

## **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 an adequate level of customer service.

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 MWSOft's H<sub>2</sub>O<sub>Net</sub> hydraulic modeling software, which operates in an AutoCAD computer-aided design and drafting environment. The H<sub>2</sub>O<sub>Net</sub> 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<sub>2</sub>O<sub>Net</sub> 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 connections 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<sub>2</sub>O 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 Reservoir), 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 as measured in 2005. 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**

Master Meter	Supply Zone	Flow Setting (gpm)	Tolt Pipeline HGL <sup>(1)(2)</sup> (ft)		
			Average Day	Maximum Day	Contract Minimum
MM No. 1	451 Zone	1,500	700	630	565
MM No. 2	451 Zone	1,500	700	623	570
MM No. 3	451 Zone	2,500	696	612	565
MM No. 4	601 Zone	300	692	602	560
MM No. 5A	380 Zone	1,000	687	591	555
MM No. 5B	537 Zone	3,000	687	591	555
MM No. 6	473 Zone	0	678	576	540
MM No. 7	530 Zone	2,500	674	566	535

(1) Datum is NGVD 1929.

(2) Average HGL in SPU system as measured in 2005. Maximum day HGL in SPU system as measured in August 2005.

**Reservoirs and Standpipes**

In H<sub>2</sub>O<sub>Net</sub>, 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<sub>2</sub>O<sub>Net</sub> are modeled as points that can provide a single function, such as a pressure reducing valve (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 a fire, when the smaller PRV can no longer maintain the necessary hydraulic grade. 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**

Booster pumps in H<sub>2</sub>O<sub>Net</sub> are modeled by entering a pump curve and providing operational settings, such as on and off set points. The District’s model includes 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 sets of demands are included in the District's model in order to assess the water system at different conditions. These demands are based on the projected system demands as provided in Table 5-16, including average day, maximum day, and peak hour demands.

### **Existing System**

Historical records of customer consumption are used to spatially distribute domestic demands. Once distributed, demands are uniformly increased so that the total modeled demand equals the projected 2006 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 fire hydrant tests at various locations throughout the water system. Twenty fire hydrant tests were conducted, with the assistance of District staff, on July 21 and 22, 2004. During these 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, and 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 hydrant tests.

Static pressure results are generated by running the model with only 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 150 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. Modeled residual pressures are within 4 psi of the measured residual pressure. Hydraulic models are required to be within 5 psi of measured pressure readings for long-range planning, according to the DOH, Water System Design Manual, Table 8-1.

**TABLE 6-2**

**Calibration Results**

Test No.	Flow (gpm)	Static Pressure (psi)			Residual Pressure (psi)		
		Field	Model	Difference	Field	Model	Difference
1	1,270	81	85	-4	60	60	0
2	1,270	93	93	0	87	83	4
3	1,300	90	91	-1	83	81	2
4	1,630	108	112	-4	103	106	-3
5	1,450	76	78	-2	68	65	3
6	1,060	43	42	1	40	39	1
7	1,650	145	146	-1	141	138	3
8	1,330	78	79	-1	72	73	-1
9	1,060	73	74	-1	67	68	-1
10	1,090	84	83	1	80	78	2
11	1,340	82	79	3	78	75	3
12	890	44	49	-5	42	44	-2
13	980	54	59	-5	53	56	-3
14	930	49	48	1	34	38	-4
15	990	56	57	-1	53	56	-3
16	1,060	81	81	0	78	80	-2
17	1,090	130	129	1	120	116	4
18	1,190	115	117	-2	111	114	-3
19	1,270	79	79	0	76	77	-1
20	1,270	91	93	-2	88	92	-4

**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 Peak Hour Analyses**

<b>Condition</b>	<b>Value</b>
Domestic Demands	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	74 feet
Inglemoor Reservoirs Water Level	30 feet
Norway Hill Reservoir Water Level	18 feet
Kingsgate Standpipe Water Level	88 feet
Westhill Standpipe Water Level	110 feet
Lake Forest Park Reservoir Water Level	21 feet

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

Peak hour analyses do not reveal any hydraulic deficiencies. 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 Peak Hour Analyses**

<b>Pressure Zone</b>	<b>2006</b>	<b>2012</b>	<b>2026</b>
Inglemoor (601 Zone)	32 psi	32 psi	32 psi
Norway Hill/Kingsgate (451 Zone)	39 psi	39 psi	39 psi
Westhill (380 Zone)	40 psi	40 psi	40 psi
Lake Forest Park (530 Zone)	45 psi	45 psi	45 psi
Lake Forest Park (640 Zone)	49 psi	49 psi	49 psi

**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 peak 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	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	74 feet <sup>(2)</sup>
Inglemoor Reservoirs Water Level	24 feet <sup>(2)</sup>
Norway Hill Reservoir Water Level	10 feet
Kingsgate Standpipe Water Level	80 feet
Westhill Standpipe Water Level	89 feet
Lake Forest Park Reservoir Water Level	18 feet

- (1) Reservoirs are depleted of all operational, equalizing, and fire suppression storage, per Tables 7-4, 7-5, and 7-6.
- (2) Fire flow storage is removed from the Inglemoor Reservoirs but not the Inglemoor Standpipe, because the Inglemoor Booster Station is able to maintain a water level of 74 feet in the standpipe.

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 commitment greater than 1,500 gpm.

**TABLE 6-6****Available Fire Flows at High Fire Flow Locations**

<b>Location</b>	<b>Junction Node</b>	<b>Zone</b>	<b>Required Flow (gpm)</b>	<b>Available Flow<sup>(1)</sup> (gpm)</b>	<b>Flow Deficiency</b>
Knoll Lumber	J6-386	342	5,000	8,100	No
Marriott	J13-399	366	4,900	5,000	No
Moorlands Elem. School	J11-217	601	4,000	11,400	No
Juanita Elementary School	J13-642	366	3,634	4,900	No
Heritage 17 Unit Apartments	J6-220	342	3,500	7,500	No
Inglewood Village Shopping Center	J11-620	601	3,500	5,500	No
Safeway Store	J13-693	366	3,500	4,700	No
Center 405 Office Building	J13-442	366	3,500	5,000	No
Thoreau Elementary School	J11-650	601	3,500	7,800	No
Totem Lake West	J13-408	366	3,250	5,100	No
Albertson's	J13-643	366	3,000	4,900	No
Casa Lupita	J13-399	366	3,000	5,000	No
Inglemoor High School	J11-246	601	3,000	3,700	No
Inglewood Square	J6-372	342	3,000	6,900	No
James Murphy Co.	J6-221	342	3,000	7,700	No
Juanita Auto Rebuild	J13-689	366	3,000	4,800	No
Kenmore Village Apts.	J6-413	342	3,000	7,900	No
Market Place	J13-211	366	3,000	5,100	No
Northshore House	J6-249	342	3,000	7,500	No
Villa Bonita	J13-533	366	3,000	4,900	No
Bothell High School	J7-219	380	3,000	5,500	No
Holy Spirit Church	J13-281	366	3,000	5,000	No
Bothell Methodist Church	J7-199	380	3,000	5,900	No
Juanita Village	J13-197	366	2,800	5,200	No
Avalon-Juanita Village	J13-200	366	2,625	5,100	No
EHMC ER Expansion	J16-141	451	2,625	7,100	No
Evergreen Plaza	J16-105	451	2,600	7,100	No
Chelsea Court II	J22-106	388	2,500	3,600	No
Evergreen Heights Building	J16-131	451	2,500	7,100	No

**TABLE 6-6 – (continued)**

**Available Fire Flows at High Fire Flow Locations**

<b>Location</b>	<b>Junction Node</b>	<b>Zone</b>	<b>Required Flow (gpm)</b>	<b>Available Flow<sup>(1)</sup> (gpm)</b>	<b>Flow Deficiency</b>
Woodmoor Elem. School	J16-515	451	2,500	32,800	No
Ream Office Building	J16-422	451	2,500	13,800	No
Cedar Park High School	J15-101	529	2,500	4,900	No
Bothell Public Storage	J6-423	342	2,500	8,100	No
Safeway	J13-707	366	2,250	4,700	No
Kenmore Apartments	J6-239	342	2,250	7,800	No
Eastside Four Square Church	J13-995	366	2,000	4,600	No
Orcas Moon	J16-459	451	2,000	12,500	No
Northshore Junior High School	J16-425	451	2,000	18,800	No
Walgreens	J13-197	366	1,600	5,200	No

(1) Available fire flows are based on the 2006 fire flow scenario.

A figure showing the available fire flow rates is provided in the back sleeve of the Plan.

**ADDITIONAL MODELING ANALYSES**

The hydraulic model is a useful tool in evaluating the system’s vulnerability during emergency conditions. Various demand scenarios were evaluated with critical District facilities out of service to identify system response and available level of service.

**Sammamish River Water Main Crossing**

The District studied the effects of losing all transmission capacity across the Sammamish River. The District has four water mains crossing the Sammamish River, including the 24-inch transmission main to the Inglemoor Tank Farm. These sections of the Sammamish River are known to be areas of high seismic risk, which may cause pipe damage or failure. The transmission main was found to be below the liquefaction zone, thus failure is unlikely. The remaining three water mains are at risk of loss during seismic events. The hydraulic model was utilized to determine how operations would be affected if all three crossings were severed.

**Hydraulic Capacity Analysis**

The District performed an analysis in 2005 to determine the hydraulic capacity of all PRV stations. This analysis evaluated the ability of the PRVs to provide fire flows and identified the PRVs that need pressure-sustaining systems to maintain the upstream

pressure during high flow events. In addition, the analysis identified the minimum level in each reservoir at which fire flows can be provided.

### **Reservoir Contamination Hydraulic Modeling**

The District utilized the extended period simulation capabilities of the hydraulic model to evaluate the spread of contaminants in the water system. A contaminant was introduced in the model at each reservoir site and at each master meter location to determine where the contaminant plume spread and the time needed to spread to various parts of the system. The evaluation results would be used by District staff to isolate sections of the system if a contaminant is known to be introduced.

### **Evergreen Hospital Hydraulic Modeling Analysis**

The District evaluated the capacity and criticality of water mains that provide service to the Evergreen Hospital. The evaluation identified which water mains will reduce the level of service to the hospital site if they are out of service. Results indicate that the 16-inch transmission main on 124<sup>th</sup> Avenue NE is the most critical facility in supplying the hospital. Knowing this, the District can plan its response during emergencies to ensure that service is provided to the hospital.

## **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. In general, the distribution system is well looped to minimize pipe velocities and provide redundancy.