Application of a Water System Computer Model in the City of Scottsdale Arizona

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Abstract

Development, implementation and application of a computer model to simulate an urban water system are discussed. Particular emphasis is placed upon actual use of the model by municipal water supply management. Applications described include system improvements, growth planning and fire protection capability assessment.

INTRODUCTION

The City of Scottsdale, Arizona, is a growth-impacted area, where rapid residential development had led to concern over adequacy of the City's water distribution system. In summer of 1978, heavy use of water during peak demand periods indicated that the ability of the existing water distribution system to serve its growing number of consumers was doubtful. While water production capacity did need to be increased to some extent, primary concern lay with adequacy of storage and transmission capabilities in the short term.

Distribution inadequacies, in particular, were difficult to address. The City's system comprises a number of small, independent water companies purchased separately and intertied over the years. Distribution system maps were incomplete, outdated and, in some cases, nonexistent. Line sizes and valve locations, therefore, were not always known, making adjustments to the water distribution network difficult. More critically, the system's ability to deliver fire flow required to serve planned development could not be assessed realistically.

The City contracted with Southwest Computing, Inc. Inc., for development of a Water Distribution System Computer Model. The objectives of the model development were to identify problems in the existing system and then to allow simulation of planned future development. The model was completed late in 1978. Applications during the refinement stage and later after full implementation have been very successful and have allowed the City to correct, or plan for correction of, many serious system deficiencies--some of which came to light only as a result of the simulations.

This paper describes the model's configuration, the steps taken to adapt it to meet Scottsdale's needs, and some of the benefits accruing from its application to date.

MODEL CONFIGURATION

The computer program "NETWORK" was used to solve the steady-state flow conditions in the City of Scottsdale water distribution system. The program, developed originally by Dr. Roland Jeppson of Utah State University, was modified to run on the IBM 370/165 system.

The program was written to allow the user versatility in obtaining a computer solution to any steady-state flow problem dealing with flow in pipe systems. A solution may be obtained for any combination of pipes, wells, reservoirs, booster pumps, pressure reducing valves and minor loss devices that may be existing or added to the system.

"NETWORK" generates a set of simultaneous equations for pipes and junctions (nodes) within the system. The simultaneous equations are then solved utilizing the Newton-Raphson Method of successive approximations. Generally this solution lends itself to efficient use on third generation computers with large core capabilities. "NETWORK"

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presently is designed to handle 800 pipes and 630 nodes. Capability may be expanded, if necessary, by redimensioning arrays in the program.

A unique integer number is assigned to each node within the system. These numbers may be in any random order, and need not be consecutive. Pipes are defined by the numbers assigned to the nodes connected by the pipe. Only nodes must be numbered. However, pipes may be numbered, or may be left blank and numbered internally. Reservoirs may be specified at any point in the system. Pump curves for booster pumps or well pumps may be simulated and the program will determine the operating flows and pressures. It is not necessary to estimate flow or number of loops.

The printout from the program is easy to read. Exhibit 1 is a reproduction of the first section of printout, showing input characteristics and parameters. In this particular simulation, pipes were numbered and the pipe number appears on the printout, along with the two connecting node numbers, the length of the pipe in feet, diameter in inches, and a coefficient (130 in the example) which indicates the roughness of the pipe's interior. The Area Number indicates the geographical area being simulated.

The second section of the printout, shown in Exhibit 2, presents input and calculated data for each pipe in the simulation. The direction of flow is indicated by the "From - To" node numbers. An asterisk to the left of the pipe number indicates that flow direction is the reverse of that implied by the input node numbers. Input data on pipe length, diameter and roughness are shown. Calculated data includes flow rate in gallons per minute (gpm), velocity in feet per second (fps), head (pressure) loss in feet, and head loss per 1000 feet.

Exhibit 3 shows the node data printout, which includes demand at each node in cubic feet per second (cfs) and gpm, elevation, pressure in feet of head and in pounds per square inch (psi), and the hydraulic gradeline elevation.

SCOTTSDALE SIMULATION

The computer model is designed to react similarly to the actual physical water system. The steady-state analysis reflects a specific, singular occurrence in the water system. As summer is the most critical water demand period for Scottsdale's system, the model was constructed to simulate the peak hour conditions on an average day during the peak month of July. Because Scottsdale's water system is supplied exclusively with ground water from over 20 widely dispersed wells, peak conditions were initially estimated based on metered water delivered during the month of July, and a peaking factor of 1.3 was used to obtain the peak hour rate. Later, peak hour estimates were verified by hourly readings of a sample of well pump meters during a period of extremely high water demand.

A system pipe layout was developed using the City's Water Location Map, existing water quarter-section maps, "as-built" plans (as available) and extensive field investigation in cooperation with City Water Operations personnel. Node numbers were assigned to all junctions affecting water distribution. Node elevations were obtained by interpolation from the City's bench circuit data and United States Geological Survey contours. Exhibit 4 graphically depicts the pipe-node system configuration.

Consumption records were analyzed and various individual large users were identified by the City staff. These users' consumption levels during the peak month were assigned to the nearest node on the computer model. Consumption at apartment complexes was allocated to individual units on a full occupancy basis. Finally, the single family residential users were allocated throughout the City on the basis of full saturation of all subdivided land.

SCOTTSDALE APPLICATIONS

Initial runs of the model showed that the City's water system could be separated into three distinguishable operational areas. Although some flow occurs between areas under certain conditions, essentially each is independent of another due to elevations and characteristics of the distribution network. This finding meant that the simulation could be split into three detailed "zones" or area models, any of which could be run separately against a skeletal model of the entire system. Splitting the model substantially reduced costs of a particular problem simulation. More importantly, identification of the independent nature of the three areas allowed the City to move to interconnect one oversupplied area to another where development was occuring and water supply was critical.

Runs made for purposes of debugging and refinement also identified bottlenecks which field investigation showed to be caused by closed valves or deteriorated and/or undersized lines. The City was able to immediately begin correcting such defects.

Once the model was fully operational, it was used to simulate future conditions which would result from planned development. Typical examples of future case simulations and consequent actions by the City were:

Exhibit 1. MODEL INPUT DATA

```
*RUN31     * SCOTTSDALE WATER SYSTEM * AREA 1 *
*
*          PEAK HOUR - EXISTING CONDITIONS
*          NO FIRES
*
***
* $SPECIF PEAKF=+0.890,NPGPM=1,ITERA=30 $END
*PIPES
*    1    1    336    100.    8.     130. /
*    2    2    358    100.    8.     130. /
*    3    3    314    100.    8.     130. /
*    4    4    311    100.    10.    130. /
*    5    5    369    680.    10.    130. /
*    6    6    388    1320.   16.    130. /
*1000   307    308    1980.   8.     130. / AREA 1
*1001   308    309    1150.   8.     130. / AREA 1
*1002   308    728    670.    8.     130. / AREA 1
*1003   309    390    370.    8.     130. / AREA 1
*1004   309    727    750.    8.     130. / AREA 1
*1005   310    311    650.    10.    130. / AREA 1
*1006   310    390    170.    10.    130. / AREA 1
*1007   310    726    780.    6.     130. / AREA 1
*1008   311    312    230.    10.    130. / AREA 1
*1009   312    343    1430.   8.     130. / AREA 1
*1010   312    700    290.    6.     130. / AREA 1
*1011   313    342    1320.   8.     130. / AREA 1
*1012   313    686    270.    6.     130. / AREA 1
*1013   313    698    520.    6.     130. / AREA 1
*1014   314    315    280.    6.     130. / AREA 1
*1015   314    341    1320.   8.     130. / AREA 1
*1016   314    688    530.    6.     130. / AREA 1
*1017   315    385    1400.   6.     130. / AREA 1
*1018   315    690    260.    6.     130. / AREA 1
*1019   316    691    530.    6.     130. / AREA 1
*1020   316    692    400.    6.     130. / AREA 1
*1021   316    696    1010.   6.     130. / AREA 1
*1022   317    339    1330.   8.     130. / AREA 1
*1023   317    597    300.    6.     130. / AREA 1
*1024   317    693    770.    6.     130. / AREA 1
*1025   318    338    1320.   6.     130. / AREA 1
*1026   318    338    1310.   6.     130. / AREA 1
*1027   318    592    1020.   6.     130. / AREA 1
*1028   318    594    410.    6.     130. / AREA 1
*1029   319    543    650.    8.     130. / AREA 1
*1030   319    544    510.    8.     130. / AREA 1
*1031   319    592    310.    6.     130. / AREA 1
*1032   320    321    580.    8.     130. / AREA 1
*1033   320    394    840.    8.     130. / AREA 1
*1034   320    804    660.    8.     130. / AREA 1
*1035   321    323    830.    8.     130. / AREA 1
*1036   321    535    150.    8.     130. / AREA 1
*1037   322    323    240.    8.     130. / AREA 1
*1038   322    529    380.    6.     130. / AREA 1
*1039   322    533    340.    8.     130. / AREA 1
*1040   322    534    170.    8.     130. / AREA 1
*1041   322    824    200.    6.     130. / AREA 1
```

Exhibit 2. PIPE DATA

PIPE DATA:

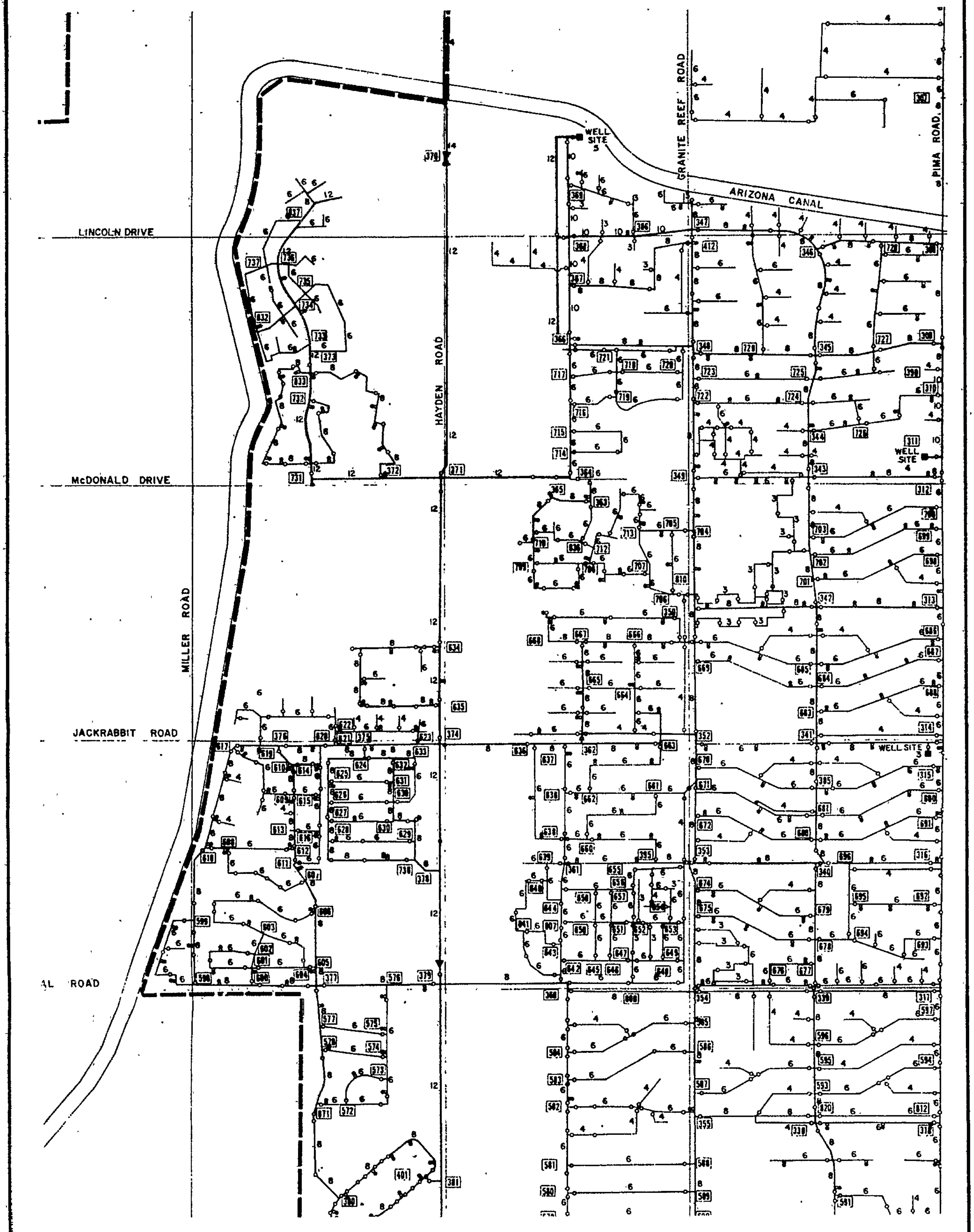
PIPE NO.	NODES FROM	TO	LENGTH	DIAM	COEF	FLOW RATE	VELOCITY	HEAD LOSS	HLOSS /1000
*1144	588	355	520.	8.0	130.0	27.17	0.17	0.01	0.02
*1145	388	356	1320.	12.0	130.0	854.17	2.42	2.50	1.89
1146	356	392	730.	8.0	130.0	141.79	0.90	0.36	0.49
1147	356	500	700.	6.0	130.0	102.50	1.15	0.76	1.09
1148	357	564	150.	6.0	130.0	13.83	0.16	0.00	0.03
*1149	569	357	360.	6.0	130.0	3.13	0.04	0.00	0.00
1150	358	359	230.	8.0	130.0	539.39	3.44	1.34	5.82
1151	358	556	120.	6.0	130.0	311.06	3.53	1.02	8.53
1152	359	382	1350.	12.0	130.0	271.60	0.77	0.31	0.23
1153	359	579	280.	6.0	130.0	256.93	2.92	1.68	5.99
*1154	379	360	1380.	8.0	130.0	86.81	0.55	0.27	0.20
1155	360	584	620.	6.0	130.0	74.98	0.85	0.38	0.61
*1156	641	360	710.	6.0	130.0	27.57	0.31	0.07	0.10
*1157	642	360	300.	6.0	130.0	47.66	0.54	0.08	0.26
*1158	808	360	650.	6.0	130.0	35.67	0.40	0.10	0.15
*1159	395	361	1050.	6.0	130.0	26.75	0.30	0.10	0.09
*1160	638	361	270.	6.0	130.0	98.91	1.12	0.28	1.02
1161	361	639	200.	6.0	130.0	63.18	0.72	0.09	0.45
1162	361	644	310.	6.0	130.0	62.48	0.71	0.14	0.44
1163	362	637	250.	8.0	130.0	277.77	1.77	0.43	1.70
*1164	663	362	810.	8.0	130.0	141.96	0.91	0.40	0.49
*1165	665	362	580.	8.0	130.0	158.52	1.01	0.35	0.60
1166	363	364	210.	8.0	130.0	198.75	1.27	0.19	0.92
*1167	710	363	770.	8.0	130.0	116.95	0.75	0.26	0.34
*1168	836	363	420.	6.0	130.0	96.40	1.09	0.41	0.97
1169	364	365	380.	6.0	130.0	198.75	2.26	1.41	3.72
1170	365	371	1320.	14.0	130.0	530.12	1.10	0.49	0.37
*1171	714	365	260.	6.0	130.0	347.23	3.94	2.72	10.46
*1172	367	366	650.	10.0	130.0	398.86	1.63	0.73	1.12
1173	366	717	150.	6.0	130.0	213.36	2.42	0.64	4.24
1174	366	721	650.	6.0	130.0	70.80	0.80	0.36	0.55
*1175	368	367	680.	10.0	130.0	464.18	1.90	1.01	1.49
1176	367	412	1770.	8.0	130.0	21.20	0.14	0.03	0.01
*1177	369	368	580.	10.0	130.0	729.07	2.98	1.99	3.43
1178	368	386	730.	10.0	130.0	247.11	1.01	0.34	0.46
1179	369	386	1110.	6.0	130.0	145.86	1.66	2.33	2.10
*1180	371	370	3430.	12.0	130.0	16.66	0.05	44.27	12.91
1181	371	372	660.	12.0	130.0	224.11	0.64	0.10	0.16
1182	371	634	1680.	12.0	130.0	285.97	0.81	0.42	0.25
1183	372	373	1870.	8.0	130.0	37.71	0.24	0.08	0.04
1184	372	731	730.	12.0	130.0	152.32	0.43	0.06	0.08
*1185	731	373	2200.	8.0	130.0	17.39	0.11	0.02	0.01
*1186	732	373	760.	12.0	130.0	62.76	0.18	0.01	0.02
1187	373	733	320.	12.0	130.0	77.77	0.22	0.01	0.02
1188	374	378	1330.	12.0	130.0	190.69	0.54	0.16	0.12
1189	374	623	260.	8.0	130.0	225.70	1.44	0.30	1.16
*1190	635	374	400.	12.0	130.0	244.73	0.69	0.07	0.19
*1191	636	374	1070.	8.0	130.0	192.28	1.23	0.92	0.86
1192	375	621	440.	8.0	130.0	37.27	0.24	0.02	0.04
*1193	623	375	610.	8.0	130.0	166.26	1.06	0.40	0.66

Exhibit 3. NODE DATA

NODE DATA:

NODE NO.	DEMAND (CFS)	(GPM)	ELEV	HEAD	PRESSURE	HGL ELEV
506	0.040	17.78	1228.	182.54	79.10	1410.54
507	0.042	18.76	1228.	182.50	79.08	1410.50
508	0.040	17.78	1230.	180.46	78.20	1410.46
509	0.092	41.48	1232.	178.42	77.32	1410.42
510	0.073	32.59	1234.	176.26	76.38	1410.26
511	0.079	35.55	1236.	174.03	75.41	1410.03
512	0.070	31.60	1239.	170.82	74.02	1409.82
513	0.042	18.76	1240.	169.80	73.58	1409.80
514	0.057	25.68	1241.	168.80	73.14	1409.80
515	0.068	30.61	1236.	174.26	75.51	1410.26
516	0.031	13.83	1238.	172.14	74.59	1410.14
517	0.037	16.79	1237.	173.16	75.04	1410.16
518	0.013	5.93	1237.	173.27	75.09	1410.27
520	0.044	19.75	1235.	175.34	75.98	1410.34
521	0.024	10.86	1230.	180.77	78.33	1410.77
522	0.037	16.79	1238.	172.01	74.54	1410.01
524	0.042	18.66	1240.	169.87	73.61	1409.87
525	0.033	14.81	1239.	170.93	74.07	1409.93
526	0.068	30.61	1240.	169.93	73.64	1409.93
527	0.033	14.81	1241.	168.83	73.16	1409.83
528	0.0	0.0	1243.	166.82	72.29	1409.82
529	0.035	15.80	1243.	166.79	72.28	1409.79
530	0.0	0.0	1244.	165.79	71.84	1409.79
531	0.037	16.79	1244.	165.79	71.84	1409.79
532	0.018	7.90	1244.	165.79	71.84	1409.79
533	0.0	0.0	1244.	165.79	71.84	1409.79
534	0.0	0.0	1243.	166.79	72.28	1409.79
535	0.002	0.99	1243.	166.79	72.28	1409.79
536	0.031	13.83	1245.	164.83	71.42	1409.83
537	0.064	28.64	1244.	165.83	71.86	1409.83
538	0.031	13.83	1245.	164.83	71.43	1409.83
539	0.035	15.80	1245.	164.80	71.42	1409.80
541	0.064	28.64	1245.	164.80	71.42	1409.80
542	0.070	31.60	1248.	161.82	70.12	1409.82
543	0.0	0.0	1247.	162.82	70.56	1409.82
544	0.033	14.81	1249.	160.85	69.70	1409.85
545	0.066	29.63	1247.	162.92	70.60	1409.92
546	0.020	8.89	1247.	162.94	70.61	1409.94
547	0.024	10.86	1249.	161.03	69.78	1410.03
548	0.035	15.80	1249.	161.16	69.84	1410.16
549	0.051	22.71	1244.	165.83	71.86	1409.83
550	0.035	15.80	1245.	164.83	71.43	1409.83
551	0.035	15.80	1245.	164.84	71.43	1409.84
552	0.035	15.80	1246.	163.86	71.01	1409.86
553	0.070	31.60	1246.	163.90	71.03	1409.90
554	0.070	31.60	1248.	162.41	70.38	1410.41
555	0.055	24.69	1248.	162.56	70.44	1410.56
556	0.040	17.78	1248.	165.24	71.60	1413.24
557	0.040	17.78	1248.	163.77	70.97	1411.77
558	0.040	17.78	1247.	163.87	71.01	1410.87

Exhibit 4. GRAPHIC REPRESENTATION OF PIPE-NODE CONFIGURATION



- A simulation of planned airport industrial park development showed that the water demand would exceed the system's capacity, given planned landscaping and green belt water requirements. The City's planners changed landscaping requirements to native (arid) plantings only on airport area developments.

- Water demand at a large planned subdivision designed to serve residents from a City storage reservoir was simulated. Results showed that the reservoir could not serve as a source of water supply to the planned development. At peak demand, the reservoir would empty faster than it could be refilled. Approval of the subdivision was delayed until additional production, storage and transmission facilities could be provided.

- The City was scheduled for an Insurance Service Office (ISO) survey to determine fire protection capability. The survey was to take place during a time of moderate to heavy water demand. A poor ISO rating affects insurance rates throughout the area, so ability to deliver water on demand at approved fire flow rates is extremely important.

  The model was used to simulate fire flow requirements at specific locations, and a number of deficiencies were identified. In the short run, these simulations gave City operations crews sufficient information to allow manual adjustment of the system in the event of a fire to provide adequate fire flow at key locations. In the long run, the simulation information is being used to increase fire flow by looping lines, installing booster pumps, adding storage reservoirs, and replacing undersized or deteriorated lines.

These are some of the more dramatic results of the model's application. Other uses include:

- Simulation of system development alternatives for purposes of cost/benefit analyses;

- Simulation of effects of situations such as power or well failure, and development of emergency operating plans to maintain water supply until the situation is corrected;

- Development of detailed information on water quality at any point in the system under various operating conditions, so City staff are able to better serve the consumer who may need to know, for example, how much fluoride is in his baby's drinking water. Swimming pool contractors, carpet cleaners and water softener contractors found this service particularly useful; and

- Detailed pressure and flow information throughout the system to assist contractors and citizens in designing water services and sprinkler systems.

SUMMARY

Overall, the application of a Water Computer Model has enabled the City of Scottsdale to move in a rational and expedient manner to improve its water system efficiently and economically. A model, no matter how theoretically sound, how carefully tested, refined and implemented, is only as valuable as the worth derived from its applications. In Scottsdale, informed and concerned staff, from field level through top management, have proven the Water Computer Model's worth.