APPENDIX C - OPERATIONS MODEL DESCRIPTION

APPENDIX C

OPERATIONS MODEL DESCRIPTION

C.1 INTRODUCTION

This appendix describes a computer model of the City's proposed Integrated Local Water Supply (ILWS) system that has been developed to simulate system operation under various scenarios. The primary purpose of the operations model is to aid in the evaluation of concept design alternatives for the Equus Beds ASR Project by testing the reliability and impacts of the proposed system under various simulated conditions using historical streamflow.

C.2 HISTORIC STREAM DISCHARGE

The operations model for the ILWS system requires estimates of historic stream discharge at several locations in the project vicinity. In the United States, stream discharge data are collected primarily by the U.S. Geological Survey (USGS). Although the USGS maintains a network of stream gaging stations located throughout the country, it does not operate gaging stations at all points of interest for this study. Therefore, it was necessary to derive some of the stream discharge data used in the operations model from those data that are available. This section describes the stream discharge data that are available and procedures used to estimate discharge at other locations.

The USGS gaging stations used in the development of the operations model are listed in Chapter 3, Table 3-1, along with other pertinent data on these gages. The locations of these gages are shown on Figure 3-2. The period of record for each of these gages is also listed in Table 3-1. The recorded mean daily discharge data available at each of these gages were obtained from the National Water Information System (NWIS-W) via the Internet (USGS, 1999).

In this analysis, the recorded discharge data retrieved from the USGS are treated as natural discharge data. Natural discharge is the discharge that would have occurred in a stream without any man-made influences, such as construction of a reservoir or withdrawals for water supply or irrigation. This assumption is generally considered valid for all gages listed in Table 3-1, except those on the mainstem of the Arkansas River and the lower Ninnescah River. Numerous reservoirs and diversions in the Arkansas River basin exist upstream of Wichita, but the mainstem of the Arkansas River is not the primary focus of this study. Also, the primary human influence on the lower Ninnescah River is Cheney Reservoir. Therefore, the extensive effort required to naturalize the discharge data for these streams is not considered justified.

Several of the stream gages listed in Table 3-1 were adopted as system nodes in the operations model. Several additional nodes at critical locations were also added. For those system nodes located on streams, it is desirable to have as long a period of streamflow record as possible. This allows the operations model to demonstrate the operation of the ILWS system through multiple drought cycles.

Only two stream gages are available in the project vicinity that have long, continuous records. These are the Little Arkansas River gage at Valley Center, Kansas (Valley Center gage) and the

Arkansas River gage at Arkansas City, Kansas (Arkansas City gage). These two gages have been in continuous operation since June 1922 and October 1921, respectively. Because of the records available at these two gages, a 74-year simulation period — water years 1923 to 1996 (10/1/1922 - 9/30/1996) — is used in the operations model. Historic streamflow at the other system nodes is estimated by combining the records of two or more gages and/or by statistical methods. The synthesis of the historic streamflow records at each stream node is discussed in the following section.

C.3 DERIVATION OF STREAMFLOW ESTIMATES

The discharge record at each stream node is derived using the following procedure.

- Where and when available, actual recorded discharge data at the target location are used.
- For locations or time periods not covered by actual recorded data, use data recorded at another representative stream gage to estimate discharge at the target location. Preferably, this stream gage should be located on the same stream.
- If there are overlapping discharge records at the target location and at the source gage, use regression analyses to develop an adjustment ratio for the two gages. If there is no overlap, use a simple drainage area ratio instead.

The specific source(s), and derivation when applicable, of the stream discharge data used in the operations model is described in Table C-1, along with the source(s) and means used to estimate these discharge data.

The operations model requires estimates of the unregulated inflow at each system node. Unregulated inflow is the incremental runoff at a node that occurs between the node and any upstream nodes. Only the system nodes listed in Table C-1 have unregulated inflow. None of the other system nodes have unregulated inflow. For the nodes listed in Table C-1, their unregulated daily inflow was calculated, using the discharge estimates described above, by subtracting any flow at upstream nodes. For example, the unregulated inflow at Node 100 (Ninnescah River near Peck) is calculated by subtracting out the estimated flow at Node 90 (Cheney Reservoir inflow) for each day in the 74-year simulation period. Due to inaccuracies in these discharge estimation procedures, the incremental discharge at some nodes is negative on some days, although generally small in magnitude. The operations model treats negative inflow as a flow depletion.

Over the simulation period for the operations model, there have been periods of extreme drought and flood. The variability of streamflow in the project vicinity is illustrated in Figure 3-4. Review of this figure shows that there have been two serious drought periods during the simulation period, one occurred in the 1930's and the other in the mid-1950's. During these drought years, the discharge in area streams was typically about 10 percent of the average. In contrast, during 1993 discharge was several times the average.

Table C-1 Stream Discharge Estimates

Model Node No.	Node Name	Source Gage No.	Applicable Time Period	Adjustments		
				Drainage Area Ratio	Regres-sion Coef.	R^2
10	Arkansas River near Hutchinson, KS	07143400	10/22–09/34	0.992	---	---
		07144300	10/34-09/59	---	0.536	0.959
		07143330	10/59–09/96	---	---	---
20	Arkansas River near Maize, KS	07143400	10/22–09/34	0.998	---	---
		07144300	10/34–02/87	---	0.789	0.971
		07143375	03/87–09/96	---	---	---
30	Little Arkansas River at Alta Mills, KS	07144200	10/22–06/73	---	1.022	0.993
		07143665	07/73–09/96	---	---	---
40	Little Arkansas River at Halstead			see Note	---	---
50	Little Arkansas River near Sedgwick, KS	07144200	10/22–09/93	---	1.112	0.995
		07144100	10/93–09/96	---	---	---
60	Little Arkansas River at Valley Center, KS	07144200	10/22–09/96	---	---	---
70	Little Arkansas River at Mouth	07144200	10/22–09/96	1.049	---	---
80	Arkansas River at Wichita, KS	07146500	10/22–09/34	---	0.593	0.970
		07144300	10/34–09/96	---	---	---
90	NF Ninnescah River at Cheney Reservoir	07146500	10/22–09/50	0.018	---	---
		07144800	10/50–09/64	0.969	---	---
		07146500	10/64–09/65	0.018	---	---
		07144780	10/65–09/96	1.207	---	---
100	Ninnescah River near Peck, KS	07146500	10/22–03/38	---	4.803	0.958
		07145500	04/38–09/96	---	---	---
110	Arkansas River at Arkansas City, KS	07146500	10/22–09/96	---	---	---

Note: Calculated using average of unit daily runoffs at Alta Mills and Sedgwick times contributing drainage area at Halstead of 757 square miles.

C.4 RESERVOIR EVAPORATION

The ILWS system includes two principal water storage facilities. These are Cheney Reservoir and the Equus Beds Aquifer. Since water stored in Cheney Reservoir is exposed to the atmosphere, evaporation from this reservoir can represent a significant water loss. Evaporative losses from the Equus Beds aquifer are assumed to be negligible.

The City has collected pan evaporation data at Cheney Reservoir since September 1965, just after the reservoir was placed in service. There are no evaporation data available at the reservoir prior to this time, but there are other sources of evaporation data from the general vicinity. These data are used with Burns & McDonnell's ETCALC evaporation model to estimate evaporation rates at Cheney Reservoir prior to September 1965. This analysis is described in detail by Burns & McDonnell (1997).

Gross evaporation rates are a function of meteorological conditions, such as temperature, cloud cover, and wind, which vary seasonally. These conditions do not however vary significantly from year to year, so annual gross evaporation rates vary only within a fairly narrow range. However, net evaporation rates can vary significantly from month to month and year to year. Net evaporation is the difference between the amount of water that may evaporate from a water surface and that which is replaced by direct precipitation. Since precipitation rates can vary significantly, net evaporation rates will also. Table C-2 presents statistics on monthly gross and net evaporation rates at Cheney Reservoir. Figure C-1 shows the variability in annual gross and net evaporation rates.

C.5 WATER DEMAND

The City's projected raw water supply demands are listed in Table C-3. Included in this table are average daily and maximum daily demands. For the operations model, it is necessary to estimate the system water demand for each day of the year. Daily water demands were estimated using the total demand data (Table C-3) and the daily demand distribution shown in Figure C-2.

Table C-2 Summary of Cheney Reservoir Evaporation Rates

Month	Gross Evaporation (inches)			Net Evaporation (inches)		
	Average	Minimum	Maximum	Average	Minimum	Maximum
Jan	1.16	0.65	1.69	0.57	-3.53	1.62
Feb	1.30	0.81	1.87	0.62	-0.79	1.87
Mar	1.96	1.37	2.54	0.57	-4.25	2.33
Apr	2.70	1.99	3.28	0.85	-6.34	3.02
May	3.46	2.93	4.42	0.63	-4.82	3.73
Jun	4.59	3.90	5.43	1.55	-3.08	4.79
Jul	5.72	4.78	7.06	3.34	-4.58	6.74
Aug	5.46	4.56	6.71	3.27	-0.71	6.69
Sep	3.93	3.29	4.82	1.65	-3.60	4.41
Oct	2.92	2.17	3.69	1.30	-1.70	3.45
Nov	1.73	1.39	2.08	0.64	-2.36	2.03
Dec	1.25	0.63	1.60	0.46	-1.94	1.29
Annual	36.19	34.24	39.90	15.46	1.39	27.42

Figure C-1 Annual Reservoir Evaporation at Cheney Reservoir

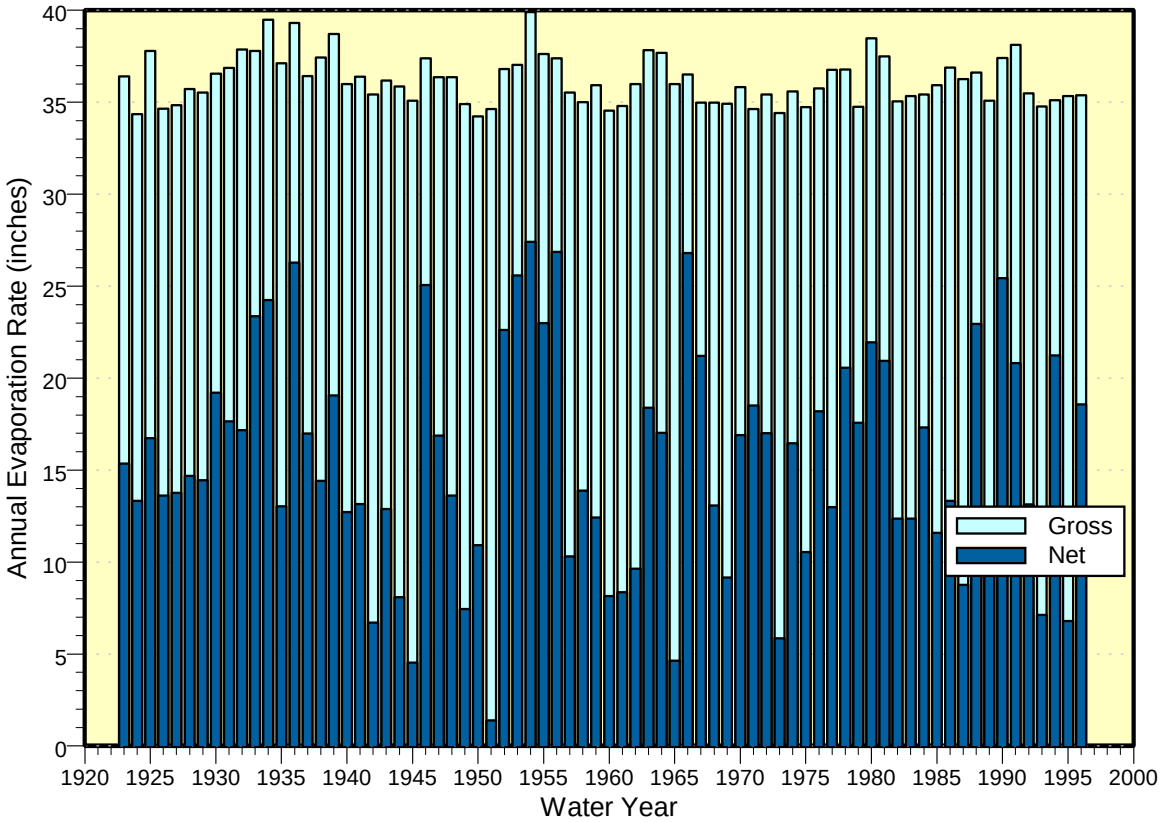


Table C-3
City of Wichita
Projected Water Demands

Year	Daily Raw Water Demand (MGD)	
	Average	Maximum
2000	70.4	140.3
2010	84.6	168.6
2020	92.8	184.9
2030	99.4	198.1
2040	105.7	210.6
2050	111.6	222.4

The daily distribution shown in Figure C-2 is based on actual 1991 water usage data for the City. To represent the potential impacts of water conservation programs, the daily demand distribution was segregated into zones based on percentages of the total annual water demand. The colored bands in Figure C-2 represent these demand zones. For example, the top 5 percent of the total annual water demand (95-100 percent by volume) occurs when daily demands exceed approximately 124 percent of the average day demand. Stated differently, limiting peak daily demands to 124 percent of the average day demand would decrease annual demand volumes by 5 percent and the maximum day by 38 percent. This limitation is consistent with a conservation program that limits lawn watering. The specific demand zone boundaries are listed in Table C-4.

Figure C-2 -2 Daily Demand Distribution

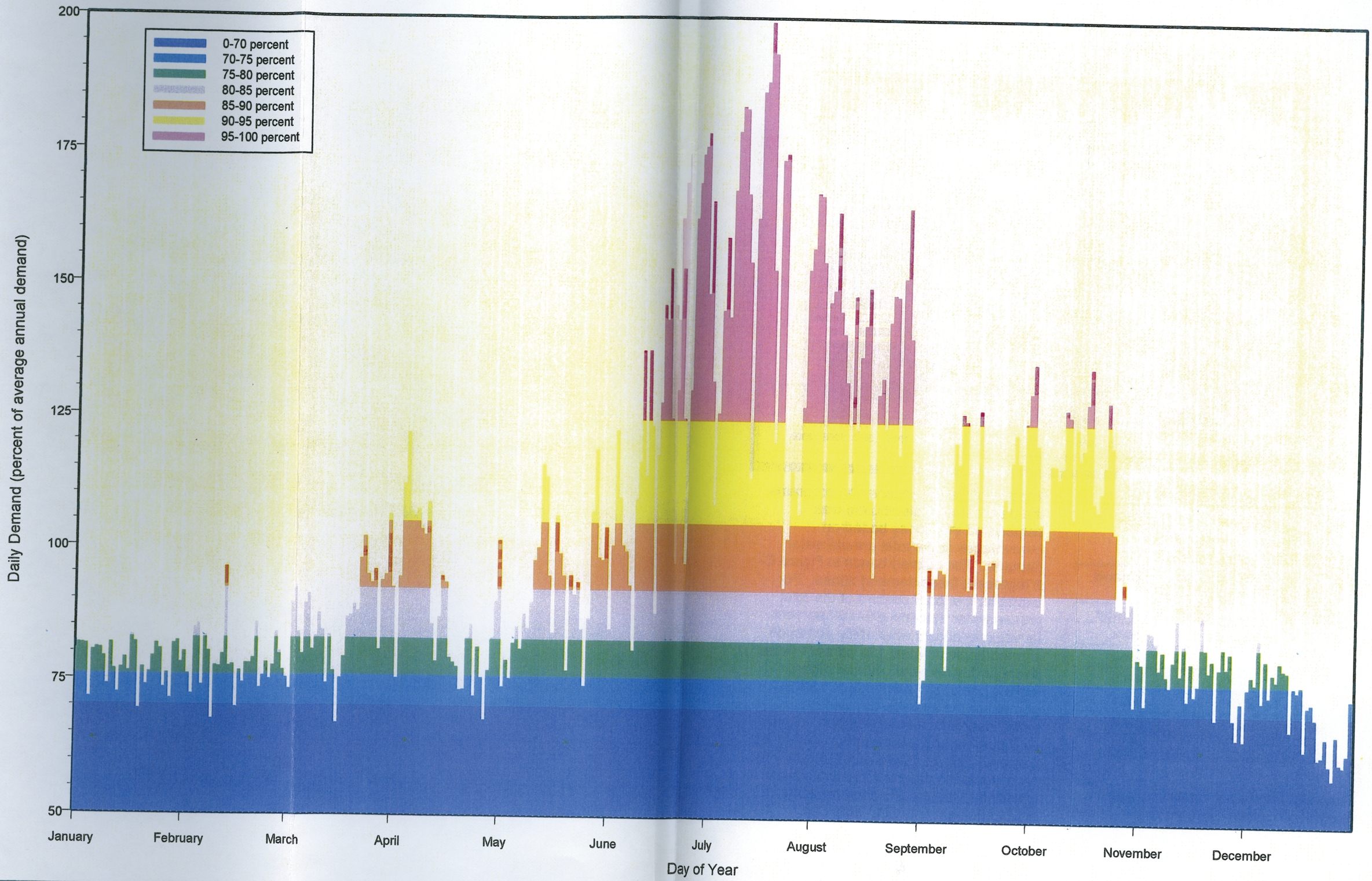


Table C-4 Demand Zones

Demand Zone (% of Annual)	Range in Daily Demand (% of avg. day)
0– 70	0- 70.3
70- 75	70.3- 75.8
75- 80	75.8- 82.8
80- 85	82.8– 92.2
85- 90	92.2-104.9
90- 95	104.9-124.3
95-100	124.3–199.3

Operations model scenarios were run with and without additional conservation.

C.6 RESERVOIR PHYSICAL DATA

The two water storage facilities included in the ILWSP system are Cheney Reservoir and the portion of the Equus Beds aquifer in the City's well field. The relationship between water levels, water surface areas and storage in Cheney Reservoir are listed in Table C-5 and shown graphically in Figure C-3. The top of the designated fish and wildlife pool at Cheney Reservoir is at elevation 1,392.9 feet while the top of the conservation pool is at elevation 1421.6 feet. These two elevations represent the limits of the conservation (water supply storage) pool at Cheney Reservoir. That is, the City can store water in the reservoir up to elevation 1,421.6 feet and withdraw water from the reservoir, when needed, down to elevation 1,392.9 feet.

Data on water levels in the Equus Beds and corresponding storage are presented in Table C-6. Also listed in this table are estimates of the infiltration gain rates from the Arkansas River and seepage loss rates to the Little Arkansas River. Both of these rates are dependent on the storage contents of the aquifer. A graphical representation of these data is shown in Figure C-4.

As stated above, the storage deficits listed in Table C-6 are relative to the amount of water contained in the Equus Beds aquifer in the City's well field area under pre-development conditions. As a result of well development and pumping by the City and irrigators, the water stored in the aquifer had declined by about 200,000 acre-feet by 1993. One of the goals of the ILWS Plan is to limit periods when the aquifer storage deficit exceeds 200,000 acre-feet.

C.7 OPERATIONS MODEL ARCHITECTURE

The operations model for the ILWS system was developed using Burns & McDonnell's Reservoir Network (RESNET) simulation model (Foster, 1989). This computer model represents the stream/reservoir system being simulated as a circulating network. This network representation allows the RESNET model to efficiently determine an optimum solution in each daily time step using network optimization techniques. This architecture makes it possible for RESNET to simulate systems of virtually unlimited complexity.

A schematic of the operations model for the ILWS system is shown in Figure C-5. In the ILWS system, water can be supplied to the City's water treatment plant(s) — Node 200 in model schematic — from a number of sources. These sources and their supply limits are shown in Figure C-6. Further discussion of these supply sources is provided below.

Cheney Reservoir: The City's original water right for Cheney Reservoir allowed for a withdrawal up to 47 MGD. This

Table C-5 Cheney Reservoir, Elevation-Area-Storage Data

Elevation (feet)	Surface Area (acres)	Storage (acre-feet)	Elevation (feet)	Surface Area (acres	Storage (acre-feet)
1,370	14	13	1,420	8,976	152,222
1,380	445	1,545	1,430	12,835	260,557
1,390	1,504	10,241	1,440	17,466	411,058
1,400	3,291	33,761	1,450	23,387	616,350
1,410	5,785	78,897	---	---	---

Figure C-3 Cheney Reservoir Elevation-Area-Storage

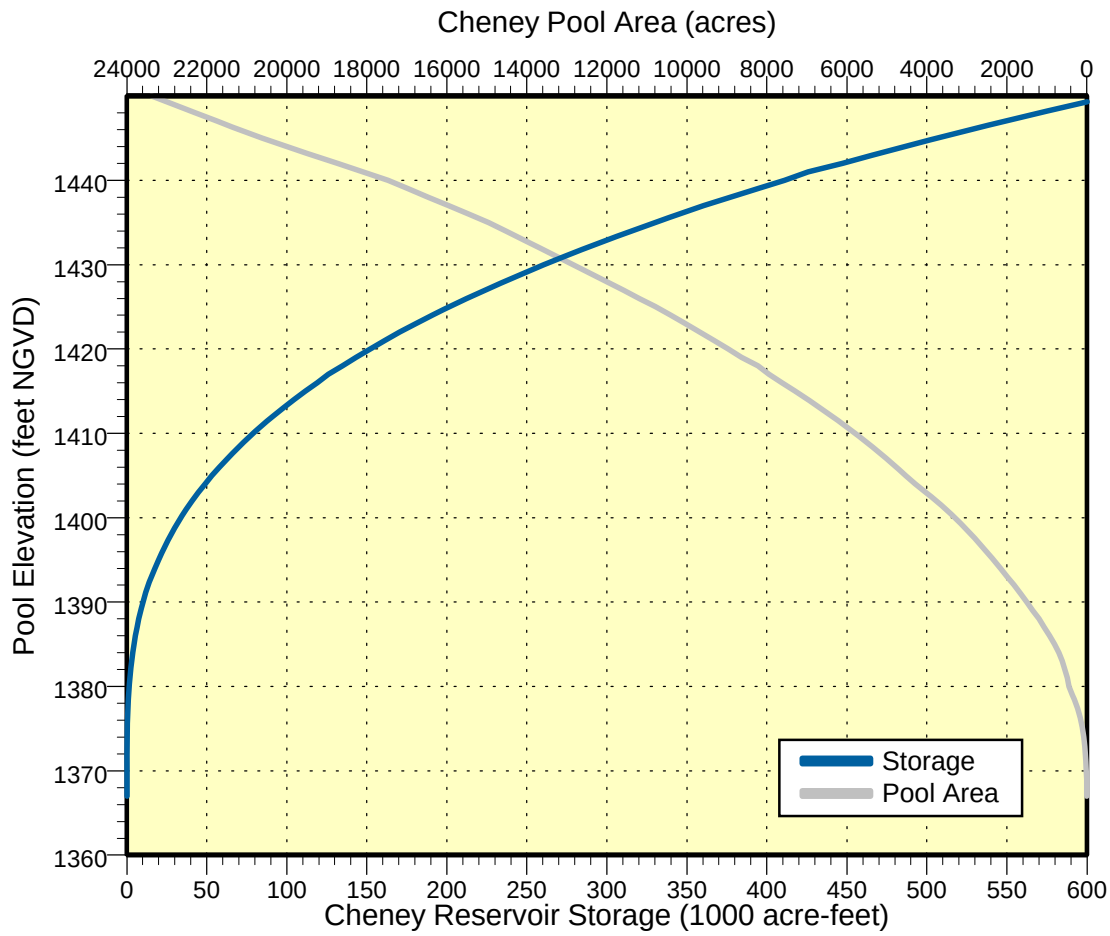


Table C-6 Equus Beds Elevation-Storage-Gain-Loss Data

Elevation (feet)	Storage Deficit (acre-feet)	Gain from Arkansas River (cfs)	Loss to Little Arkansas River (cfs)
1,342	647,233	138.2	-2.0
1,360	429,067	90.5	8.2
1,366	356,345	74.5	11.6
1,370	307,864	63.9	13.9
1,375	248,468	57.3	19.8
1,380	196,696	50.2	29.2
1,385	140,879	40.3	41.9
1,390	79,804	29.1	56.3
1,395	14,697	17.7	72.0
1,396	0	15.1	75.2

Figure C-4 Equus Beds Elevation-Storage

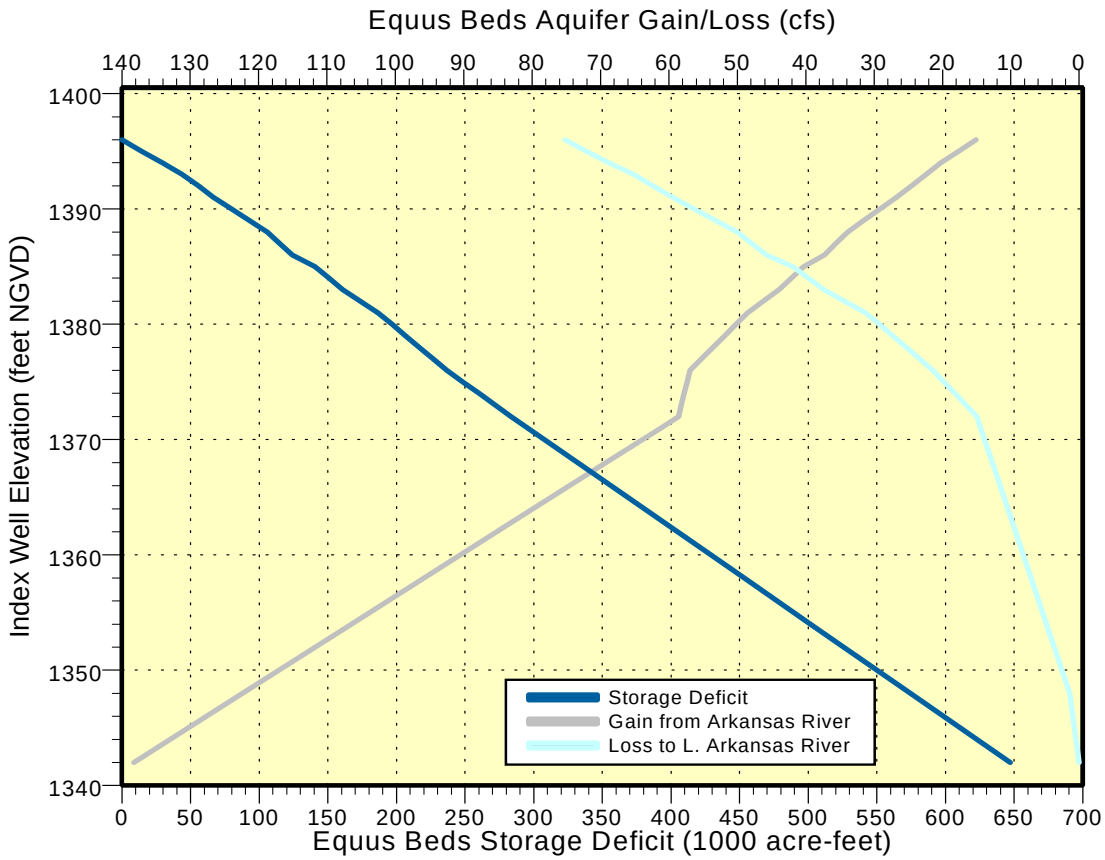


Figure C-5 Operations Model Schematic

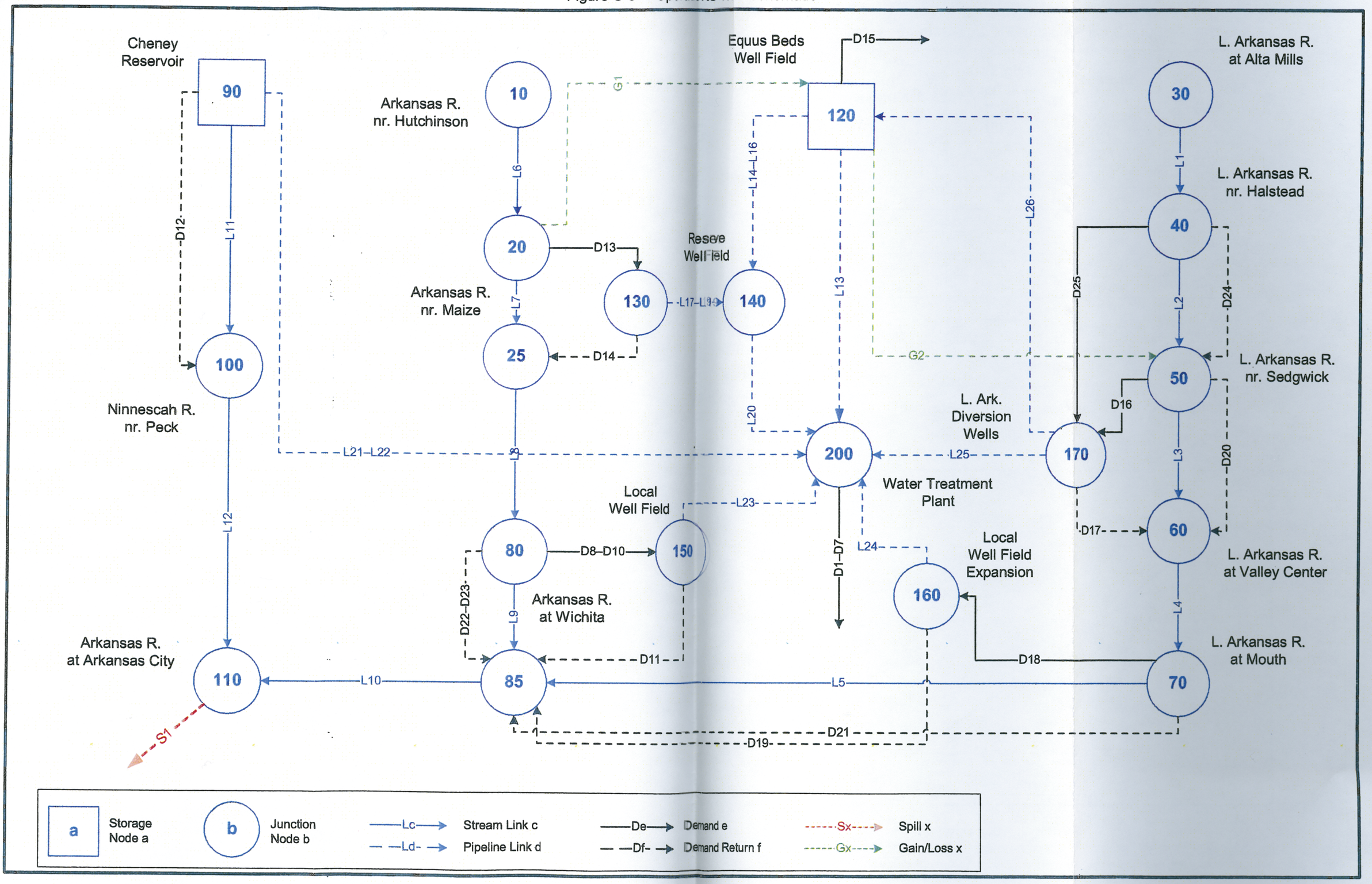
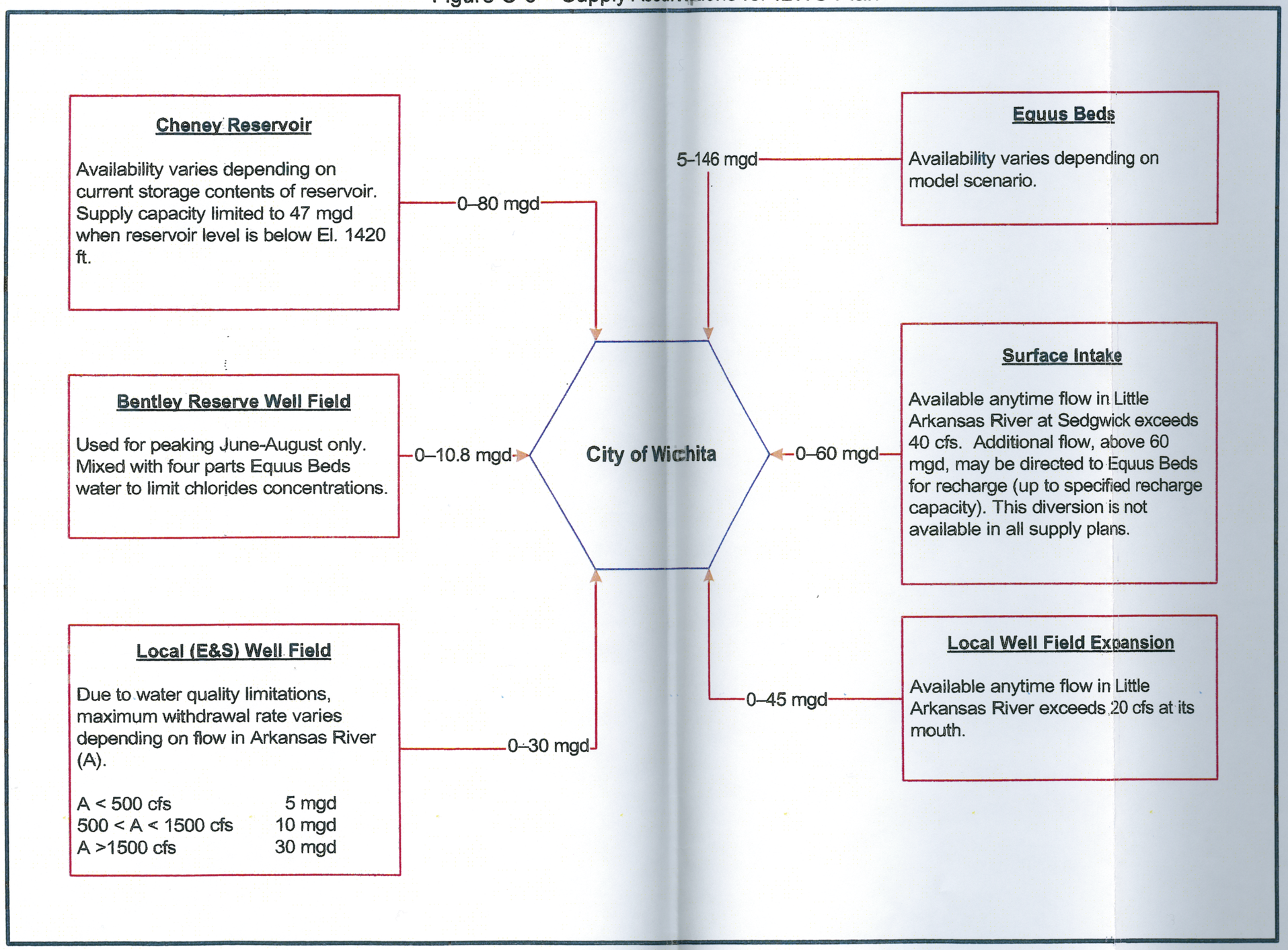


Figure C-6 Supply Assumptions for ILWS Plan



withdrawal limit was based on the estimated reservoir firm yield, which has since been revised downward. When the reservoir's pool level is at or below normal (elevation 1,421.6 feet), the operations model limits the maximum withdrawal rate to 47 MGD.

After a flood event, when there is water stored temporarily in the reservoir's flood control pool, the maximum withdrawal rate is increased to 80 MGD to allow the City to capture more of these floodwaters before they are released downstream. While the reservoir's two existing outlets have a combined discharge capacity of 3,600 to 5,900 cfs,[1] the operations model assumes that the flood control pool would be evacuated at a constant rate of 2,000 cfs. This release rate is considered to be fairly conservative (that is, high) since it was derived considering the existing downstream channel capacity, which is reported to be 1,900 cfs. Although the Corps makes all decisions about flood control releases, it was assumed that the Corp would generally be reluctant to release water from Cheney at a rate that exceeds the downstream channel capacity unless conditions at the time warranted more extreme action.

The operations model attempts to preserve the water stored in the conservation pool at Cheney Reservoir by using other available sources first. When it is necessary to drawdown Cheney Reservoir to meet current water demands, the model attempts to balance withdrawals from Cheney Reservoir and the Equus Beds Aquifer.

Equus Beds: The City's Equus Beds well field is assumed to have a capacity of up to 146 MGD. For maintenance reasons, it is assumed that at least a few wells would be operated at all times so the minimum withdrawal rate from the Equus Beds is 5 MGD. As stated above, the operations model attempts to preserve the water stored in the aquifer and maximize artificial recharge when possible.

The regulations associated with the proposed aquifer storage and recovery system are still under development by the State. However, since these regulations could have a significant impact of the operation of the ILWS system, some basic assumptions regarding these regulations are made and incorporated into the operations model. Although the assumptions used in the operations model may later prove to be inaccurate, the overall performance of the system is not expected to vary drastically from the results reported from the operations model. The specific regulatory assumptions used in the operations model include:

- The aquifer has 200,000 acre-feet of storage available. This is the difference in the estimated aquifer storage under pre-development conditions and those reported in January 1993. By artificially recharging the aquifer, the City can obtain recharge credits up to a maximum of 200,000 acre-feet.

[1] The uncontrolled morning glory spillway has a discharge capacity of 3,000 cfs at the top of the surcharge pool. When water levels are within the flood control pool (elevation 1,421.6–1,429.0 feet), this discharge is estimated to range from zero to about 2,000 cfs. Over these same pool elevations, the river outlet has a discharge capacity that ranges from 3,600 to 3,900 cfs. Therefore, the total discharge capacity from the flood control pool ranges from 3,600 to about 5,900 cfs.

- The recharge account is credited with any water delivered to the aquifer for recharge and any infiltration gains from the Arkansas River. Aquifer leakage amounts to the Little Arkansas River are debited from the recharge account.

- When the City withdraws water from the aquifer, these volumes are subtracted from the recharge account until such time as it is exhausted. As long as the City has recharge credits, they can pump from the aquifer at a rate up to 146 MGD.

- Once all recharge credits are exhausted, the City can continue withdrawing water under its base water right of 40,000 acre-feet per year. The maximum allowable pumping rate under this water right is approximately 78 MGD.

The natural aquifer recharge is estimated to average about 3.2 inches per year, or a total of 18,800 acre-feet per year. Although the actual natural recharge will vary with the amount of precipitation, in the operations model it is assumed to remain constant each year and be distributed evenly across each day of the year.

Irrigators in the Equus Beds Well Field area are assumed to withdraw an average of 26,500 acre-feet per year from the aquifer. As with natural recharge, these withdrawals are assumed to remain constant each year. The volume of water withdrawn each year for irrigation is assumed to be evenly distributed from mid-May through mid-September.

Bentley Reserve Well Field: Because of water quality limitations, the Bentley Reserve Well Field would be used only during times of peak water demand, assumed to be June–August. This well field will has a maximum withdrawal rate of 10.8 MGD. In order to mitigate the high chlorides concentration in the water from this well field, the operations model will mix this water with three parts Equus Beds water.

Surface Intake: When the flow in the Little Arkansas River exceeds 40 cfs, the surface intake may withdraw water from the river up to a maximum of 60 MGD. This water could be delivered to the Equus Beds well field for recharge or delivered directly to the water treatment plant for immediate use. This last option, direct delivery from the surface intake to the water treatment plant, was not included in any of the alternatives investigated for the EIS.

Local (E&S) Well Field: Because of its location near the Arkansas River, hydrogeologic studies have shown there is a strong hydraulic connection between the river and the Local Well Field aquifer. Therefore, the quality of the water available from this source closely matches that of the river. It has been shown that the water quality of the Arkansas River improves at higher flow rates so the maximum pumping capacity of the Local Well Field is tied to flow rates in the river as shown in Figure C-6.

Local Well Field Expansion: The collector wells associated with the Local Well Field Expansion will be installed adjacent to the Little Arkansas River so pumping these wells will induce infiltration from the river. These collector wells will have a maximum capacity of 45 MGD, but can only be operated when the flow in the Little Arkansas River exceeds 20 cfs at its mouth.

C.8 REFERENCES

Burns & McDonnelll. 1997. *"Cheney Reservoir Yield Study."* City of Wichita, Kansas, Water & Sewer Department, 1997.

Foster, G. L. 1989. "*RESNET: A Reservoir Network Simulation Model."* Unpublished master's thesis, University of Kansas, Lawrence.

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