There are isolated residential areas that cannot supply sufficient fire flow. In general, the distribution system is well looped to minimize pipe velocities and provide redundancy.