APPENDIX L

Fresno Water System Hydraulic Model Development

APPENDIX L. FRESNO WATER SYSTEM HYDRAULIC MODEL DEVELOPMENT

INTENDED USE OF MODEL

The City of Fresno's hydraulic water system model is a planning level tool meant for evaluating the hydraulic capabilities of the existing water system, identifying facility deficiencies, and sizing future facilities. It is a conceptual model that provides hydraulic system pressures and flows with reasonable accuracy, but not necessarily detailed accuracy. It is therefore recommended that this model not be used for detailed time-varying operational studies without first updating, calibrating and verifying the model.

HYDRAULIC MODEL

The City's hydraulic model was developed using an H_2ONET water distribution system modeling software package by MWHSoft, Inc. The software transforms information about the physical water system into a mathematical model that solves for various flow conditions. For each set of specified demands, the model generates information such as pressure, flow, velocity, and head loss that can be used to analyze the water system performance and identify system deficiencies. The model can also be used to identify the need for and size recommended water system improvements.

The water distribution system is represented in the model as a network of nodes and node-connecting elements. Junction nodes represent specific points in the water distribution system such as pipe intersections, pipe ends, and fire hydrants. Boundary nodes represent points in the water system that define specific hydraulic grades, such as reservoirs and storage tanks. Node-connecting elements or links represent various system components that affect the flow rates and energy losses throughout the system. Examples of links are pipes. The model can be run under steady state conditions.

The modeling software performs the water distribution system network analysis using an iterative process to solve the Energy Equation for the network. The Energy Equation is:

$$\frac{p_1}{\gamma} + z_1 + \frac{V_1^2}{2g} + h_p = \frac{p_2}{\gamma} + z_2 + \frac{V_2^2}{2g} + h_L$$

Where:

Where:	p	is the pressure (lb/ft^2)
	γ	is the specific weight of the fluid (lb/ft^3)
	z	is the elevation at the centroid (ft)
	V	is the fluid velocity (ft/sec)
	g	is the gravitational constant (ft/sec^2)
	h_p	is the head gain from a pump (ft)
	h_L	is the combined head loss (ft)

The factor h_L is made up of two factors, friction losses (h_f) and minor losses (h_m). The friction loss is calculated by using one of the standard equations: Hazen-Williams Equation, Manning's Equation, or the Darcy-Weisbach Equation. All friction losses for this evaluation were calculated using the Hazen-Williams Equation:

$$h_f = \frac{4.73L}{C^{1.85} d^{4.87}}$$

Where:	L	is the pipe length (ft)
	C	is the Hazen-Williams roughness coefficient
	d	is the pipe diameter

The minor losses were calculated using the minor loss equation:

$$h_L = \frac{0.0252Kq^2}{d^4}$$

Where:	K	is the minor loss coefficient
	q	is the flow rate (ft^3/sec)
	d	is the diameter (ft)

The total head loss (h_L) is the sum of the friction loss (h_f) and the minor loss (h_m). By solving the Energy Equation, the model determines the flow in each pipe segment and the resulting pressure at each node.

MODELING ASSUMPTIONS AND CRITERIA

Establishing computer modeling assumptions and criteria is critical for developing, verifying, running the model, and interpreting the results of the simulations. The assumptions and criteria used for the City's water distribution system hydraulic model update include:

- Generally, pipe sizes of 8 inches and above were modeled, except where smaller diameter pipelines were required to complete a loop or to provide service to an isolated area.
- Information on pipe length and diameter was extracted from the City's GIS shapefiles.
- Pipe C-factors were assigned based on pipe material and age.
- Pump station piping configurations were obtained from "as-built" plans, and descriptions from City operations staff.
- Well pump design points were estimated from SCADA system data.
- Pipe length accuracy was assumed to be ±25 feet.

- Ground surface elevations were estimated using the Topo Depot digital topographic maps. Elevations were estimated to the nearest foot where spot elevations were not available.
- The water demands in the model were expressed in gallons per minute (gpm).

HYDRAULIC MODEL ELEMENT NAMING SCHEME

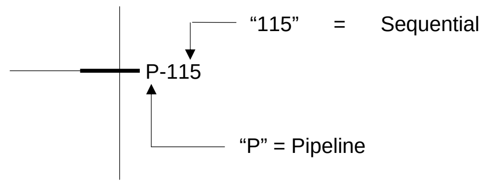
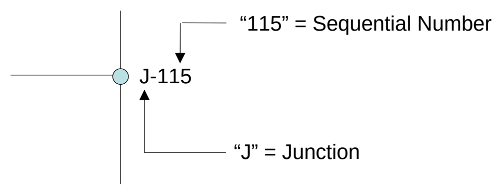
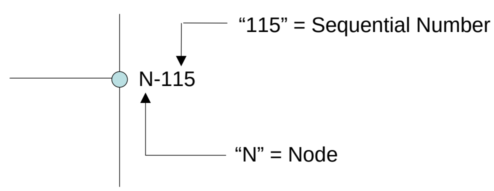
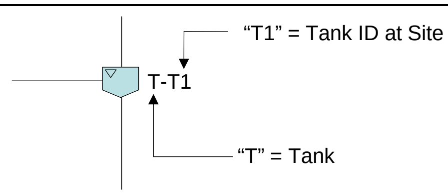
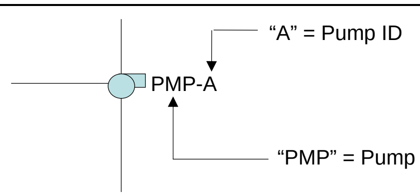
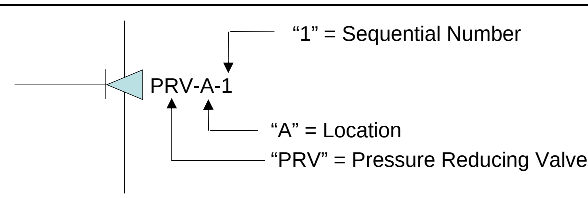
Models are set up with specific element names representing key hydraulic facilities because this allows the modeler to easily locate specific elements while modeling. As each facility is created in the model, pipes, nodes, pumps, tanks, and valves must be named logically and sequentially. Table L-1 summarizes the hydraulic element functions.

Table L-1. Hydraulic Network Elements

Type	Description	Prefix
Junction	Removes (demand) or adds (inflow) water from/to the system	J
Node	Represents transition in pipeline characteristic or point where pressure or water quality is monitored	N
Tank	Represents storage capacity	T
Reservoir	Represents an infinite external source	R
Pump	Raises the hydraulic grade to overcome elevation differences and friction losses	PMP
Control Valves	Controls flow or pressure in the system based on specified criteria	PRV/PSV /FCV
Pipelines	Conveys water from one node to another	P

Table L-2 shows the naming scheme used in the hydraulic model update. This scheme is based on the hydraulic element prefix and facility identification numbers, where available.

Table L-2. Naming Scheme for Hydraulic Network Elements

Model Element	Naming Scheme
Pipelines	
Junctions	
Nodes	
Tanks	
Pumps	
Control Valves	

WATER SYSTEM MODEL DEVELOPMENT

The City's hydraulic model was developed to reflect the existing facilities such as pipelines, wells, water treatment plants, tanks, control valves and pumps that had been constructed as of December 2005. The representation of the water system facilities in the hydraulic model is described below.

Pipelines

Pipelines were imported from the City's water system base map using GIS shapefiles provided by the City. Pipelines greater than 6 inches in diameter were imported. However, the resulting model was skeletonized using the *Skeletonizer* feature in H_2ONET. Skeletonization is the process by which water networks are stripped of pipelines not considered essential for the intended analysis purpose. Generally, pipelines greater than 8 inches in diameter were maintained, except in critical areas of the system where smaller diameter pipelines were required to complete a loop or to provide service to an isolated area.

The hydraulic input data for the pipelines consisted of length, diameter, material and pipe C-factor. Pipeline length, diameter and material were imported from the GIS shapefiles. Pipe C-factors were estimated based on industry standards for similar pipeline materials, service age and WYA's experience. Table L-3 summarizes the pipeline C-factors by age and material type.

Table L-3. Pipe C-factors

Pipe Material	Age, Years						
	0	5	10	20	30	40	50
Asbestos Cement	140	136	133	130	126	123	120
Cast Iron	130	120	111	96	87	80	60
Ductile Iron	130	120	111	96	87	80	60
Plastic (PVC)	150	148	146	144	142	141	140
Steel	125	115	106	91	82	75	65

Junctions

Input data for each junction included elevation and a constant flow (demand). The elevation of each junction was determined by using the *Smart Topography* feature in the H_2OMAP software. Digital topography, in shapefile format, was imported into the model as a GIS theme and then, using the *Smart Topography* feature, the elevations were automatically computed and allocated to junction nodes. A shapefile was then generated from H_2OMAP and imported into the H_2ONET model. Demand allocation to the junctions is presented later in this Appendix.

Wells

The groundwater wells were modeled as fixed head reservoirs with pumps. The pumps were configured to pump directly into the distribution system except as noted otherwise. Pump design points were estimated from SCADA data due to lack of original pump curves.

Surface Water Treatment Facility

The Surface Water Treatment Facility's hydraulics upstream of the treated water storage tank was represented in the model by a fixed grade reservoir followed by a hypothetical flow control valve. The flow control valve is followed by the treated water storage tank and booster pump station.

Storage Tanks/Reservoirs

The City's existing storage tanks were simulated in the model using variable-head tanks. Minimum levels, maximum levels, bottom elevation, and diameters for the tanks were input into the model. The storage tank/reservoir modeling data is summarized in Table L-4.

Table L-4. Storage Tank/Reservoir Modeling Data

Reservoir name	Nominal Capacity, MG	Height from base to overflow, ft	Bottom Elevation, ft	Diameter, ft
WTP Storage Tank	1.5	20.0	359	113
South East Tank	2.0	23.6	305	120

Booster Pumps

Each booster pump was modeled using a design-point curve from pump curves and performance tests received from the City. The design-point curve specifies the pump design head and flow. The configurations of pump stations in the water distribution system were confirmed using record drawings.

Control Valves

The control valves within the distribution system consisted of pressure reducing valves and pressure sustaining valves. These were modeled by choosing the appropriate valve type and assigning the required pressure setting.

WATER DEMAND ALLOCATION IN MODEL

This section presents the allocation of demands to junctions in the hydraulic model. The steps used to allocate the base demands in the hydraulic model are summarized below:

1. Assign large water user demands based on actual meter records to specific nodal locations in the model; and
2. Allocate estimated demands (excluding large users identified in step (1)), based on land use and water duty factors.

These two steps are described in more detail below.

Large Water User Demand Assignment Based on Metered Data

There are about a hundred large water users in the City. They constitute approximately 13 percent of the average day demands of the City. Their actual metered use was assigned in the model using data provided by the City.

Demand Allocation Based on Land Use

After the large water user demands were assigned, the remaining water demand was allocated using land use data provided by the City and the unit water demand factors calculated for each of the City's major land use types. The water demands were allocated based on direct spatial intersection between land use and Theissen polygons that represent the demand node area coverage. Nodal demands were then converted from average day to maximum day and peak hour demands by multiplying each demand by the appropriate peaking factor.

WATER SYSTEM MODEL VERIFICATION

This section describes the verification of the City's existing water distribution system computer model. Model verification is the process of ensuring that a water distribution system model can replicate the actual system operation in terms of pressure and flow during the test period. Model verification typically occurs after model calibration. However, as requested by the City, no calibration was conducted (as the City felt comfortable that the previous hydraulic model of the water system was sufficiently calibrated to skip this step). This model verification included system operation data collection and the matching of the computer simulation results with those observed throughout the distribution system.

Data Collection

SCADA system data for August 29, 2005 in hourly intervals was received from the City. The data included total flow and discharge pressure from the Surface Water Treatment Facility (SWTF) and the South East Tank over a 24-hour period. The data also included flows and discharge pressures from each of the distribution system wells that were operating. In addition to the flow and pressure data, the water levels in the storage tanks and groundwater pumping levels in the operating wells were also collected.

Model Verification and Results

A static verification was performed on the City's water distribution system model by comparing the model results to the collected time-series field data. Hour 5 of August 29, 2005 representing peak SWTF production time, was used for the static verification. Model-simulated flows and pressures were compared to their field-measured counterparts. Where significant discrepancies existed between the model results and the field measurements, adjustments were made to the water system model configuration and parameters until a better fit between the model and field data sets was obtained. Table L-5 shows a comparison of both system pressures and flows as calculated by the hydraulic model compared to the actual SCADA field data.

CONCLUSION

As shown on Table L-5, the updated hydraulic model shows reasonably good correlation to actual field SCADA data, and generally being able to simulate the water distribution system operation. Simulated pressures were generally within +/- 10 psi of the field-measured pressures. This level of accuracy is good for a hydraulic model of this size and system complexity, and the model is adequate to be used to perform water distribution system facility sizing. It is however recommended that the model be fully calibrated and verified by extended period simulation before being used for any kind of operational study in the future.

Phase 1, Metropolitan Water
Resources Plan Update
Table L: Comparison of Field and Model Results

Facility Name	Discharge Pressure, psi			Flow, gpm		
	Field	Model	Difference	Field	Model	% Diff
1A	52	40	12	421	448	-6
2B	53	44	9	2,450	2,678	-9
3A	55	44	11	2,308	2,643	-15
4A	48	39	9	-	-	0
4B	48	40	8	-	-	0
5A	56	52	4	1,254	1,310	-4
6B	58	67	-9	1,183	973	18
8A	70	59	11	410	481	-17
9A	57	45	12	1,711	2,002	-17
10A	48	40	8	388	447	-15
11A	52	51	1	1,756	1,680	4
12A	53	41	12	1,292	1,471	-14
13A	45	37	8	-	-	0
14A	50	41	9	1,799	1,991	-11
16A	57	43	14	1,638	1,951	-19
17	47	42	5	995	1,069	-7
18A	46	39	7	-	-	0
19A	47	38	9	-	-	0
19B	48	39	9	1,188	1,337	-13
20	47	40	7	1,997	2,185	-9
21A	53	42	11	2,832	3,242	-14
22A	55	48	7	2,148	2,332	-9
24B	47	37	10	-	-	0
25	50	45	5	1,829	1,959	-7
26A	56	42	14	1,713	2,058	-20
27A	56	44	12	1,467	1,698	-16
28A	48	38	10	-	-	0
30A	47	39	8	1,450	1,593	-10
31A	45	43	2	1,748	1,779	-2
32B	46	38	8	-	-	0
33A	53	41	12	1,696	2,194	-29
34A	58	54	4	2,337	2,360	-1
35A	58	54	4	1,829	1,711	6
36	51	37	14	-	-	0
37	49	41	8	1,694	1,879	-11
38A	54	45	9	979	1,080	-10
39A	49	38	11	-	-	0
41	54	48	6	1,619	1,651	-2

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Table L: Comparison of Field and Model Results

Facility Name	Discharge Pressure, psi			Flow, gpm		
	Field	Model	Difference	Field	Model	% Diff
42	48	42	6	1,251	1,352	-8
43	52	42	10	-	-	0
44A	52	51	1	1,747	1,648	6
45	49	46	3	1,493	1,551	-4
46	54	46	8	1,065	1,166	-9
47	47	44	3	2,268	2,130	6
48	44	37	7	1,544	1,678	-9
49A	50	42	8	1,706	1,888	-11
50A	50	39	11	-	-	0
51	56	49	7	1,700	1,845	-9
52	50	45	5	1,563	1,628	-4
53	50	51	-1	1,711	1,679	2
54	47	38	9	-	-	0
55-1	21	48	-27	-	-	0
55-2	21	48	-27	-	-	0
56	53	50	3	1,657	1,459	12
57	42	40	2	-	-	0
58	55	47	8	2,291	2,548	-11
59	45	39	6	570	613	-7
60	50	42	8	1,872	2,161	-15
62A	50	47	4	2,355	2,452	-4
63	45	39	6	-	-	0
64	49	49	0	1,500	1,465	2
65	45	50	-5	1,414	1,349	5
66	50	41	9	-	-	0
67	55	48	7	1,866	1,951	-5
68	45	45	0	-	-	0
69A	56	46	10	-	-	0
70	48	39	9	1,544	1,725	-12
71	47	45	2	1,680	1,754	-4
72	52	50	2	1,577	1,581	0
73	46	47	-1	1,500	1,423	5
74	44	40	4	-	-	0
75	55	63	-8	1,552	1,376	11
76	43	54	-11	1,078	792	26
77	46	37	9	992	1,069	-8
78	47	47	0	1,900	1,917	-1
79	45	49	-4	1,037	922	11

Phase 1, Metropolitan Water
Resources Plan Update
Table L: Comparison of Field and Model Results

Facility Name	Discharge Pressure, psi			Flow, gpm		
	Field	Model	Difference	Field	Model	% Diff
80	49	47	2	1,140	1,170	-3
81	51	45	6	1,006	1,092	-9
82-1	47	39	8	864	956	-11
82-2	47	39	8	575	633	-10
83	54	68	-14	-	-	0
84	47	38	9	1,130	1,348	-19
85	53	62	-9	1,201	962	20
86	48	59	-11	610	470	23
87	52	53	-1	-	-	0
88-2	55	39	16	1,390	1,855	-33
90	50	53	-3	1,705	1,796	-5
91	37	49	-12	1,725	1,442	16
92	50	60	-10	809	643	21
94	48	59	-11	909	810	11
95	52	62	-10	1,551	1,411	9
96	52	61	-9	679	507	25
97	49	49	0	1,626	1,492	8
98	56	62	-6	2,879	2,639	8
99	55	46	9	-	-	0
100-1	49	41	8	582	660	-13
100-2	49	41	8	606	684	-13
102	44	35	9	-	-	0
103	59	68	-9	128	115	10
104	57	60	-3	-	-	0
105	58	55	3	1,234	1,133	8
108	45	35	10	-	-	0
118	54	62	-8	-	-	0
125	51	40	11	561	643	-15
128	52	68	-16	-	-	0
129	48	59	-11	-	-	0
130	47	61	-14	-	-	0
131	48	58	-10	754	612	19
132	48	63	-15	-	-	0
133	51	66	-15	-	-	0
134	53	63	-10	1,509	1,348	11
135A	45	34	11	480	558	-16
137	51	60	-9	1,164	950	18
138	59	52	7	1,741	1,815	-4

Phase 1, Metropolitan Water
Resources Plan Update
Table L: Comparison of Field and Model Results

Facility Name	Discharge Pressure, psi			Flow, gpm		
	Field	Model	Difference	Field	Model	% Diff
139	53	54	-1	2,721	2,541	7
141	46	51	-5	2,665	2,396	10
142	54	40	14	2,107	2,166	-3
143	52	67	-15	-	-	0
144	53	62	-9	841	628	25
145	70	57	13	-	-	0
146	53	54	-1	1,750	1,393	20
148-1	49	60	-11	737	677	8
148-2	49	60	-11	1,182	1,086	8
150	42	54	-12	788	662	16
151	44	61	-17	-	-	0
153-1	47	42	5	880	971	-10
153-2	47	42	5	546	593	-9
154	53	52	1	2,259	2,233	1
155-1	46	36	10	-	-	0
155-2	46	36	10	-	-	0
157	52	60	-8	1,700	1,452	15
158	54	54	0	2,140	1,632	24
159	43	50	-7	2,008	1,954	3
160	57	57	0	1,571	1,274	19
161	54	57	-3	-	-	0
162	43	31	12	1,500	1,871	-25
163	55	63	-8	-	-	0
164-1	49	41	8	465	532	-14
164-2	49	41	8	731	826	-13
165-1	49	40	9	310	342	-10
165-2	49	41	8	460	483	-5
166	41	29	12	504	585	-16
169	62	50	12	1,894	1,960	-3
170	49	41	8	1,852	2,161	-17
171-1	56	52	4	-	-	0
171-2	56	52	4	-	-	0
172	53	40	13	-	-	0
174	56	52	4	2,422	2,405	1
175-1	49	60	-11	-	-	0
175-2	49	60	-11	-	-	0
176	47	62	-15	-	-	0
177	51	66	-15	-	-	0

Phase 1, Metropolitan Water
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Table L: Comparison of Field and Model Results

Facility Name	Discharge Pressure, psi			Flow, gpm		
	Field	Model	Difference	Field	Model	% Diff
178	50	60	-10	607	517	15
180-1	52	43	9	410	457	-12
180-2	52	44	8	526	569	-8
181	44	57	-13	538	294	45
182-1	44	38	6	448	494	-10
182-2	44	38	6	283	245	13
183	54	41	13	319	369	-16
184	43	40	3	-	-	0
185	45	62	-17	1,320	869	34
186	49	61	-12	-	-	0
187	49	65	-16	-	-	0
189	54	55	-1	2,108	1,781	16
192	66	58	8	1,215	1,098	10
193	45	39	6	-	-	0
197	52	39	13	-	-	0
198	47	39	8	2,342	2,540	-8
199	51	44	7	2,408	2,579	-7
202	43	43	0	328	313	5
203A	49	30	19	-	-	0
205	52	42	10	802	928	-16
206	51	42	9	1,276	1,410	-10
207	52	53	-1	523	461	12
209	44	52	-8	596	692	-16
211	45	52	-7	477	371	22
213A	49	51	-2	1,992	1,786	10
217	53	41	12	493	547	-11
218	52	43	9	-	-	0
219	49	40	9	-	-	0
220	51	40	11	-	-	0
221	52	38	14	-	-	0
222-1	53	40	13	-	-	0
222-2	53	40	13	-	-	0
224	59	43	16	799	919	-15
225		41		702	799	-14
226-2	45	39	6	-	-	0
231	45	38	7	304	340	-12
232	37	37	0	-	-	0
235	47	48	-1	291	254	13

Phase 1, Metropolitan Water
Resources Plan Update
Table L: Comparison of Field and Model Results

Facility Name	Discharge Pressure, psi			Flow, gpm		
	Field	Model	Difference	Field	Model	% Diff
236	46	48	-2	-	-	0
238	56	43	13	394	461	-17
240	44	40	4	733	718	2
241	57	43	14	783	913	-17
242	49	59	-10	545	469	14
244	51	61	-10	802	670	16
245	48	51	-3	491	451	8
250	50	50	0	1,086	1,060	2
252	45	44	1	-	-	0
253-1	43	35	8	-	-	0
253-2A	43	35	8	-	-	0
257	49	57	-8	502	442	12
258	44	51	-7	538	403	25
264	47	50	-3	679	514	24
266	45	50	-5	587	549	7
267	47	51	-4	762	639	16
271	48	54	-6	597	548	8
272	51	57	-6	587	547	7
273	50	58	-8	847	720	15
274	42	34	8	-	-	0
275	43	33	10	261	299	-15
277	44	92	-48	-	-	0
279	39	47	-8	472	451	5
280	43	48	-5	524	446	15
283	45	54	-9	1,260	1,113	12
284	45	51	-6	989	834	16
286	50	63	-13	2,067	1,703	18
287	42	52	-10	753	621	18
289-2	46	37	9	512	561	-9
290	50	56	-6	399	363	9
291	53	59	-6	286	243	15
292	50	57	-7	901	742	18
295	49	65	-16	223	198	11
297-1	47	36	11	-	-	0
297-2	47	36	11	689	791	-15
298	47	39	8	1,027	1,135	-11
300	56	39	17	549	447	19
302	58	41	17	993	1,045	-5

Phase 1, Metropolitan Water
Resources Plan Update
Table L: Comparison of Field and Model Results

Facility Name	Discharge Pressure, psi			Flow, gpm		
	Field	Model	Difference	Field	Model	% Diff
303	56	37	19		-	0
304	46	51	-5	569	517	9
306	43	51	-8	-	-	0
307	48	45	3	-	-	0
308	53	70	-17	731	592	19
318	57	69	-12	-	-	0
319	54	63	-9	1,087	1,019	6
320	55	51	4	2,504	2,641	-5
322	51	45	6	1,536	1,613	-5
WTP	68	59	9	20,474	20,474	0
SE Tank	43	41	2	2,283	2,242	2
SUM				221,284	221,715	0