Section 7: Hydraulic Model Development

This section discusses the development of the hydraulic model used to evaluate the system. As discussed earlier, the hydraulic model constructed to produce the findings of this section was done using Innovyze InfoWater, which is GIS-based hydraulic modeling and analysis software.

Kennedy/Jenks used GIS data provided by the Department to construct a water distribution model for the Department's system to conduct the water system analyses, identify hydraulic deficiencies and recommend capital improvement projects for both current and future demand conditions. Appendix D provides in depth details of the hydraulic model construction and calibration process undertaken as part of this master planning effort.

Hydraulic distribution models are frequently used for the planning, design and operational management of water distribution systems. In order to evaluate distribution system hydraulics, computerized modeling software is used to develop hydraulic models that represent actual distribution system infrastructure and its operation using complex mathematical equations. These models serve as tools to identify potential deficiencies in the system, size future facilities and develop long range planning studies. This section describes development of the hydraulic model of the Department's distribution system and the calibration methodology and results. As described above, the hydraulic model is the primary analytical tool used to determine facility sizing, capacity needs and fire flow requirements. A comprehensive calibration process is integral to increasing the ability of the model to accurately mimic actual field conditions. The calibration process of water distribution system models allows for accurate and reliable hydraulic analysis results and thus, is of utmost importance.

The methods used to develop the Department's water system hydraulic model are described in the section that follows, including model creation and model calibration. The model will subsequently be used to identify deficiencies within the existing and the future system in meeting water demand conditions. This evaluation will guide the development of a Capital Improvement Program (CIP) for the distribution system under existing and future conditions.

Figure 7-1 below shows the basic workflow for the hydraulic model development and calibration process.

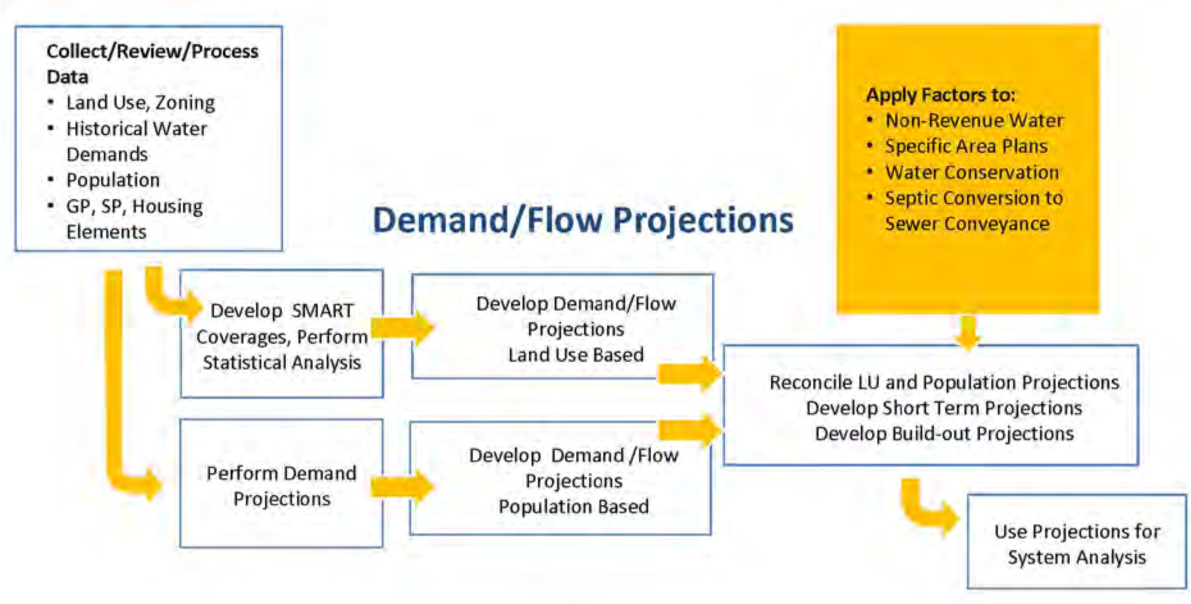

Figure 7-1: Model Development Workflow

In agreement with the Department over the needs and goals for the modeling task and how it fits in the Master Planning project, K/J's modeling team selected Innovyze's InfoWater (version 10.5) software to use for this project. The previous hydraulic model used in the 2007 Master Plan was also developed using the InfoWater software, a fully integrated Geographic Information System (GIS) hydraulic modeling software package. The software is capable of transferring data to and from the Department's water system GIS, which is integrated using ArcMap GIS as part of this Water Master Plan. The model includes all water facilities in the distribution system including water pipelines 2-inch in diameter and greater, groundwater wells, storage tanks, booster stations, inter-tie connections, pressure regulating valves, and other infrastructure within the system. Water pipelines and their associated parameters (e.g. diameter, year of installation, material, lengths, etc.) are imported from the Department's GIS into InfoWater to form the initial pipe network.

Spatial data such as location of valves, hydrants, billing meters, ground elevations (based on LIDAR data) was provided by the Department as part of this Master Plan project. Water demands and other necessary modeling data like operating conditions, control sets, system curves, etc. are also incorporated into the model using both ArcMap GIS and InfoWater. InfoWater uses Innovyze's proprietary hydraulic engine, which provides a fully dynamic solution for modeling distribution systems. InfoWater has a GIS-based model interface, and features many useful add-on tools for model development, calibration, and simulation results analysis.

7.1 Peaking Factors

In order to establish demands and peaking factors, the Department provided daily production data, daily demand data and monthly consumption data. The daily demand data was made available for the last thirteen years. Average day demand (ADD) was calculated for each of the records. The complete dataset of demand data was then used to determine a maximum day demand (MDD) peaking factor, which represents the ratio between average day demands and the demands that occur on the day during the year when the demands are the highest. Analysis of the data provided by the Department revealed that the maximum day peaking factor is 1.54.

7.2 Elevation Allocation

The elevations of all nodes in the model are established from the Department's elevation contours provided in GIS shapefile format using Light Detection and Ranging (LiDAR) data survey conducted by the San Bernardino County. The elevations for the model nodes are interpolated from the contours by using the "elevation extraction" feature in InfoWater.

7.3 Demand Allocation

The existing water demands in the hydraulic model are allocated using actual water usage information obtained from the Department's calendar year (CY) 2012 customer billing records. The future water demands are allocated using the year demand projections calculated based upon specific plan and land use information. The allocation of both existing and future water demands to the model nodes is described below.

Allocation of Existing Demands

The water demands for existing conditions are based on actual customer usage information (HTE billing data) provided by the Department. The billing data covers the water usage of approximately 44,000 accounts for the CY 2012. The average water usage for each account for the calendar year is calculated and scaled to the water production of the same year to include unaccounted for water in the model. Each billing record is geographically located in GIS by comparing the parcel's APN included in the billing data with a parcel's polygon in the shapefile provided by the Department. There are several instances where relatively new parcels identified in the billing data are not shown in the parcel shapefile. These are situations where parcels have been subdivided into smaller parcels. In these instances, the account is manually added to the shapefile by using the street address of the customer. The end product of this process is a GIS shapefile with each of the account represented as a point, which can be imported into InfoWater.

To allocate the water demands in the hydraulic model, demand nodes are selected that include all model nodes except those connected to water facilities or large transmission pipes. After the selection of demand nodes, each of the point demands corresponding to the HTE meter data is allocated to its nearest demand node in the model using the GIS Demand Allocation workflow developed by Kennedy/Jenks. The demand allocator workflow uses an advanced algorithm to locate and allocate point demands from meter/billing data to the nearest model junction.

The large demand customers are individually checked to verify that these large demands are assigned to the correct location. This procedure is used to verify the spatial accuracy of the demand allocation, since these customers sometimes have different billing addresses than their physical locations (i.e., corporate offices different from physical operations). Adjustments are made when the meter locations/addresses and the billing addresses do not correspond.

Allocation of Future Demands

The allocation of future demands is split into five categories: specific plans, area plans, infill, vacant housing and undeveloped parcels. The allocation of specific plans and area plans is performed manually on a development by development basis. For each of the proposed developments, a single demand node is manually input into the model for each zone in the development.

Infill (vacant parcel located in-between developed parcels) and undeveloped (large undeveloped areas generally at the outskirts of the City boundaries) demands are input into the model using a similar process as the existing demands. A point GIS shapefile is created, with each point representing a vacant parcel in a developed region with an associated demand (calculated by multiplying the acreage of the vacant parcel with the water duty factor). These point demands are then assigned to the model using the demand workflow methodology.

Vacant housing parcel demands are added to the demand set into the model by manually identifying the Department's existing developed lots for CY 2012 which did not show water usage. Average values of demands from previous years were calculated and assigned to these nodes to account for future demands when their lots get occupied again.

7.4 Diurnal Curve

A diurnal curve is a pattern that simulates water demand variations over a 24-hour period. The diurnal curve pattern was assigned to all demand nodes within the Department's system. Hourly summaries of water supplied to the system and incremental changes in storage volumes are used to determine approximate hourly demand and create diurnal curves (demand = supply production – storage inflows + storage outflows).

Diurnal curve creation was based on system-wide data gathered over a one month period in 2012. Individual diurnal curves were created for each day in the period and a combined diurnal curve for application in the model was created from an average of those. Sufficient data to create diurnal curves for specific areas of land use types were not available. Therefore, the same diurnal pattern was assigned to all demands within the system.

The hydraulic model uses the diurnal curve created when it is run for an Extended Period Simulation, which is when the model simulates the system being operated over a period of time. Frequently, this entails simulating a 24-hour time period, with results calculated at one-hour time steps throughout the simulation. At each time step, all demands are multiplied by the appropriate peaking factor throughout the day based on the diurnal curve and the time step being calculated. The daily diurnal pattern is displayed on Figure 7-2.

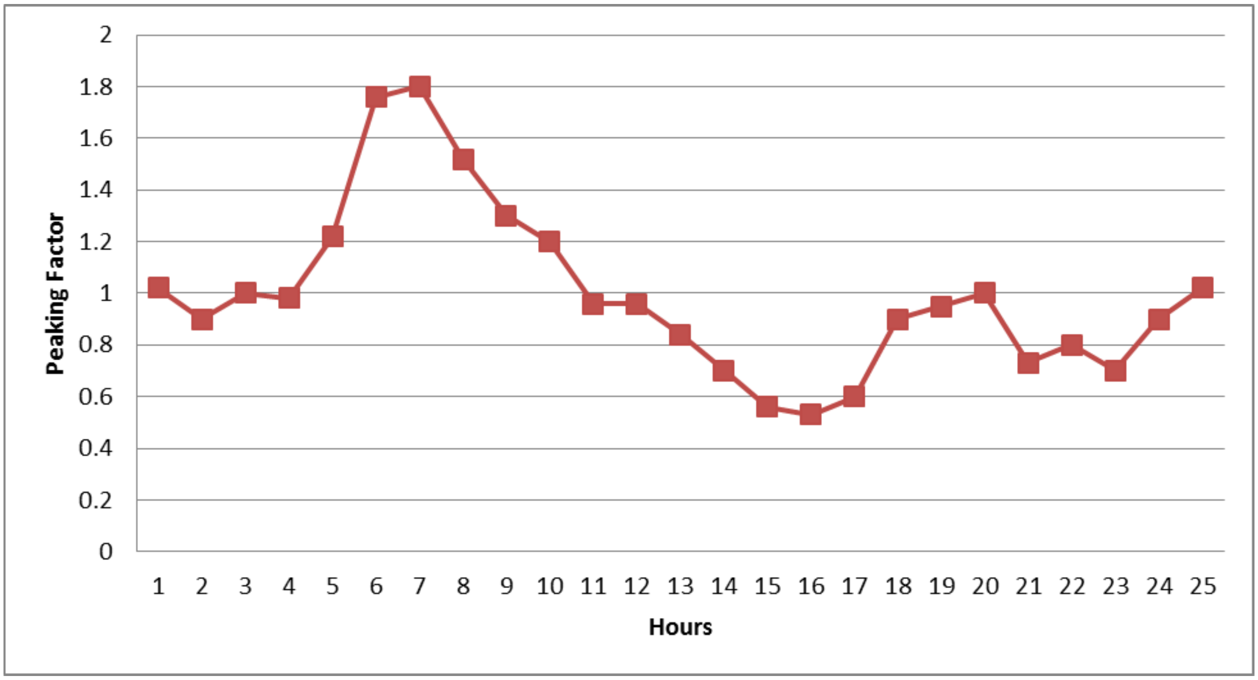

Figure 7-2: Daily Diurnal Demand Pattern

7.5 Model Calibration

During the process of developing a hydraulic model for the Department's existing water distribution system, the model was calibrated for the majority of the pressure zones within the Department's distribution system except for sub-zones or smaller zones which were relatively newer construction. The goal of calibration was to develop a computational model that closely represents actual conditions in the distribution system. Part of the calibration process involves collecting flow-test data obtained from several fire hydrants throughout the water service area. This data was then used to adjust modeling parameters e.g. friction factors, roughness coefficients etc.

In accordance with the Scope of Work for the Water Facilities Master Plan, a flow-test protocol was prepared for use by the Department to provide calibration data. This memo describes the recommended locations for flow testing, as well as the procedures that should be followed while performing the tests. It also included maps showing locations where fire flow testing was recommended. In addition, the Department maintains a comprehensive database of all fire flow tests performed as part of routine operational protocols. This database was used during the calibration of the majority of the pressure zones in the system.

Once all of the significant issues with model settings and input errors have been addressed, further model calibration was performed to fine tune the model to field conditions. Fire hydrant data was collected from the hydrant tests performed and from the Department's fire hydrant test database. The results of the actual field tests are compared to the model runs. The hydrant test points with the test data and model results are summarized in Table 7-1. The results in the table below show that most of the field conditions were replicated in the hydraulic model with a good confidence level. The deviations between field data and model results range from 0.0 to 9.8 percent for residual pressures, and range from 0.2 to 9.9 percent for static pressures.

Table 7-1: Calibration Results

Pressure Zone	Field Residual Pressure (psi)	Modeled Residual Pressure (psi)	% Difference	Field Static Pressure (psi)	Modeled Static Pressure (psi)	% Difference
Cajon	112.0	112.0	0.0%	122.0	134.1	9.9%
College/Palm	94.0	94.0	0.0%	104.0	104.2	0.2%
Daley	104.0	110.0	6.2%	116.0	115.9	-0.1%
Del Rosa	74.0	74.0	-0.4%	85.0	91.5	7.6%
Devore Meyer	110.0	116.9	6.3%	120.0	122.6	2.2%
Devore Meyer	114.0	120.0	5.3%	124.0	125.7	1.4%
Intermediate	26.0	26.5	2.1%	79.0	79.6	0.7%
IVDA	44.0	44.2	0.5%	58.0	54.6	-5.9%
Lower	84.0	84.2	0.2%	94.0	95.1	1.2%
Mountain	55.0	52.3	-4.9%	93.0	90.7	-2.5%
Mountain Sub Zone A	42.0	45.9	9.4%	73.0	74.2	1.6%
Ridgeview	60.0	65.9	9.8%	72.0	75.0	4.2%
Sycamore	60.0	54.8	-9.0%	70.1	70.2	0.1%
Terrace	52.0	52.0	0.0%	62.0	59.4	-4.2%
Upper	42.0	45.0	7.1%	56.0	54.9	-2.0%

For the pressure zones with variations more than 10% between field and model results for either static or residual pressures, multiple hydrant tests were simulated to rule out the possibility of errors in performing the tests. Initial results were shared with the Department to go over the operational controls, flow data and tank levels and verify the settings in the model. Once these were confirmed by the Department, edits/updates to the settings were performed in the model to replicate field results. In case of outstanding discrepancies between the field and model results, the Department provided directions on assumptions for these pressure zones for the hydraulic analysis.

There are several possible causes of the discrepancies between the model results and field data observed during calibration which are seen in the tables and graphs above. Some of these include:

- Fire flow tests in the model are based on flow at the nearest model node. The hydrant piping branch run and losses through the hydrant are not included in the model.

- Pressure meters and flow meters used for the fire flow testing have some level of inaccuracy, both in the actual measuring and reading of such meters.

- Demand varies temporally between various days. The diurnal curve created for calibration is used to determine demand at each hour for the fire flow tests. However, the actual demand pattern varies from day to day.

- Demand varies spatially between different times. The demand allocation spatially distributes the demand using annual average billing data. All demand nodes are assigned the same diurnal curve.

- The elevation data contains possible inaccuracies, both in the source contours and the interpolation process.

- Groundwater levels fluctuate. A nominal groundwater level is used in the model, which may not accurately represent the level the day the field data was obtained.

- Not all facility settings are captured by SCADA data. One example is a closed isolation valve that is normally open.

- Limitation in the model software to represent exact field conditions i.e. automatic settings, etc.

Additional work was performed for the Cajon, Daley, Del Rosa, IVDA and Sycamore pressure zones to improve calibration. Table 7-1 reflects the results of the final calibration and includes the additional work for those five zones.