Missouri
Water Supply Studies

By

Jerry Edwards
Sherry Chen
And
Steve McIntosh

FORWARD

The Missouri Department of Natural Resources, Water Resource Center and Missouri's Safe Drinking Water Program has the responsibility of assisting state residences in assuring an adequate and safe water supply. The purpose of the water supply study is to ensure availability of water information for effective decision-making by communities and MoDNR program managers. In addition, this study is expected to be used to determine and allocate existing water supplies. The scope of this study primarily addresses surface water supplies for cities and communities that are expected to experience water shortages during an extended drought. Surface water supplies consist of lakes, rivers and streams and in many cases combinations of both.

PREFACE

This 2005 Water Supply Report is a result of the State's Water Resources Law water planning mandates and done under the direction of the Missouri Drought Assessment Committee. This report and several previous compact disc versions since 2000 have examined communities at risk and their ability to sustain themselves during drought. Many of these water supplies had only months of water supply assured during recent droughts of 1999-2000 and 2002-2004. Most of the communities are located in the northern and western areas of Missouri. These areas are groundwater poor and dependent upon surface water supplies. Four community supplies that draw most of their water supplies from streams in northern and southern Missouri were also examined for firm yield capability. This study is not a complete evaluation of all communities at risk of depletion of water. Updates to this 2005 Water Supply Report are expected and will be produced by compact disc until the next published edition is planned in 2008.

The authors determined that a hard cover edition was needed to better illustrate to a wider audience the critical water quantity needs of many marginal water supplies in the state.

Contents

List of Figures

Figure:	Description	Page

Streams and River Analysis Figures

Figure: Description Page

50. Perryville: Saline Creek

60. Poplar Bluff: Black River

Water Supply Projections

List of Tables

INTRODUCTION

This report was prepared by Missouri Department of Natural Resources to address water supply needs and distribution as a result of extremely dry weather during the drought beginning in 1999 and extending into year 2004. Reservoirs were surveyed by USGS to determine the remaining storage of water for use by cities, communities, and rural water districts. This data is used for drought planning in establishing a network of available water supplies to be used to distribute to needed locations in North and West Central Missouri where water needs are met by surface sources. This report is not meant to be used as a regulatory manual.

Surface water supplies studied and contained in this report are:

Water Supply Systems

1. Adrian
2. Breckenridge
3. Butler
4. Brookfield
5. Cameron (4 lakes)
6. Concordia (E.A. Pape Lake)
7. Creighton
8. Dearborn
9. Drexel
10. Garden City (2 lakes)
11. Green City
12. Hamilton
13. Harrison County Rural Water District #1
14. Higginsville
15. Holden
16. James Port
17. King City (4 lakes)
18. Lamar
19. Middle Fork Grand River (Stanberry)
20. Milan (3 lakes) (Elmwood, Golf Course and Shatto Lakes)
21. Marceline
22. Memphis (Lake Show Me and Old City Lake)
23. Moberly
24. Monroe City RTE “J”
25. Ridgeway
26. Sedalia (Spring Fork Lake)
27. Shelbina
28. Unionville (Lake Mahoney and Lake Thunderhead)

Also, this report contains Stream Flow analysis to selected cities obtaining their water supply from rivers and streams. These streams are:

1. Black River at Poplar Bluff
2. Saline Creek at Perryville
3. Shoal Creek at Joplin
4. Thompson River at Trenton

In addition, staff gages were installed in five lakes. The gages will aid in making estimates of remaining water supplies and projections during drought periods. These lakes are:

1. Butler
2. Eagleville, Harrison County Rural Water District #1
3. Hamilton
4. Marceline
5. Monroe City Rte. “J“

Additional lakes planned for study during year 2005 are:

1. Kirksville	Forest Lake
2. Kirksville	Hazel Creek Lake
3. Bowling Green	City Lake #1
4. Bowling Green	City Lake #2
5. Vandalia	City Lake

Lakes planned to be surveyed in 2005 and now delayed.

1. Fayette	DC Rogers Lake
2. Fayette	Old City Lake

ACKNOWLEDGEMENTS

Missouri Drinking Water Program staff members contributed to this project. They provided funding, direction and assistance to the study for communities having or expecting to have water shortage problems. Persons contributing were Jerry Lane, Don Scott, Everett Baker, and Bill Hills.

The United States Geological Survey staff located in Rolla, Missouri made field surveys of lakes.

EXECUTIVE SUMMARY

Missouri Department of Natural Resources Water Resources Program Surface Water Supply Staff has prepared an analysis of 34 communities water systems within Missouri. These include 30 lake systems and four systems using streams as their main water supply source. These systems are mostly in the north and western part of the state. Many of the cities and water supply districts in northern and western Missouri must obtain their supplies from surface water sources in areas where there is either a lack of available wells, poor water quality or both. Two of the southeastern streams studied are the exception. They are Black River at Poplar Bluff and Saline Creek at Perryville.

The objective of this water supply study is to provide technical hydrology and water resource engineering assistance to communities on how to allocate their water supplies during the critical drought of record in order to satisfy their needs during an extended multi-year dry episode. How we manage our water greatly effects the well being and economic stability of the area.

Scenario illustrations are presented for several communities to assist local decision-makers in allocating scarce water supplies. Projecting these scenarios upon current water demands through the most severe drought of record by placing optimum demands upon the reservoirs, streams, and off channel storage facilities in area will assist community leaders in determining if additional water supplies must be found or developed to advert water supply emergencies.

The 1950's drought is the most severe extended drought of record for Missouri. The time period 1951 through 1959, the “drought of record” was used as a base for determining the adequacy of present reservoir water supply capability.

Several of the examined water supply systems are from a collection of surface water sources, which can include several small lakes in series or tandem and often supplemented by in-stream diversion pumps. These analyses were made for some of the most critical supplies. Cities usually use two sources to supply their needs. These sources are lakes and flowing streams. Water stored in lakes comes from rainfall runoff to the lakes. Many of the lakes are too small in size and drainage area to satisfy local needs. As a result, the supply provided by the lakes must be supplemented by other sources. A common practice is to pump from streams into the lakes during high stream flows in an attempt to keep water levels in lakes near full. During droughts one can expect the streams to dry up or stream flow to be so low that pumping cannot be achieved. Basic engineering programs were used to study lake capacities and stream flows.

Staff gages are planned to be or have been installed on five of the lakes. By using these reservoir stage gages and with the analysis of historical droughts, supply projections can be made. We also produced frequency of depletion type charts. These charts can assist engineers to assess water needs and distribution. If an additional step is taken by the local communities to monitor supplies the local operators can project for themselves their remaining storage to empower public works directors on how to allocate existing water supplies.

Because of the gradual increases in demand for water, these charts will also assist in determining the urgency of providing new reservoirs and additional water storage facilities.

Tables one and two show the dependability of water supplies for each system. Not all systems could withstand a drought such as the one in the 1950’s with their present demands.

MISSOURI WATER SUPPLY STUDIES

CITY	Lake Name	Drainage area Acres	Drainage area Sq.Mi.	Annual Demand Gallons	Annual Demand MGD	Optimum Yield MGD from lake	Optimum Yield with pumping MGD	Year of Maximum Use	Lake Storage Acre-Ft	Comments
Adrian	City Lake	517	0.81	135,999,600	0.373	0.050	0.492	2000	290	
Breckenridge	City Lake	416	0.65	21,535,000	0.059	0.520	NA	2004	140	
Butler	City Lake	1990	3.11	366,878,000	1.010	0.270	1.010	2000	749	Lake & Marais Des Cygnes River
Brookfield	City Lake	650	1.02	620,000	0.620	0.207		2000		Lake only
	City Lake + stream			620,000	0.620		0.617			Lake plus stream
	City Lake			620,000	0.620		0.620			Lake, stream and holding basins
Cameron	GLM Lake	13382	20.91		1.000	1.000			1869	
	Cities 3 Lakes	3314	5.18						1382	3 Lake system
	Total	16696	26.09	556,000,000	1.500	1.500		2002	3251	Lakes in combination
Concordia	E.A. Pape Lake	5425	8.48	180,424,873	0.494	0.839	NA	2001	2740	
Creighton	City Lake	630	0.99	10,220,000	0.028	0.066	NA	2001	113	
Dearborn	City Lake	350	0.55	22,724,000	0.062	0.010	NA	1999	52	Dearborn now buys from K.C.
Drexel	City Lake #1	2989	4.67	0	0	0	NA			Not used for water supply
	City Lake #2	535	0.84	37,522,000	0.103	0.119	NA		345	Lakes not in series
	Total	3524	5.51	37,522,000	0.103	0.119	NA	2001		
Eagleville	Lake	3009	4.70	30,660,000	0.086	0.044	NA	2000	139.5	
	Basin	0	0.00			0.087				Storage basin added for volume
Garden City	Cities New Lake	430	1.70	29,889,810	0.082	0.182	NA	2000	441	
	Cities Old Lake	109	0.67	20,311,090	0.550	0.069	NA	2000	177	
	Total	539	2.37	50,200,900	0.632	0.251			618	
Green City	City Lake	800	1.25	66,612,500	0.183	0.149	NA	1999	428	
Hamilton	City Lake	1142	1.78	94,900,000	0.260	0.190	0.260	1999	896	Lake and Marrowbone Creek
Higginsville	City Upper Lake	1730	2.70	0	0.000	0	NA		128	For sediment control
	City Lower Lake	1700	2.66	348,980,000	0.956	0.462	1.310	2001	1462	Pump from Mo.River to lake
Holden	City Lake	2572	4.02	91,250,000	0.250	0.567	NA	2001	3810	
Jamesport	City Lake	900	1.41	21,900,000	0.060	0.069	NA	1999	163	
King City	South Lake	550	0.86		0.074	0.078		1999	417	
	North upper lake	60	0.09		0.005	0.005			39	
	North middle Lake	240	0.38		0.007	0.008			65	
	North lower lake	210	0.33		0.039	0.042			332	
	Total	1060	1.66	45,625,000	0.125	0.133	NA	1999	853	
Lake Thunderhead	Private Lake	14700	22.96	0	0.000	3.361	NA	NA	15,400	Not designed for water supply
Lamar	City Lake	3050	4.77	175,144,800	0.480	0.427	NA	2001	1582	Also use one well
	Well					0.430	NA			(2)600 GPM pumps
	Total					0.587	NA			Assume can pump 1/2 time
Marceline	Newer City Lake	2388	3.73	163,420,300	0.448	0.412	NA	2000	1990	
	Older City Lake	271	0.42	0	0.000	0.060	NA		est-462	Old Lake not used or surveyed
	Total	2659	4.15	163,420,300	0.448	0.472	NA	2000	2452	

Table 1

MISSOURI WATER SUPPLY STUDIES

CITY	Lake Name	Drainage area		Annual Demand		Optimum Yield MGD from lake	Optimum Yield with pumping MGD	Year of Maximum Use	Lake Storage Acre-Ft	Comments
		Acres	Sq.Mi.	Gallons	MGD					
Memphis	Lake Show Me	1700	2.66	153,300,000	0.420	0.780	NA	2000	4125	
	Old City Lake	965	1.51	0	0.000	0.095	NA		220	Downstream of New Lake
	Total	2665	4.17	153,300,000	0.420	0.875	NA	2000	4345	
Middle Fork	Lake	4037	6.30	127,750,000	0.350	0.381	NA	2000	915	Serves Stanberry
Milan	Elmwood Lake	4100	6.41	602,250,000	1.650	0.738	0.790	2000	2503	
	Golf Course Lake	680	1.06	0	0.000	0.116	0.116		555	
	Total	4780	7.47	602,250,000	1.650	0.854	0.906			Lake and Stream
Moberly	Sugar Creek Lake	7170	11.05	561,159,100	1.537	1.200	1.54	2001	5250	
Monroe City	Rt. J Lake	5250	8.20	152,701,000	0.418	1.010	NA	2001	1245	
Ridgeway		5723	8.94	13,991,000	0.038	0.246	NA	1999	461	
Sedalia	Spring Fork Lake	7030	10.98	990,657,900	1.535	1.059	NA	2001	1249	
Shatto	Lake near Milan	170	0.26			0.083	NA	NA	662	Not used for water supply
Shelbina	Lake	1542	2.41	127,249,000	0.349	0.273	0.380	1999	406	Pump from Salt River
Unionville	Lake Mahoney	1900.00	2.97	139,500,000	0.382	0.283	NA	2000	620	

Table 1

MISSOURI WATER SUPPLY STUDIES

Stream low flows

CITY	STREAM	Drainage Area	Annual Water use		7-day Q10 low flows		1 year In 50 * Lowest Mean monthly flow		1 year In 100 Lowest Mean monthly flow		Year 2000 Mean Base Flow	Comments
		Sq.Mi.	Daily MGD	Total Gallons	cfs	MGD	cfs	MGD	cfs	MGD	cfs	
Joplin	Shoal Creek	427	10.82	3,949,175,941	43	28	46.0	30	38.0	25	226	No off channel storage
Perryville	Saline Creek	55.83	0.79	289,448,000	1	1	0.9	1	0.7	0.5	18	No off channel storage Use wells
Poplar Bluff	Black River	1245	3.08	1,122,486,000	216	140	254.0	164	222.5	144	603	No off channel storage
Trenton	Thompson	1670	1.90	694,520,000	9	6	7.5	5	4.6	3	55	Off Channel Storage

cfs is cubic feet per second
MGD is million gallons per day
* 1 year in 50 is the lowest mean monthly flow that is expected to occur one year out of 50 years.

Table 2

Introduction to Lake Analysis

These analyses were made for the drought of record, which was through the 1950's. At least two conditions are presented in all cases. The first run was made with current demand and the second was to optimize that demand to establish the firm yield. Other runs were made if necessary, such as effects of different schemes of pumping from a creek. If pumping from a stream was incurred, additional runs were made to evaluate effects of pumping.

USDA's Natural Resource Conservation Service reservoir operations computer program "RESOP" was used to make each evaluation. Computations are in one-month increments and represent end of month results. The "RESOP" program uses:

1. Lake volume and surface area
2. Rainfall
3. Runoff
4. Lake Evaporation
5. Seepage
6. Demand or water usage
7. Other inflow such as pumping from a stream.

Sources of data used to evaluate remaining storage in each reservoir are:

- Reservoir Storage - Reservoirs were surveyed for remaining available storage by the USGS from year 2000 to 2004.
- Time Period - The analysis for drought effects was selected to be the 1950's. This was the longest and most severe drought of record.
- Rainfall - Rainfall for each water supply lake was the nearest NOAA weather station. If there were missing days in the data, then the next nearest station was used to fill in the gaps.
- Runoff - Regional monthly runoff from nearest stream gages were used. If the Runoff did not look to be reasonable, i.e. Runoff greater than rainfall for a certain month, adjustments were made to the runoff by examining each individual rainfall event for that month. To make the runoff determination, five-day rainfall was used to estimate the anticedent moisture. The NRCS cover complex number was used to estimate runoff for each storm. See appendix "A" for an explanation.
- Evaporation - The nearest NOAA weather station with pan evaporation data was used. Pan evaporation was then adjusted to lake evaporation.
- Seepage - Seepage was estimated based on experience. In north Missouri seepage is very low.
- Demand - Demand is the amount of water available for consumptive uses. This value comes from community records.
- Other - Other is used to identify other inflow or outflow such as pumping from a stream.

"RESOP" is a DOS program. The users manual and software for the "RESOP" program are not included in this report but are available on CD upon request.

Missouri drinking water supplies studied and dates surveyed.

Water Supply Lake	Date of Lake Bathymetry Survey
1. Adrian…………………………………………..	April 2003
2. Breckenridge……………………………………	April 2004
3. Butler……………………………………………	April 2001
4. Brookfield……………………….……………	July 2000
5. Cameron …………..Grindstone Reservoir....	Aug 1991
………….. (3 City Lakes)…………	June 1997
6. Concorde……………………………………….	June 2002
7. Creighton……………………………………….	June 2003
8. Dearborn………………………………………..	June 2000
9. Drexel…………………………………………..	June 2003
10. Garden City……….(2 lakes)...………………	April 2004
11. Green City……………………………………..	July 2000
12. Hamilton……………………………………….	July 2000
13. Harrison County Rural Water Dist. #1………	May 2003
14. Higginsville…………………………………….	June 2002
15. Holden…………………………………………	June 2003
16. James Port…………………………………….	July 2000
17. King City…………..(4 lakes)…………………	July 2000
18. Lake Thunderhead Association ……………	April 2003
19. Lamar………………………………………….	May 2002
20. Middle Fork Grand River Lake….……………	July 2004
21. Milan………………(2 lakes)…..…………….	June 2000
22. Marceline………………………………………	May 2003
23. Memphis…………..(2 lakes)…………………	June 2001 & June 2002
24. Moberly…………………………………………	Dec. 2003
25. Monroe City RTE “J”………………………….	June 2004
26. Ridgeway………………………………………	May 2003
27. Sedalia…………………………………………	April 2002
28. Shatto Lake………………………………….	July 2000
29. Shelbina………………………………………..	June 2001
30. Unionville………………………………………	April 2004

Adrian, Missouri
Water Supply Study
City Lake

Adrian Lake is located just East of the city in Northern Bates County, Missouri.

Adrian has two lakes, the main lake supplies their water needs. A smaller upstream lake is used to catch sediment to keep the lower lake from losing capacity.

Rainfall at Butler was used for this analysis. Average annual rainfall for 1970 through 2000 was 42.05 inches. Annual Rainfall at Butler for 1953 through 1957 is 28.8, 35.7, 28.4, 21.3, and 37.5 inches.

Adrian used approximately 0.373 million gallon per day during year 2000.
The optimized use without pumping from South Grand River is estimated to be only 49,500 gallon per day.

Because the city's lake has a small capacity, it will not supply Adrian's total needs. As a result they pump from South Grand River into their lake from a location East of highway 71. The demand of 0.373 MGD can be met by pumping from South Grand River 2/3 of the time that flow in the river exceeds 3 cubic feet per second.

Adrian's Lake analysis consisted of using the NRCS's computer program "RESOP". This program analyzes remaining stored water at the end of each month by summing gains and losses.

Following is the data and procedures for input to the "RESOP" program.

STO-AREA Elevation-Storage and Elevation-Area data were determined from June 6, 2003 survey made by USGS.

Adrian Lake

Elevation (feet)	Area (acres)	Volume (acre-ft)	
Lower Lake			
832	0.4	0.1	
834	2.9	3.4	
836	7.1	12.7	
838	13.9	33.5	
840	21.5	69.1	
842	29.7	120.0	
844	42.0	190.0	
846	47.7	280.0	Water Surface 6/6/2003
846.2	49.8	290.0	Spillway Elevation
Upper Lake			
844	0.1	0.01	
846	0.9	1.0	
848	2.9	4.0	
850	5.8	13.0	
850.7	7.4	17.0	Water Surface 6/6/2003
852	12.7	31.0	
852.3	13.8	35.0	Spillway Elevation

LIMITS	Upper Lake	
	Full Pool storage	35 Ac.Ft.
	Minimum Pool storage	0 Ac.Ft.
	Lower Lake	
	Full Pool storage	290 Ac.Ft.
	Minimum Pool storage	40 Ac.Ft.

Starting storage was considered at full pool elevation.

The upper lake drainage is 0.55 square miles and the lower lake has a total drainage including the drainage area of the upper lake of 0.81 Square Miles (517 Acres).

GENERAL The adjustment factor of 0.76 to convert from Pan evaporation to Lake evaporation as applied prior to entering the data for the control word EVAP. As a result a factor of 100 is applied.

The record period of drought is in the 1950's. The analysis period was January 1951 through December 1959

SEEPAGE The reservoir seepage for the upper lake is near zero. Most of any seepage would appear in the lower lake. A value of 0.2 inches per month when full was used and 0 seepage as the water level approached the lower limits of the pool.

Seepage from the larger, lower lake was estimated at 2 inches per month when full to 0 at the lower limits of the pool.

The material in the dam is compacted earth of clayey soils. As a result seepage rates are low.

RAINFALL Rainfall data came from the Butler, Mo. rain gage and supplemented where needed with the Appleton City rainfall data.

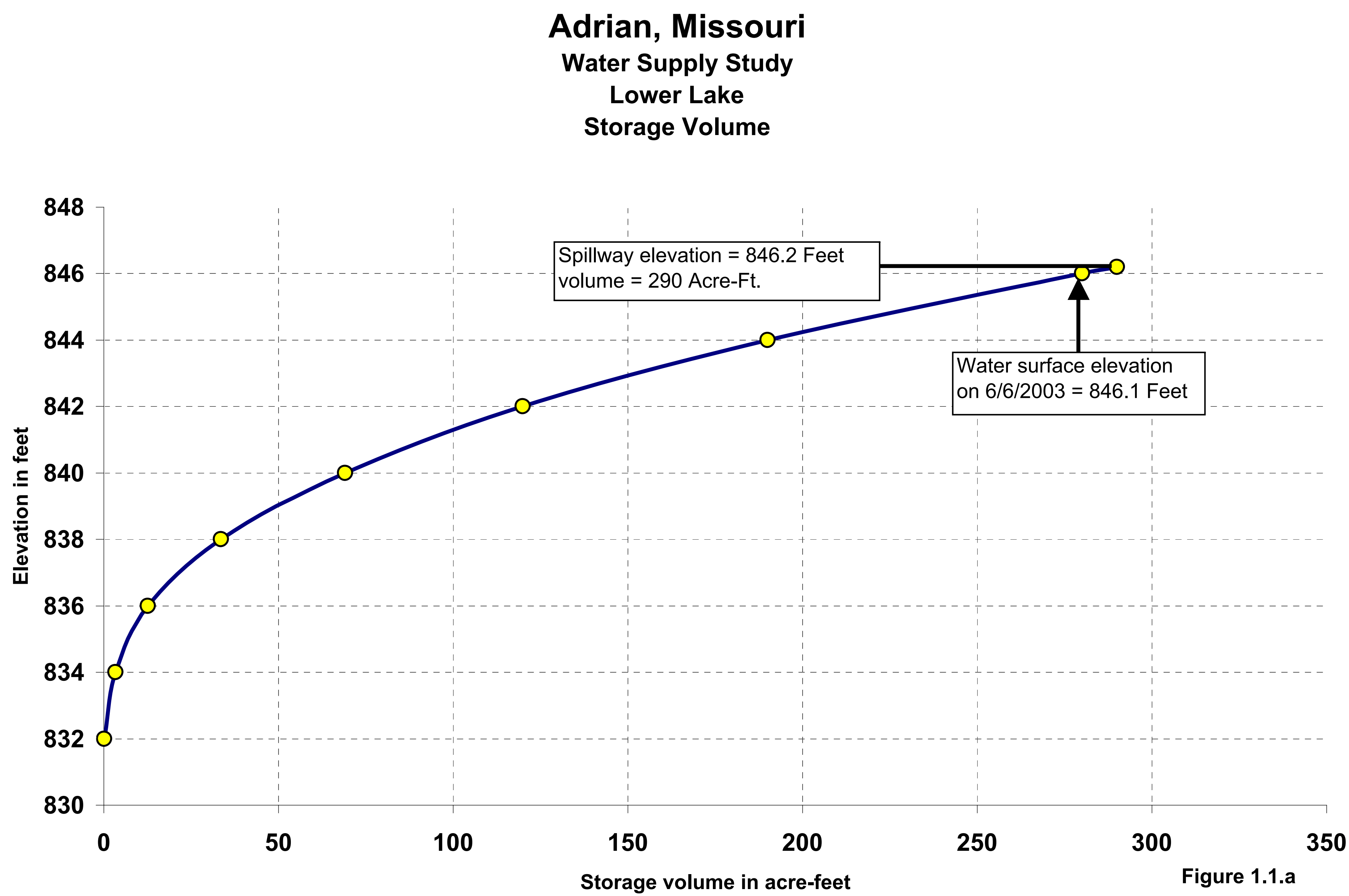
RUNOFF This is the runoff into the lake from its drainage area. Regional monthly runoff values were determined from stream gage data.

Monthly runoff volumes in watershed inches was determined at the Little Blue River gage near Lake City. Another gage on Cedar Creek near Pleasant View, Missouri was also analyzed. Results at the lake were nearly the same. Because the soils and topography of Little Blue River is more nearly like that at Adrian, it was selected to represent regional runoff. Some urban area exists in the Little Blue River drainage area, however, the additional monthly runoff volume expected from this area did not seem to effect the result. If runoff did not appear reasonable when compared to rainfall, it was necessary to examine daily rainfall values for that month. Antecedent moisture was estimated for each rainfall event and adjustments to NRCS runoff curve number was made to arrive at runoff for each storm.

EVAP. Pan evaporation at the Lakeside gaging station near the Lake of the Ozarks was used to determine Pan evaporation. The adjustment to lake evaporation was 0.76.

DEMAND Adrian water use is shown in file ADRIAN HISTORICAL WATER USE.XLS.
Since 1992 the demand has been fairly constant at 0.373 MGD. The optimized use without pumping from South Grand River is estimated to be only 49,500 gallon per day.

An analysis of stream flow was made for South Grand River at the intake site.


Adrian, Missouri
Water Supply Study
Lower Lake
Storage Volume
Elevation in feet
848
846
844
842
840
838
836
834
832
830
0
50
100
150
200
250
300
350
Storage volume in acre-feet
Spillway elevation = 846.2 Feet
volume = 290 Acre-Ft.
Water surface elevation
on 6/6/2003 = 846.1 Feet
Figure 1.1.a

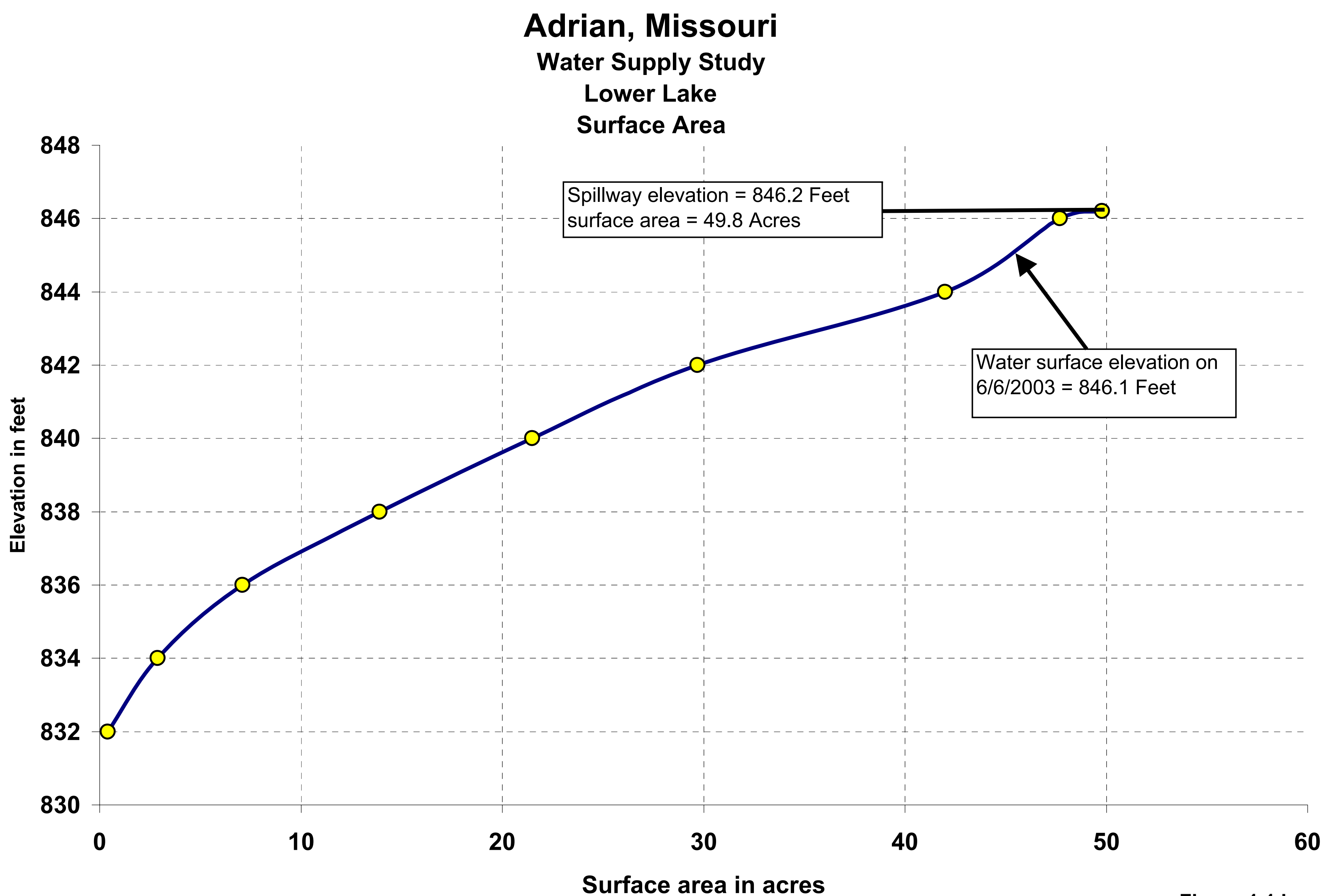
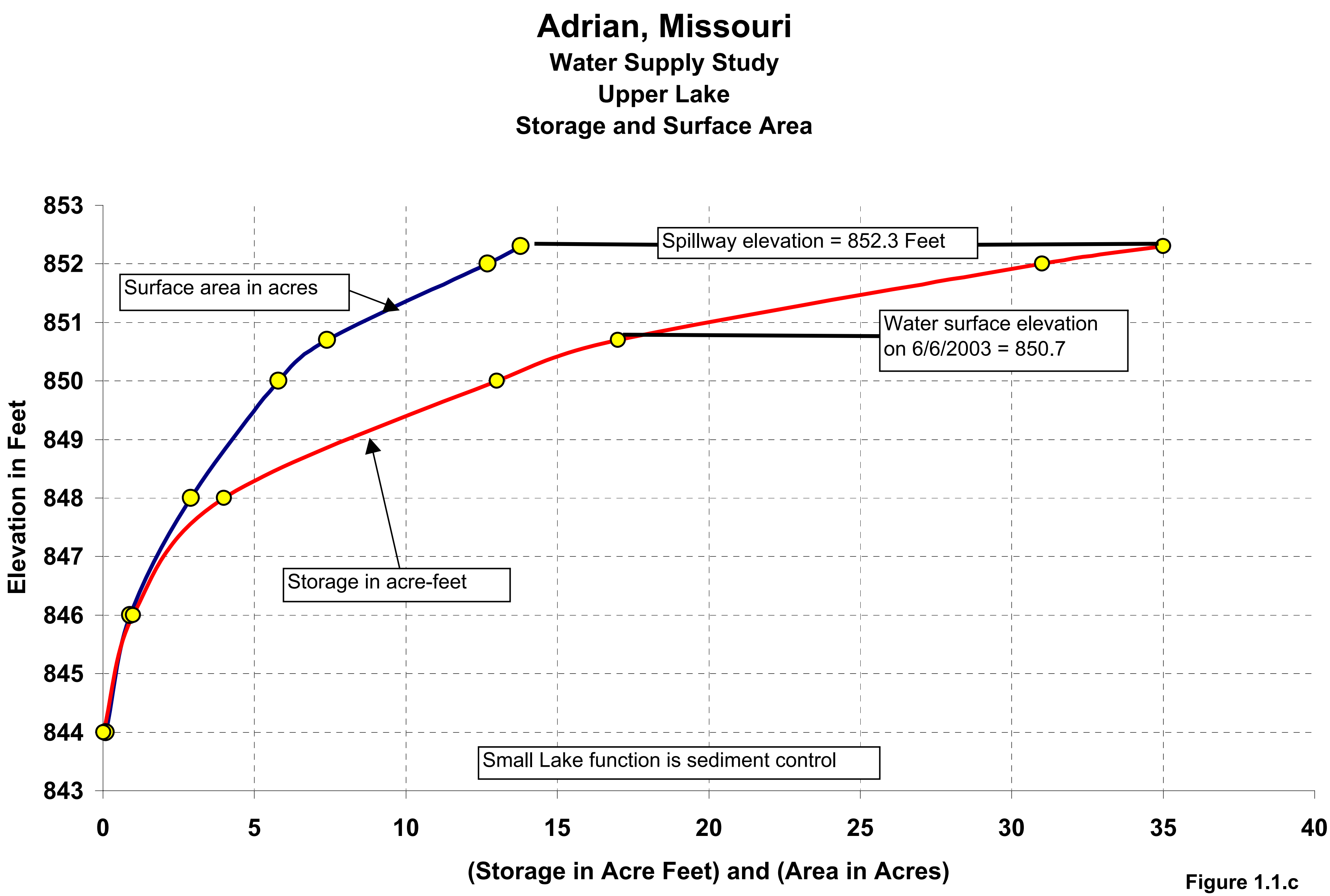

Adrian, Missouri
Water Supply Study
Lower Lake
Surface Area
Spillway elevation = 846.2 Feet
surface area = 49.8 Acres
Water surface elevation on
6/6/2003 = 846.1 Feet
Elevation in feet
848
846
844
842
840
838
836
834
832
830
0
10
20
30
40
50
60
Surface area in acres

Figure 1.1.b



Adrian, Missouri
Water Supply Study
Upper Lake
Storage and Surface Area
Elevation in Feet
853
852
851
850
849
848
847
846
845
844
843
0
5
10
15
20
25
30
35
40
(Storage in Acre Feet) and (Area in Acres)
Surface area in acres
Spillway elevation = 852.3 Feet
Water surface elevation
on 6/6/2003 = 850.7
Storage in acre-feet
Small Lake function is sediment control

Figure 1.1.c

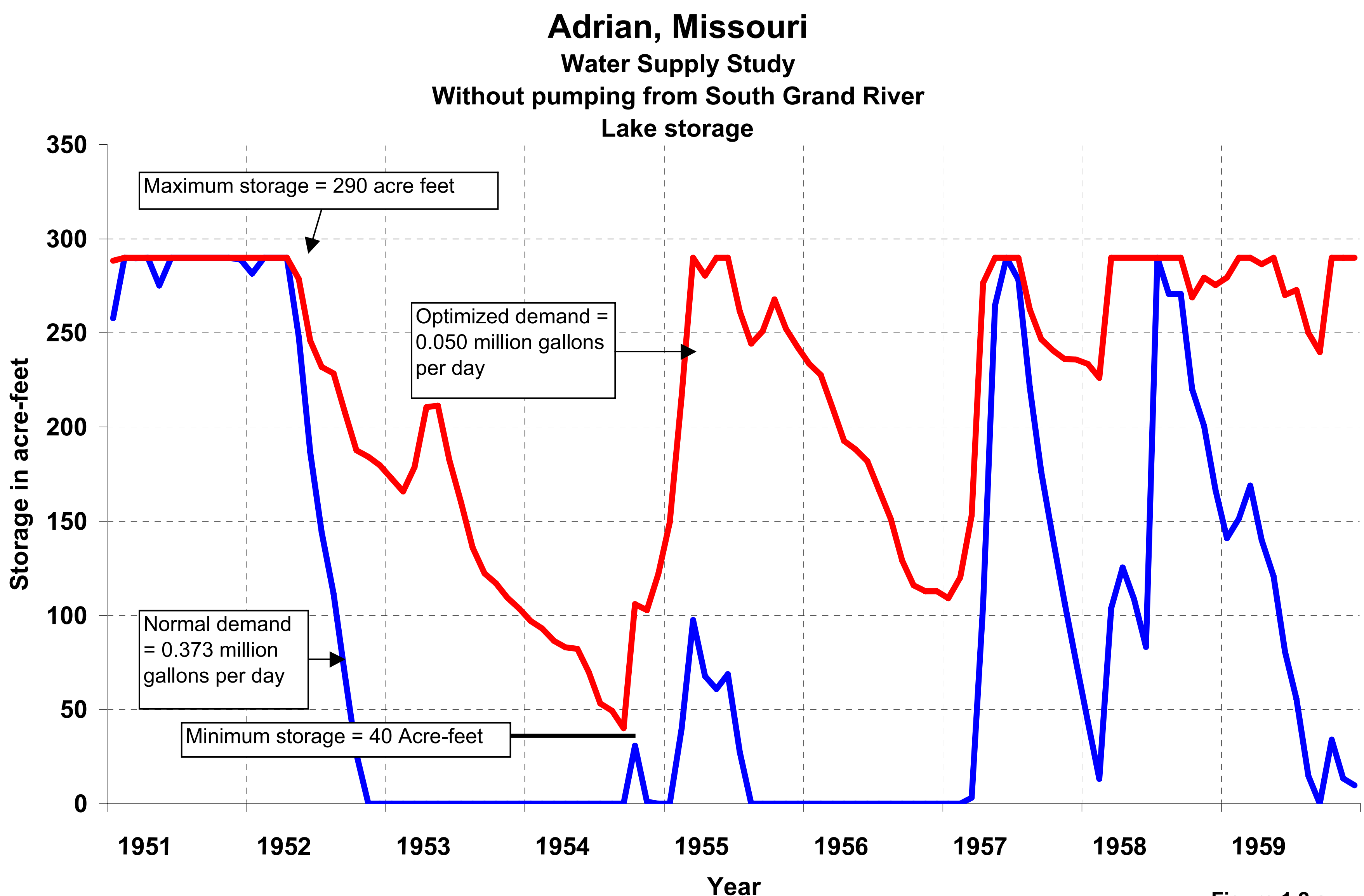

Adrian, Missouri
Water Supply Study
Without pumping from South Grand River
Lake storage
Storage in acre-feet
350
300
250
200
150
100
50
0
Maximum storage = 290 acre feet
Optimized demand = 0.050 million gallons per day
Normal demand = 0.373 million gallons per day
Minimum storage = 40 Acre-feet
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year

Figure 1.2.a

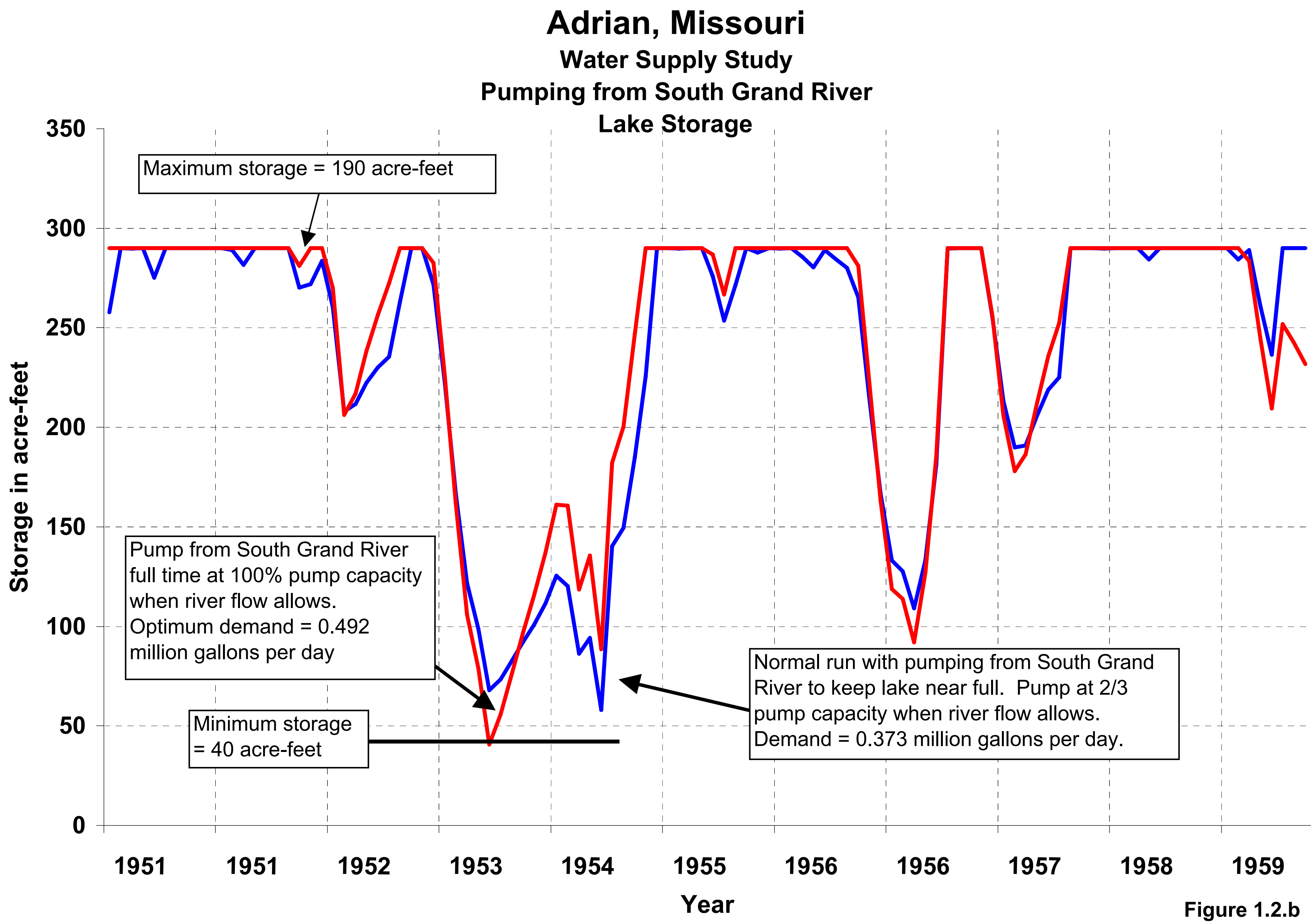

Adrian, Missouri
Water Supply Study
Pumping from South Grand River
Lake Storage
Maximum storage = 190 acre-feet
Pump from South Grand River full time at 100% pump capacity when river flow allows. Optimum demand = 0.492 million gallons per day
Minimum storage = 40 acre-feet
Normal run with pumping from South Grand River to keep lake near full. Pump at 2/3 pump capacity when river flow allows. Demand = 0.373 million gallons per day.
Storage in acre-feet
350
300
250
200
150
100
50
0
1951
1951
1952
1953
1954
1955
1956
1956
1957
1958
1959
Year

Figure 1.2.b

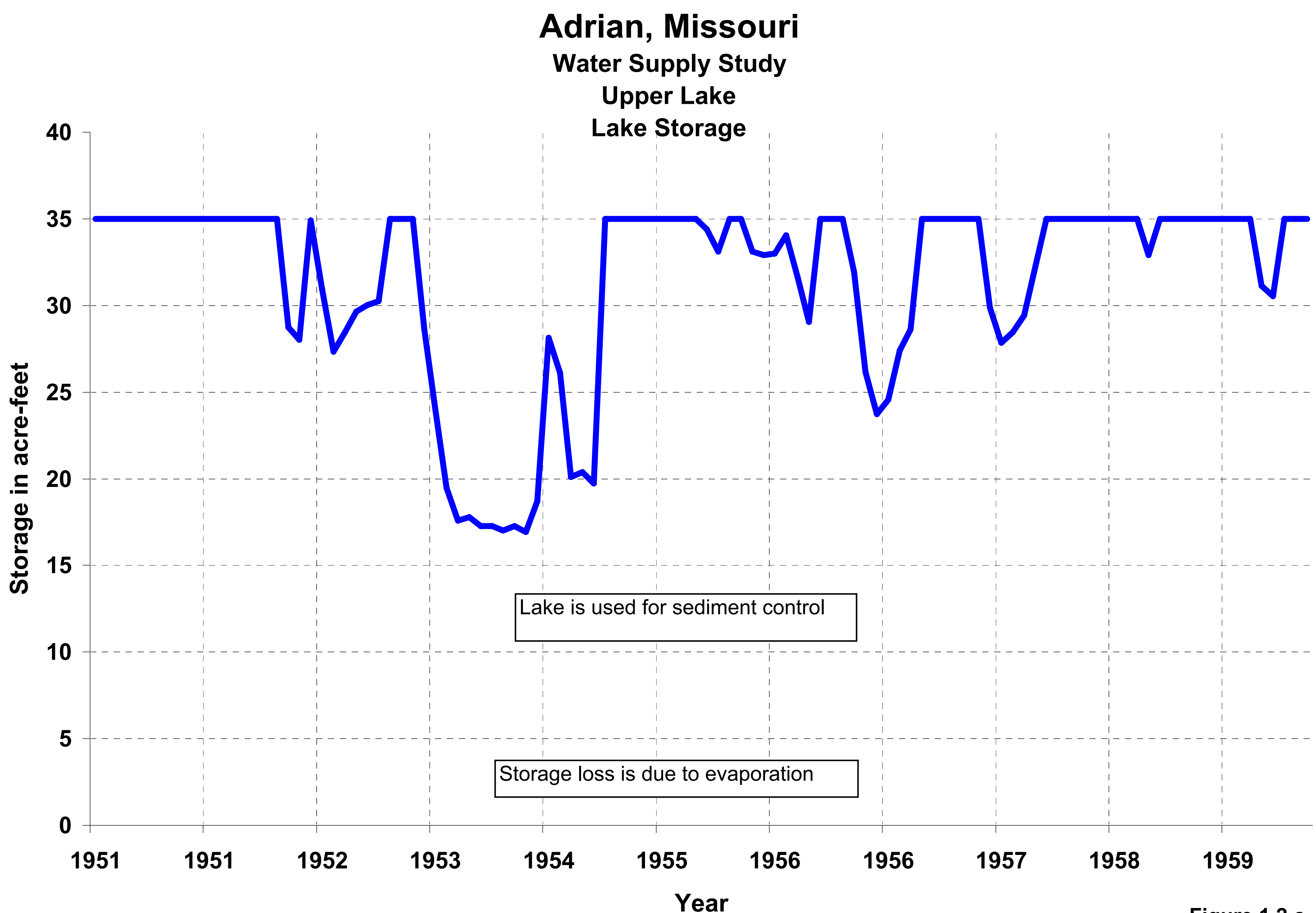

Adrian, Missouri
Water Supply Study
Upper Lake
Lake Storage
Storage in acre-feet
40
35
30
25
20
15
10
5
0
1951
1951
1952
1953
1954
1955
1956
1956
1957
1958
1959
Year
Lake is used for sediment control
Storage loss is due to evaporation

Figure 1.2.c

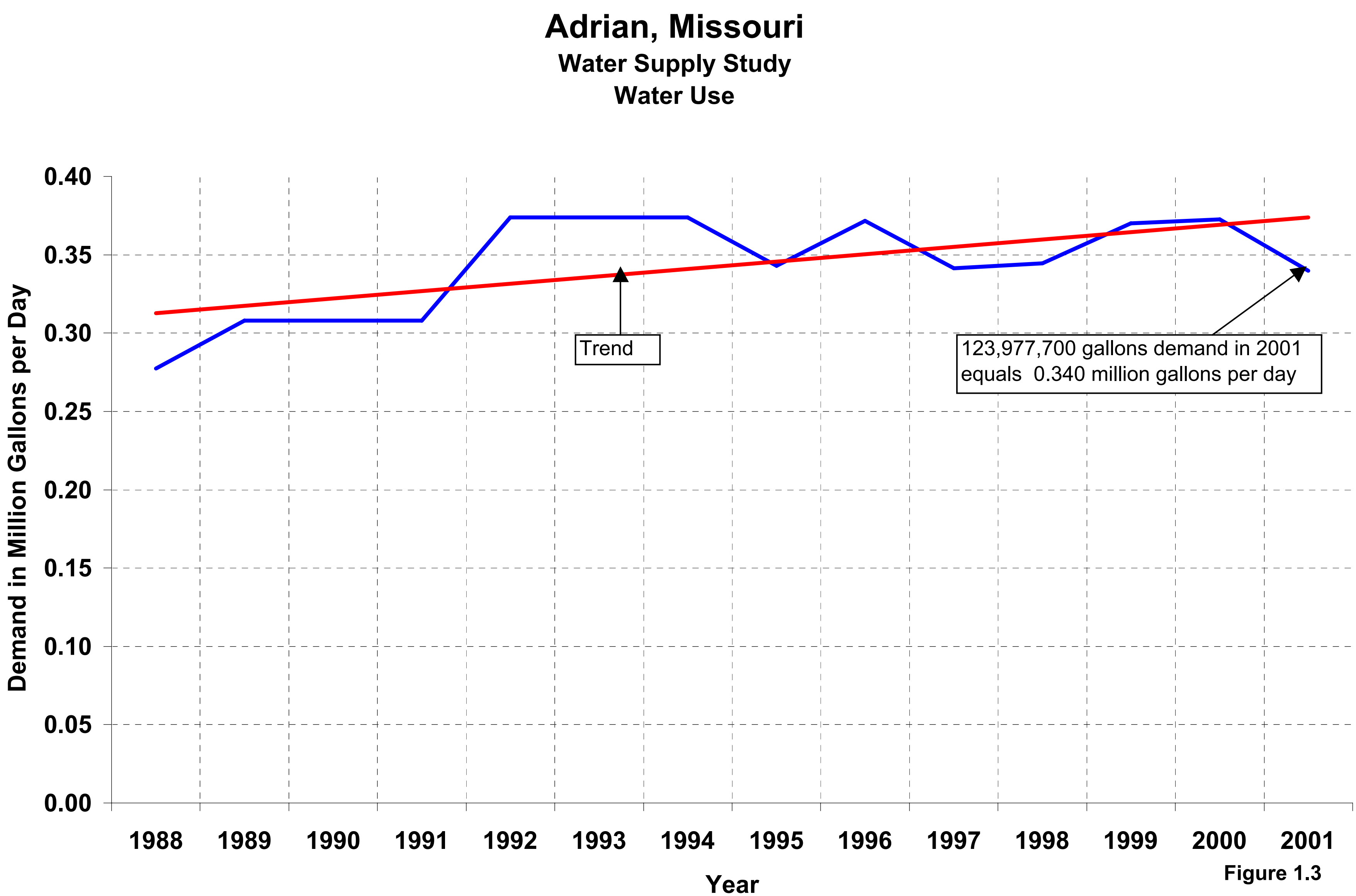
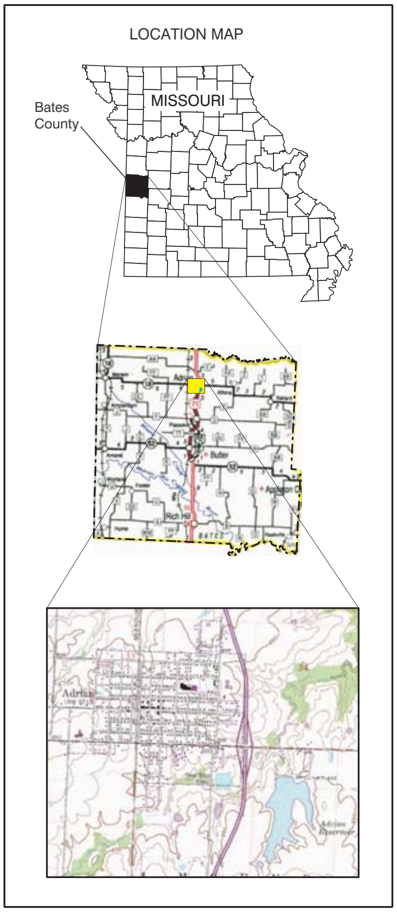
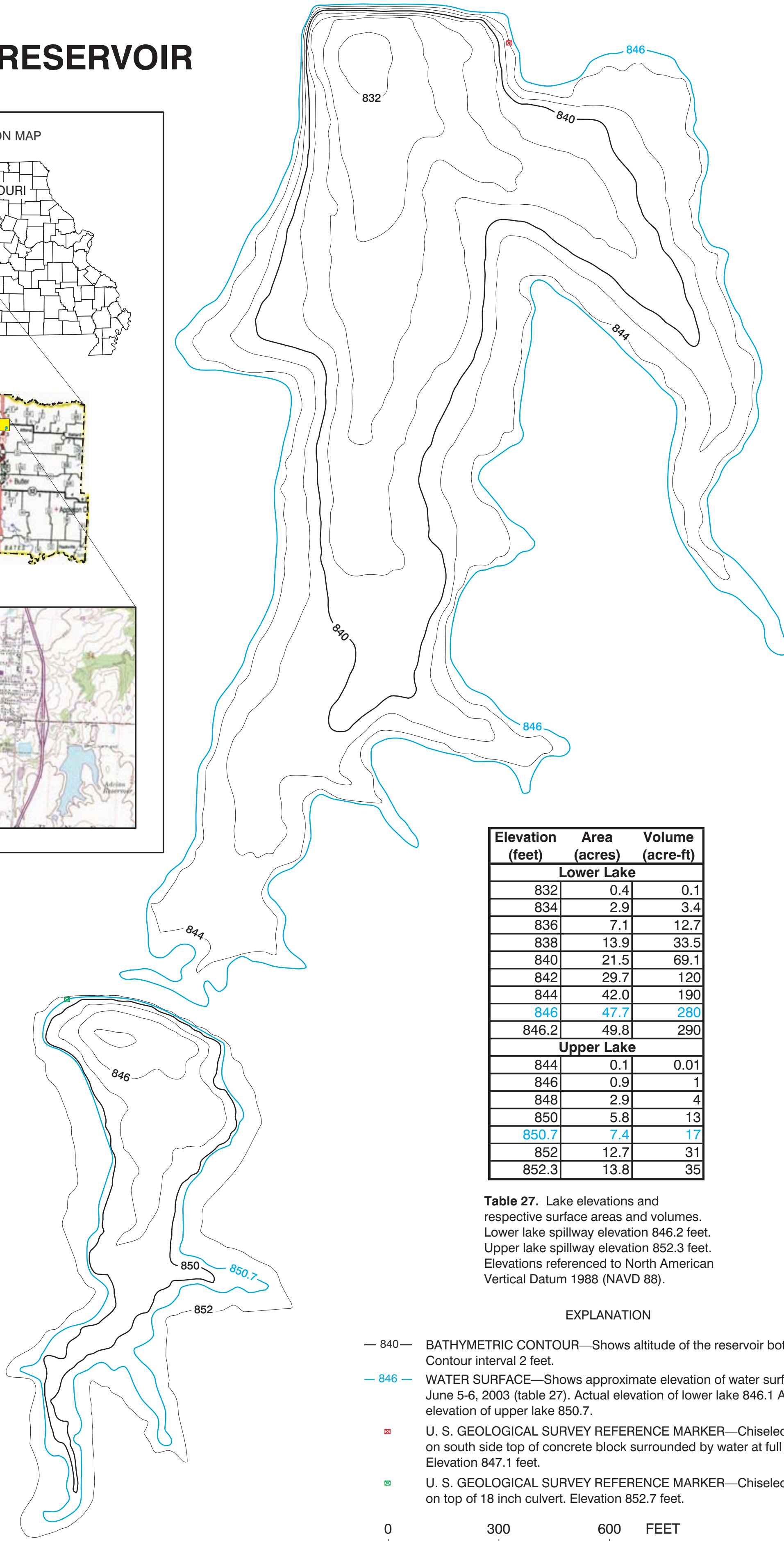

Adrian, Missouri
Water Supply Study
Water Use
Demand in Million Gallons per Day
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Trend
123,977,700 gallons demand in 2001
equals 0.340 million gallons per day
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
Year

Figure 1.3

ADRIAN RESERVOIR





Elevation (feet)	Area (acres)	Volume (acre-ft)
Lower Lake		
832	0.4	0.1
834	2.9	3.4
836	7.1	12.7
838	13.9	33.5
840	21.5	69.1
842	29.7	120
844	42.0	190
846	47.7	280
846.2	49.8	290
Upper Lake		
844	0.1	0.01
846	0.9	1
848	2.9	4
850	5.8	13
850.7	7.4	17
852	12.7	31
852.3	13.8	35

Table 27. Lake elevations and respective surface areas and volumes. Lower lake spillway elevation 846.2 feet. Upper lake spillway elevation 852.3 feet. Elevations referenced to North American Vertical Datum 1988 (NAVD 88).

EXPLANATION

— 840 — BATHYMETRIC CONTOUR—Shows altitude of the reservoir bottom. Contour interval 2 feet.

— 846 — WATER SURFACE—Shows approximate elevation of water surface, June 5-6, 2003 (table 27). Actual elevation of lower lake 846.1 Actual elevation of upper lake 850.7.

U. S. GEOLOGICAL SURVEY REFERENCE MARKER—Chiseled arrow on south side top of concrete block surrounded by water at full pool. Elevation 847.1 feet.

U. S. GEOLOGICAL SURVEY REFERENCE MARKER—Chiseled arrow on top of 18 inch culvert. Elevation 852.7 feet.

0 300 600 FEET

0 100 200 METERS

USGS science for a changing world

Figure 27. Bathymetric map and area/volume table for Adrian Reservoir near Adrian, Missouri.

In cooperation with Missouri Department of Natural Resources

Breckenridge, Missouri
Water Supply Study
City Lake

Breckenridge is located near the Northeast corner of Caldwell County, Missouri. It is approximately 14 miles West of Chillicothe, just North of highway 36.

The record period of drought was used to estimate adequacy of Breckenridge's water supply during this period. The drought of record was determined to be during the 1950's.

The 30-year average rainfall, years 1970 to 2000, is approximately 37.5 inches. Rainfall at the Chillicothe gage was used in this analysis. For the period of the severest part of the drought of 1953 through 1957, annual rainfall was 20.07, 33.55, 28.27, 27.88, and 42.38 inches.

Breckenridge uses less than the 100,000 gallons of water per day. As a result, they are not considered a major water user and do not report their use to Department of Natural Resources. In years 2000 and 2001 Missouri public drinking water program registered 45,000 gallons per day and in 2004, 59,000 gallon per day. For this analysis 59,000 gallon per day was used. Optimum demand is 52,000 gallons per day.

Breckenridge Lake is located approximately 1 mile North of the city.

Breckenridge Lake Physical Data

Elevation (feet)	Area (acres)	Volume (acre-ft)	
780.0	0.3	0.1	
782.0	0.9	1.3	
784.0	1.4	3.7	
786.0	1.9	7.0	
788.0	2.5	11.3	
790.0	3.0	16.7	
792.0	3.7	23.3	
794.0	4.6	31.6	
796.0	5.6	41.8	
798.0	7.0	54.4	
800.0	8.3	69.6	
802.0	9.8	87.6	
806.0	13.7	130.0	Water Surface on April 5, 2004
806.5	14.3	140.0	Spillway
808.0	15.9	160.0	
809.4	17.7	190.0	Top of Dam

Breckenridge's Lake analysis consisted of using the NRCS's computer program "RESOP". This program analyzes remaining stored water at the end of each month by summing gains and losses.

Following is the data and procedures for input to the "RESOP" program.

STO-AREA Elevation-Storage and Elevation-Area data were determined from April 5, 2004 surveys of both lakes made by USGS.

LIMITS
Full Pool storage 140 Acre Feet
Minimum Pool storage 11.3 Acre Feet
Drainage Area 0.65 Square Miles

Starting storage was considered at full pool elevation.

GENERAL	The adjustment factor of 0.76 to convert from Pan evaporation to Lake evaporation was applied prior to entering the data for the control word EVAP. As a result a factor of 1.00 is applied. The record period of drought is in the 1950's. Analysis began in January 1951 and ending December 1959
SEEPAGE	The reservoir seepage varied from 0 seepage near empty to a maximum of 1.00 inch per month at full pool. The material in the dam is compacted earth of clayey soils.
RAINFALL	Rainfall data came from the Chillicothe, Mo. rain gage for the period 1951 through 1959.
RUNOFF	Monthly runoff volumes in watershed inches were determined at the Jenkins Branch stream gage, a tributary to Platte River. The drainage area is 2.72 Sq. Mi. Jenkins Br. gage is located approximately 35 miles West from Breckenridge. The monthly runoff was compared to the rainfall and if the results did not appear reasonable, adjustments were made for that month by looking at individual rains and estimating antecedent moisture then adjusting runoff for each rain based on NRCS's runoff curve numbers.
EVAP.	Pan evaporation at the Lakeside gaging station was used as a base because it has data for year around evaporation. This data was updated with gage data from stations at Spickard, New Franklin, and Columbia. Depending on the latest data for the station nearest to Hamilton. The adjustment factor of 0.76 to convert from pan to lake evaporation was applied at this step.
DEMAND	Breckenridge demand came from records kept by “Missouri Public Drinking Program”. The latest value they have shows the daily use in year 2004 to be 59,000 gallon per day.

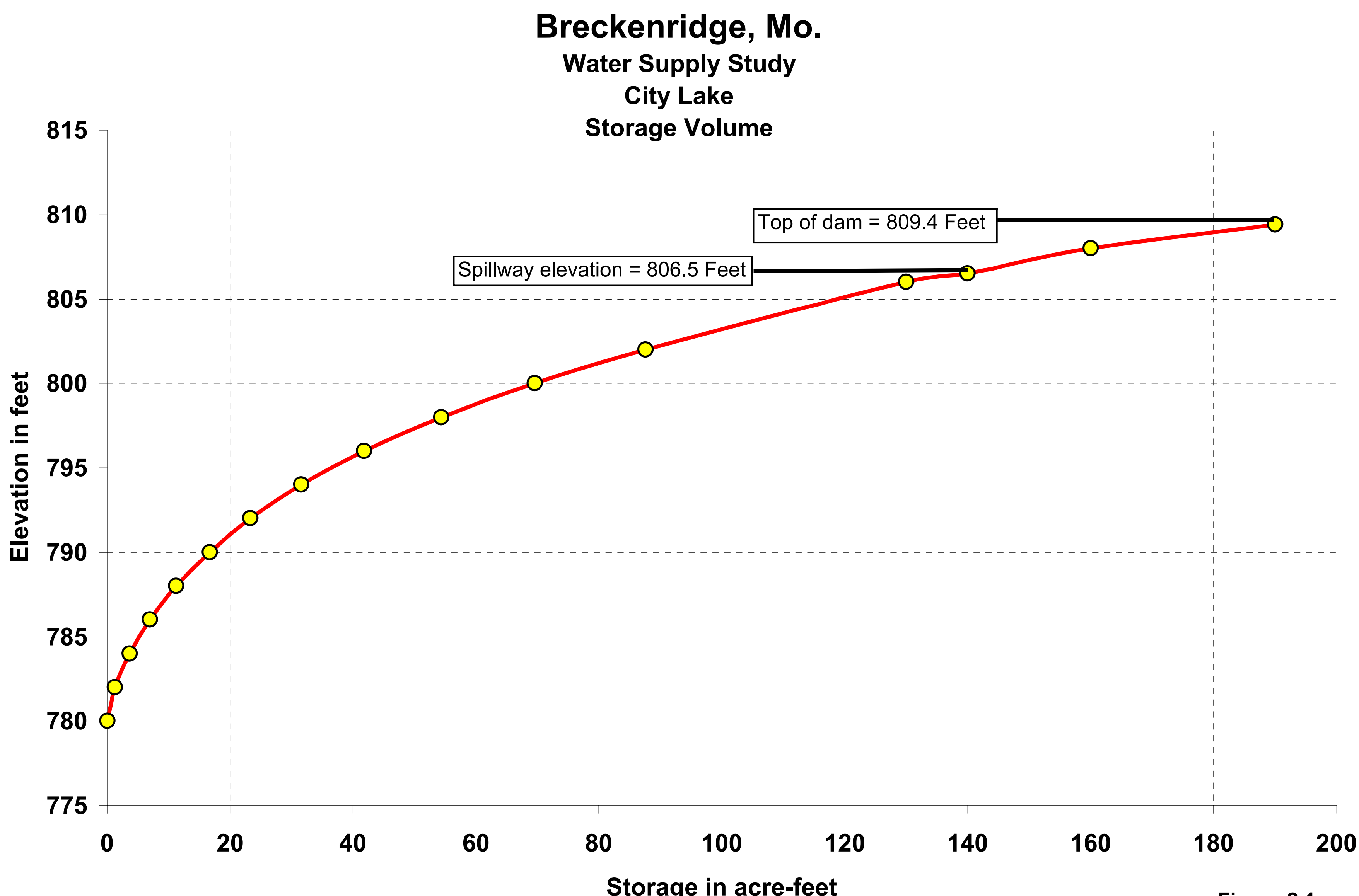

Breckenridge, Mo.
Water Supply Study
City Lake
Storage Volume
Top of dam = 809.4 Feet
Spillway elevation = 806.5 Feet
Elevation in feet
815
810
805
800
795
790
785
780
775
0
20
40
60
80
100
120
140
160
180
200
Storage in acre-feet

Figure 2.1.a

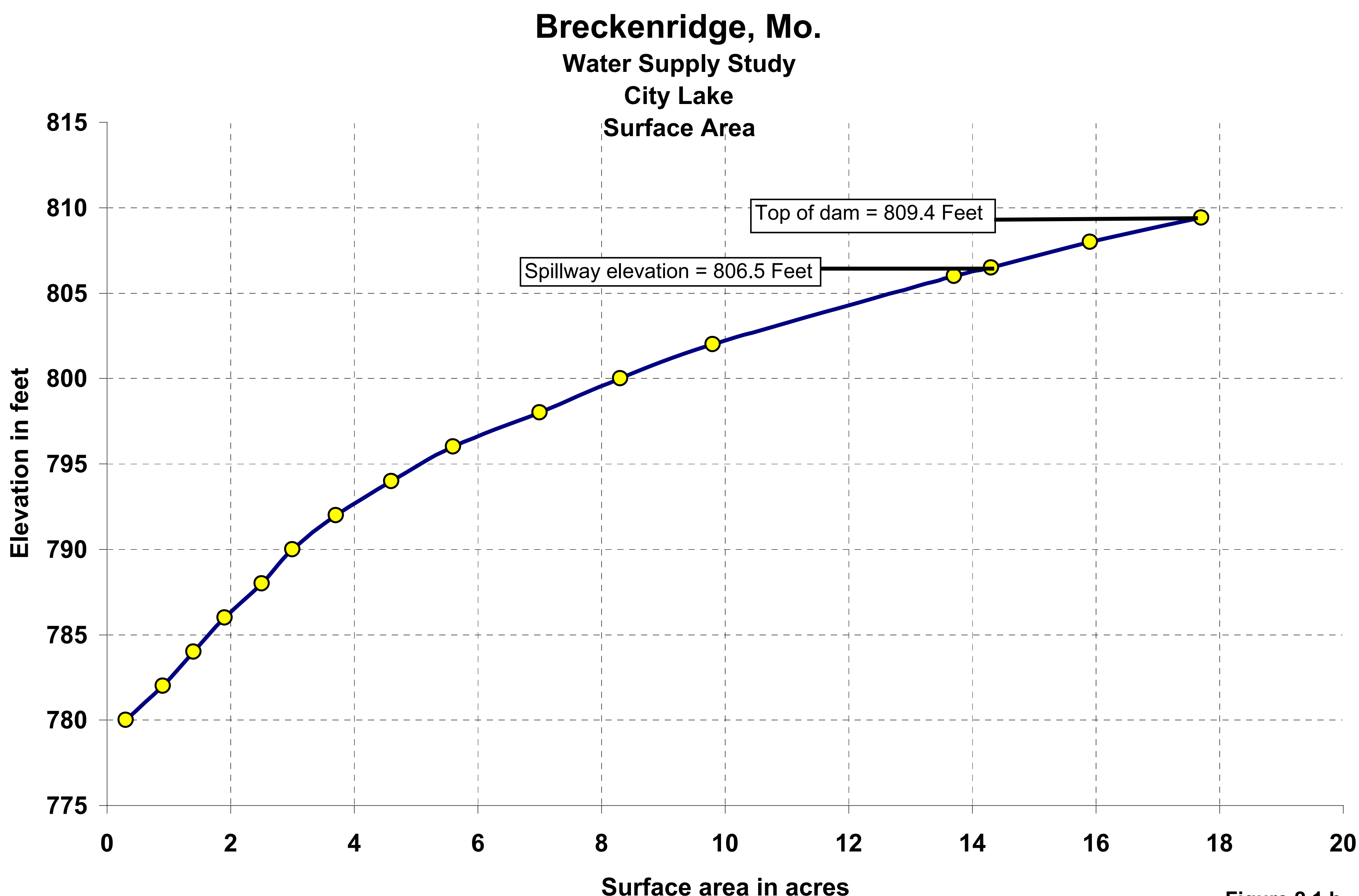

Breckenridge, Mo.
Water Supply Study
City Lake
Surface Area
Top of dam = 809.4 Feet
Spillway elevation = 806.5 Feet
815
810
805
800
795
790
785
780
775
Elevation in feet
0
2
4
6
8
10
12
14
16
18
20
Surface area in acres

Figure 2.1.b

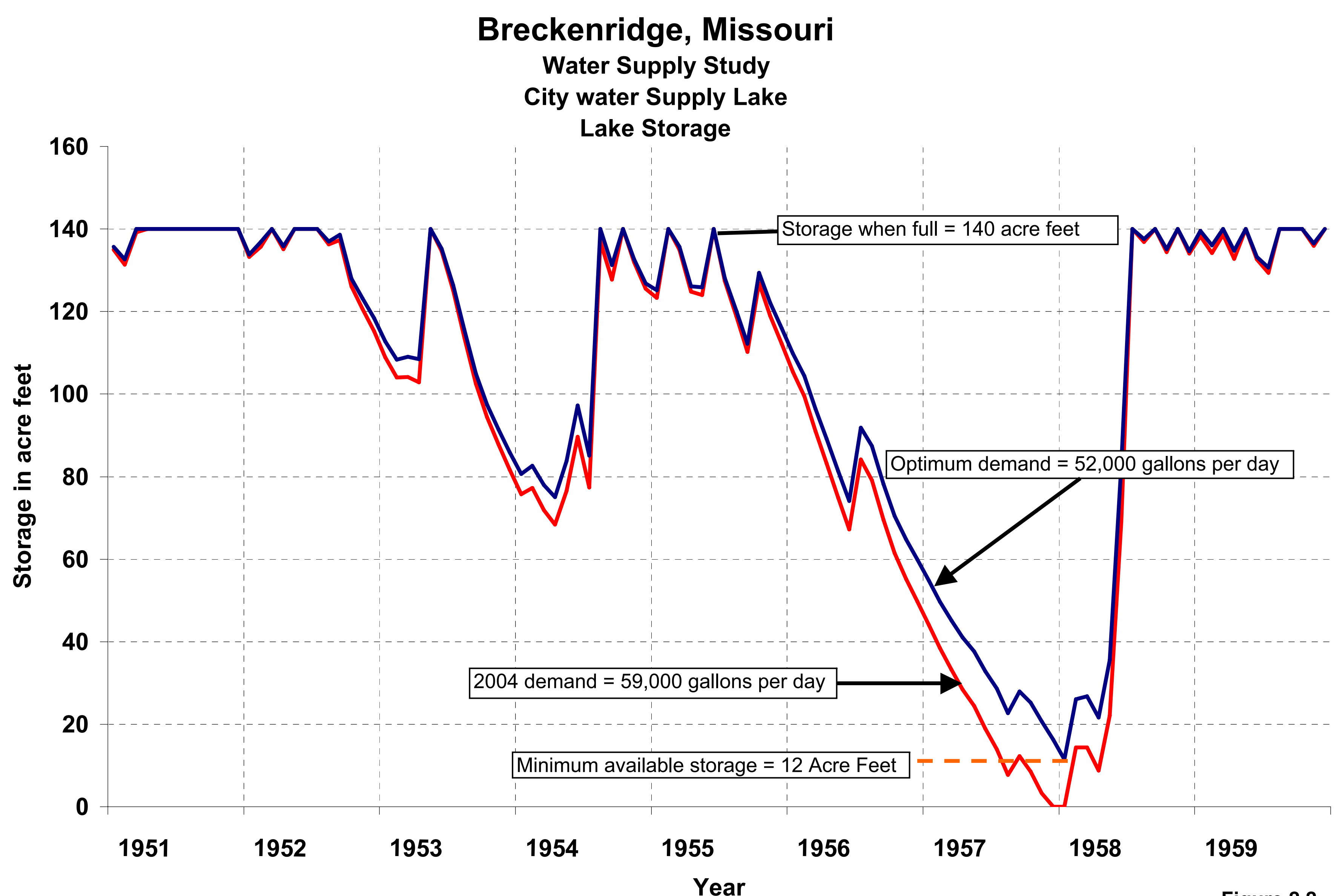
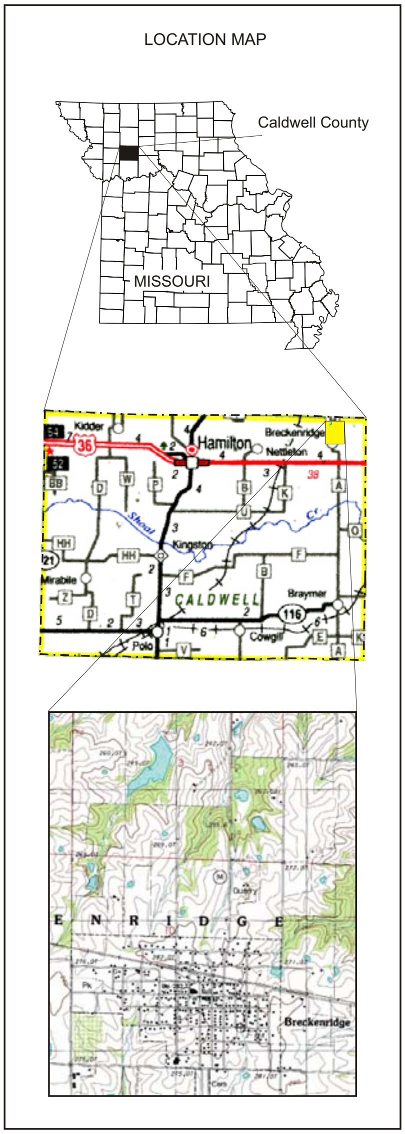

Breckenridge, Missouri
Water Supply Study
City water Supply Lake
Lake Storage
Storage in acre feet
160
140
120
100
80
60
40
20
0
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year
Storage when full = 140 acre feet
Optimum demand = 52,000 gallons per day
2004 demand = 59,000 gallons per day
Minimum available storage = 12 Acre Feet

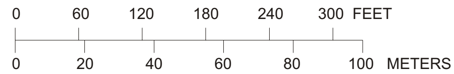
Figure 2.2

BRECKENRIDGE LAKE



Elevation (feet)	Area (acres)	Volume (acre-ft)
780.0	0.3	0.1
782.0	0.9	1.3
784.0	1.4	3.7
786.0	1.9	7.0
788.0	2.5	11.3
790.0	3.0	16.7
792.0	3.7	23.3
794.0	4.6	31.6
796.0	5.6	41.8
798.0	7.0	54.4
800.0	8.3	69.6
802.0	9.8	87.6
806.0	13.7	130
806.5	14.3	140
808.0	15.9	160
809.4	17.7	190

Table 28. Lake elevations and respective surface areas and volumes. Top of spillway structure is 806.5 feet and approximate top of dam is 809.4 feet. Elevations referenced to North American Vertical Datum 1988 (NAVD 88).




USGS
science for a changing world

Figure 28. Bathymetric map and table of areas/volumes of the Breckenridge Lake near Breckenridge, Missouri.

In cooperation with Missouri Department of Natural Resources

Brookfield, Missouri
Water Supply Study
City Lake

The primary source of water supply for Brookfield is pumping from West Yellow Creek. The pumping plan is to pump 1500 GPM from the creek into holding ponds. There are 3 of these ponds, each 10-feet deep. Surface areas are 17 acres, 7 acres and 8.5 acres. These ponds are kept full. Because the creek does not flow during dry weather, there is a lake one and one third miles East of the holding ponds. This lake has a small drainage area of 650 acres, too small to supply the lake with enough runoff for an adequate water supply. To be assured of adequate supply during a drought the city pumps from West Yellow Creek into the lake. Two pumps with 1000 GPM pumping capacity each, are used to fill the lake. When the creek does not have enough flow to fill the holding ponds, water is pumped from the lake to the holding ponds at the rate of 1000 gallon per minute.

To make this analysis, stream flow for Locust Creek gage at Linneus, for the 1950's was used. Daily flows were reduced by the ratio of drainage areas. Seven cfs were allowed to pass downstream before pumping began. This is the same ratio to drainage area as was used at Milan. The next 3.34 cfs was used to pump to The Ponds, the next 4.45 cfs was used to pump to the Lake. A minimum reserve of 450 acre-feet was maintained in the lake at all times.

The lake intake is a floating intake. It connects to the raw water piping on a concrete pillar that is roughly 3 feet above the original bottom of the lake. This raw water line passes through the dam to the lake pumping station on the downstream side of the dam. The intake can draw water over a 40 feet range.
Spillway crest is at elevation 800 feet. This is a concrete ogee crest that is level and in good shape.

Following is how the data was derived by control work.

STO-AREA Elevation-Storage and Elevation-Area data were determined from July 2000 survey made by USGS.

Brookfield City Lake

Elevation (feet)	Surface Area (acres)	Volume Storage (ac-ft)	
768	2.2	1.5	
770	6.6	10.5	
772	11.0	27.9	
774	16.5	55.2	
776	23.7	95.3	
778	29.8	149.0	
780	36.8	215.3	
782	43.1	295.6	
784	49.6	387.9	
786	57.1	494.6	
788	65.0	616.7	
790	72.9	754.4	
792	81.8	908.8	
794	90.1	1081.2	
795.8	97.1	1249.7	Water surface 7/12/00
796	98.0	1269.2	
797	102.6	1369.5	
798	107.4	1474.4	
800	117.4	1699.0	
802	125.6	1942.3	
803	130.7	2070.3	Approximate top of dam

LIMITS Brookfield City Lake Max. Pool storage 1699 Ac.Ft.
Minimum Pool storage 55 Ac.Ft.

GENERAL Record period of drought is in the 1950's. Analysis began in January 1951 and ended December 1959.

SEEPAGE Seepage when full was estimated to be 3.5 inches per month and when the pool is near empty seepage is zero.

RAINFALL Rainfall data came from the Brookfield, Mo. rain gage.

RUNOFF This is the runoff into the lake from its drainage area. Monthly runoff volumes in Watershed inches was determined at the Linneus gage on Locust creek. When runoff did not appear reasonable when compared to rainfall it was necessary to examine daily rainfall values for that month. Antecedent moisture was estimated for each rainfall event and adjustments to NRCS runoff curve number was made to arrive at runoff for each rain.

EVAP. Pan evaporation at the Lakeside gaging station was used as a base because it has data for year around evaporation. This data was updated with gage data from stations at Spickard, New Franklin, and Columbia. Depending on the latest data for the station nearest to Milan.

DEMAND This was determined by city records. They use 620,000 Gallon per day, which comes from the holding ponds.

To establish the demand for the lake, an analysis of the holding ponds was made to determine the amount of additional water, that could not be supplied by the creek, needed to keep the holding ponds full. This varied each month and was not a constant.

Holding Pond Runs

1. The first RESOP run for the holding ponds considered inflow to the ponds to be from West Yellow Creek at the rate of 1500 GPM (3.34 cfs). Seven-cfs was allowed to pass downstream to meet in-stream flow needs. The next 3.34-cfs was pumped to the ponds. Pumping was continuous when stream flow was adequate. This run produced spills.

2. Run Two was to eliminate the spills from the ponds. This gave the months and volumes of water that was deficit without the Lake contributing to the supply.

3. Run three added 1000 GPM pumped to the holding ponds. Pumping was continuous and produced spills.

4. Run four eliminated these spills to determine the demand from the lake. The lake was analyzed using this demand.

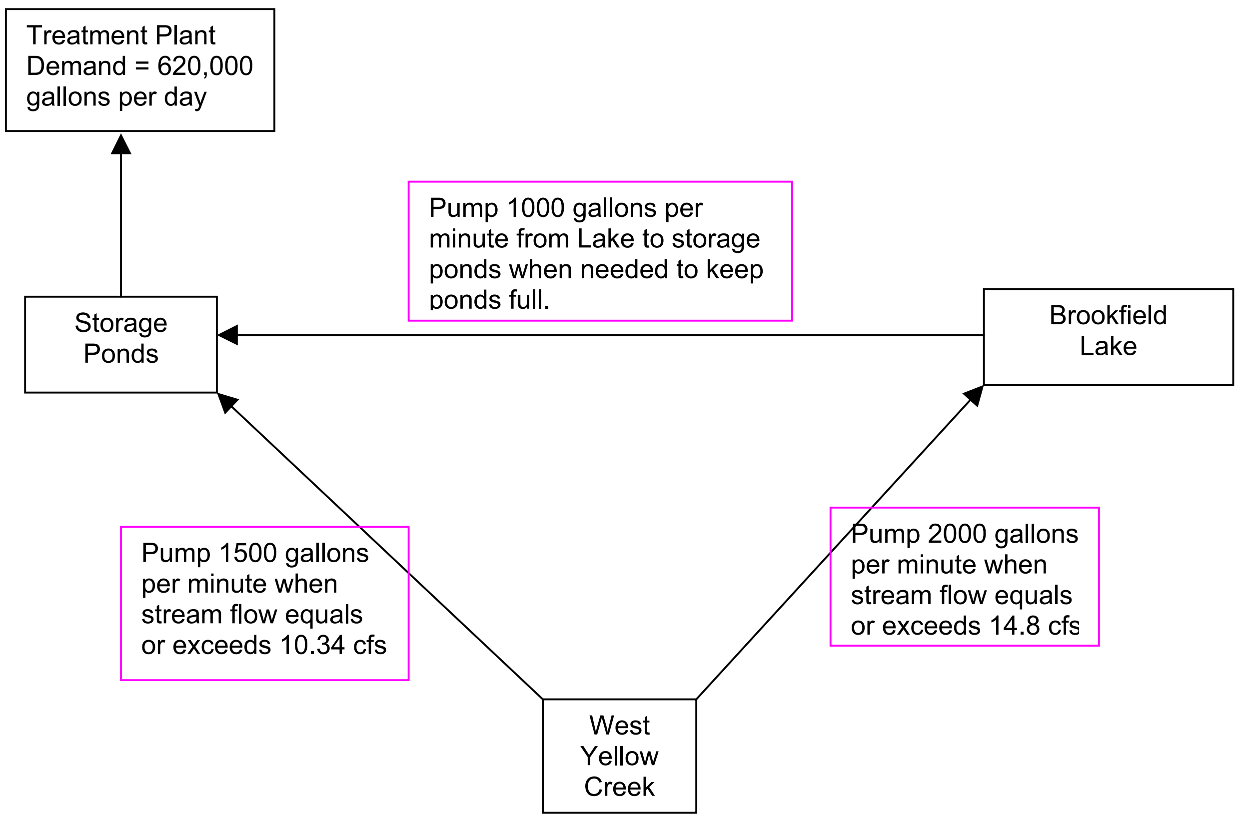
OTHER This refers to the volume of water pumped from West Yellow Creek to the holding ponds and/or to Brookfield City Lake.

Determination of the volume of water available for pumping was made using daily discharges at the stream gage at Linneus. The drainage area at Linneus is 550 Sq.Mi. and the drainage area for West Yellow Creek at the point of pumping is 159 Sq.Mi. The daily discharge rates at the point of pumping were reduced by a ratio of 159/550. Pumping was only planned for flows above 10.34 cfs, 7 cfs, for in-stream flow requirements plus 1500 GPM, 3.34 cfs for pumping to the ponds.

To fill the lake, 2000 GPM, 4.45 cfs, was planned after stream flow reached 14.79 cfs. No pumping was used when there was spillage.

BROOKFIELD WATER SUPPLY AND TREATMENT

Following is the flow chart used as a guide for the analysis of Brookfield water supply. West Yellow Creek is the primary source of water supply for Brookfield. The following scenario was used to determine if the water supply would be adequate for the 1950's drought. For this study, pumping from the creek to the holding ponds was considered the first source of water supply, pumping when needed, and if stream flow permitted. If stream flow did not permit pumping, then water was pumped from the lake to meet needs. The objective was to keep the holding ponds to within a foot of the top. As a result, the demand from the lake is not constant each month.



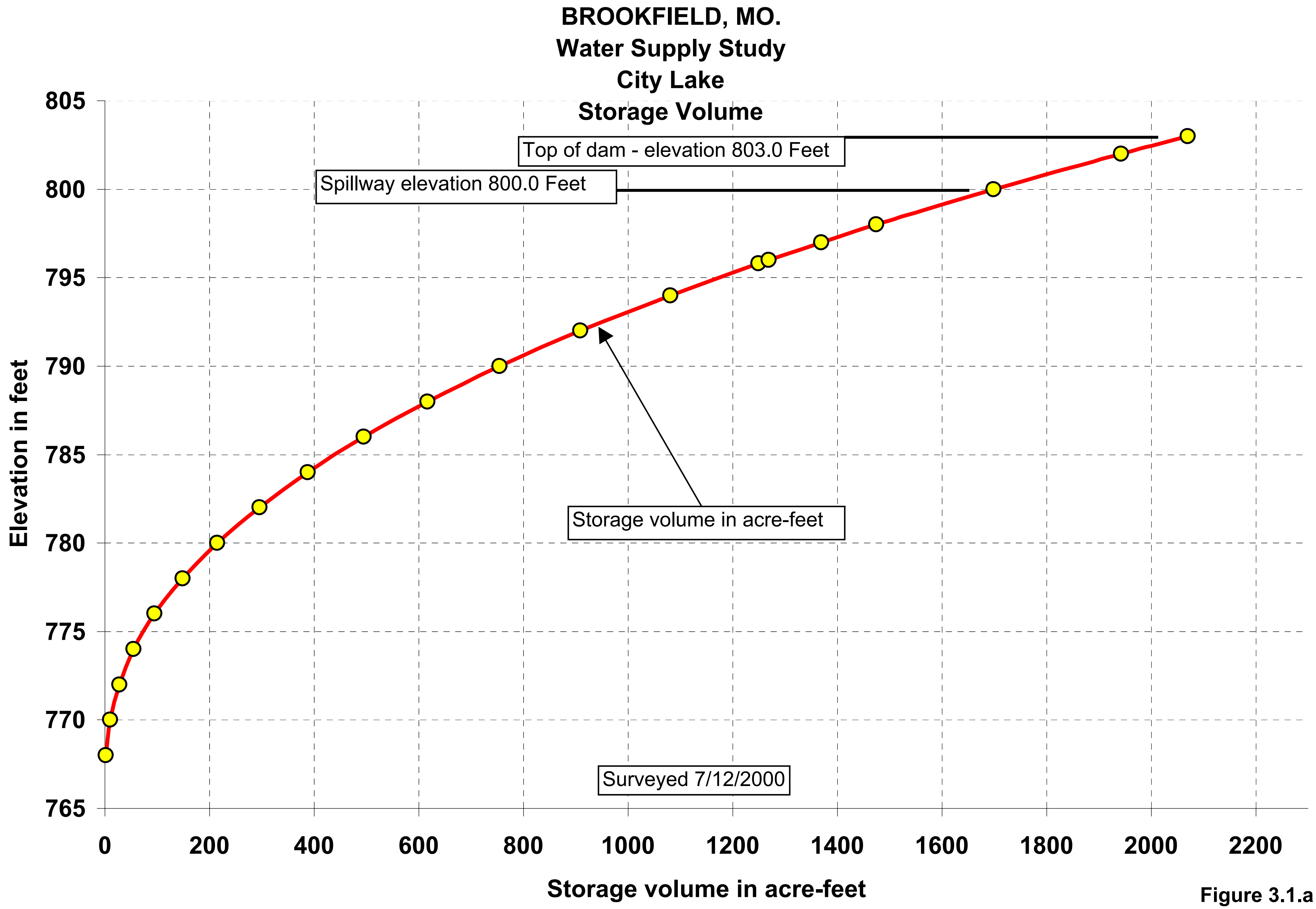
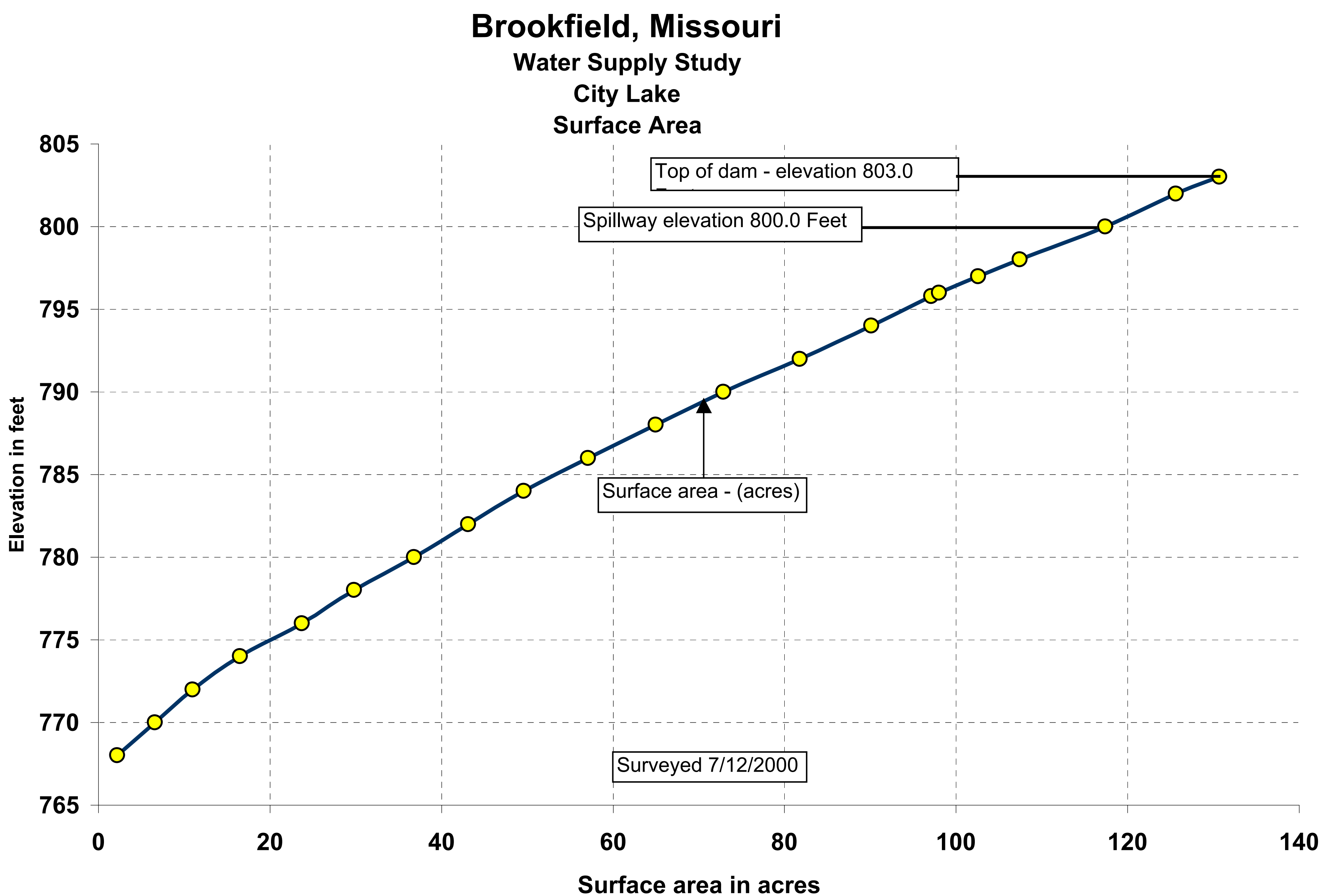

BROOKFIELD, MO.
Water Supply Study
City Lake
Storage Volume
805
800
795
790
785
780
775
770
765
Elevation in feet
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
Storage volume in acre-feet
Top of dam - elevation 803.0 Feet
Spillway elevation 800.0 Feet
Storage volume in acre-feet
Surveyed 7/12/2000

Figure 3.1.a



Brookfield, Missouri
Water Supply Study
City Lake
Surface Area
Top of dam - elevation 803.0
Spillway elevation 800.0 Feet
Surface area - (acres)
Surveyed 7/12/2000
Elevation in feet
805
800
795
790
785
780
775
770
765
0
20
40
60
80
100
120
140
Surface area in acres

Figure 3.1.b

BROOKFIELD LAKE

Water Supply Study
City Lake
Lake Storage

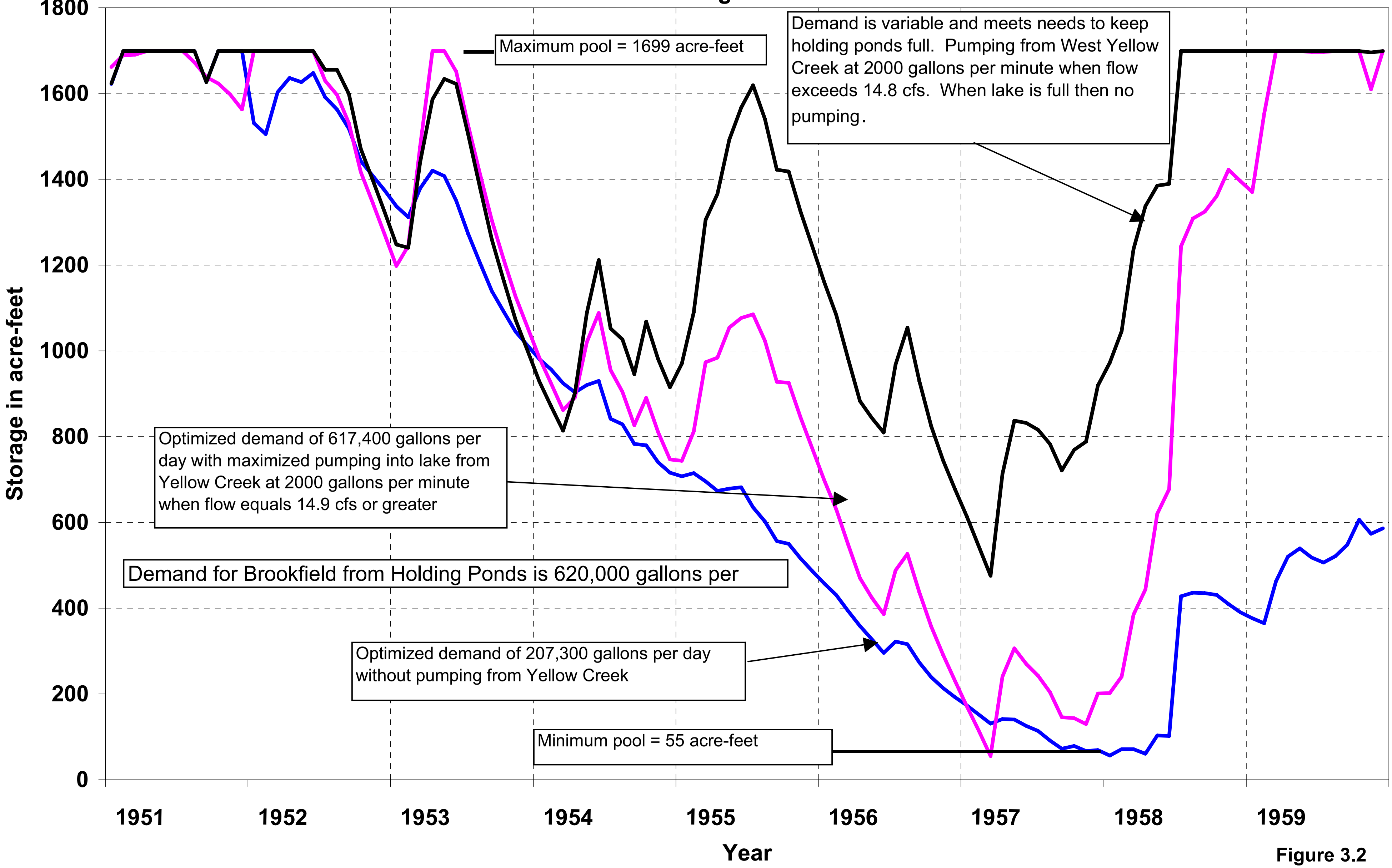
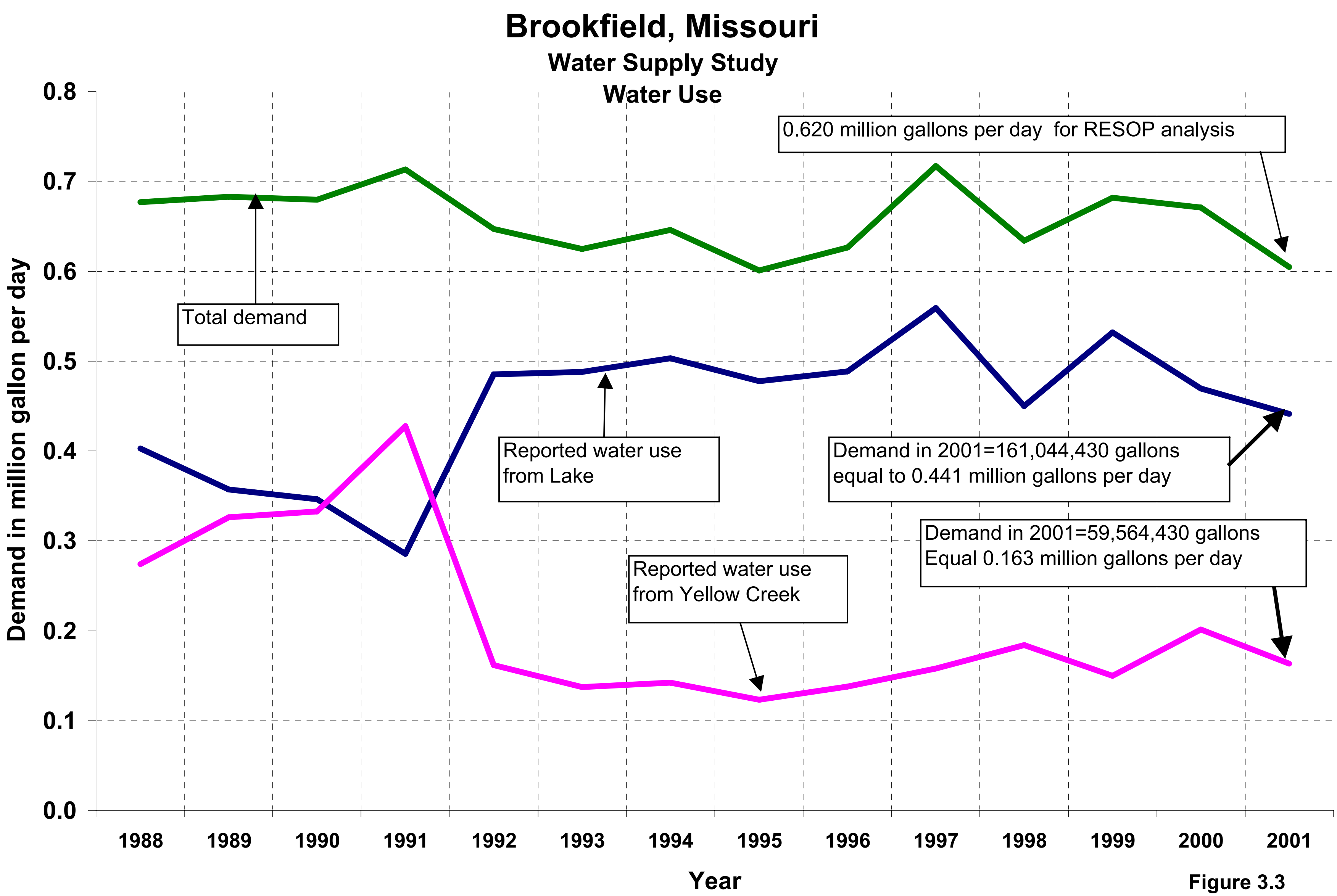


Figure 3.2



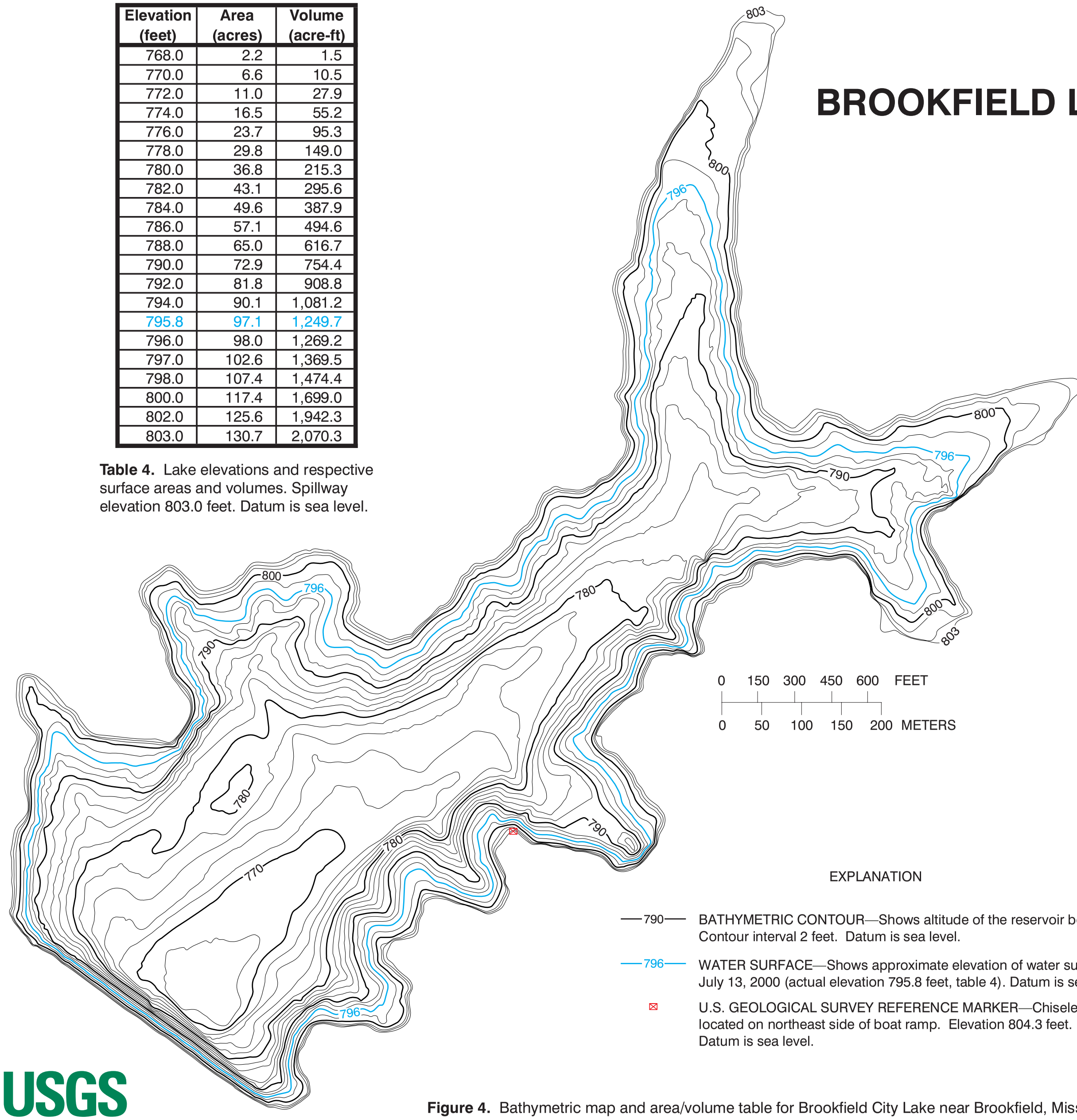
Brookfield, Missouri
Water Supply Study
Water Use
0.620 million gallons per day for RESOP analysis
Total demand
Reported water use from Lake
Demand in 2001=161,044,430 gallons equal to 0.441 million gallons per day
Demand in 2001=59,564,430 gallons Equal 0.163 million gallons per day
Reported water use from Yellow Creek
Demand in million gallon per day
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
Year

Figure 3.3

Elevation (feet)	Area (acres)	Volume (acre-ft)
768.0	2.2	1.5
770.0	6.6	10.5
772.0	11.0	27.9
774.0	16.5	55.2
776.0	23.7	95.3
778.0	29.8	149.0
780.0	36.8	215.3
782.0	43.1	295.6
784.0	49.6	387.9
786.0	57.1	494.6
788.0	65.0	616.7
790.0	72.9	754.4
792.0	81.8	908.8
794.0	90.1	1,081.2
795.8	97.1	1,249.7
796.0	98.0	1,269.2
797.0	102.6	1,369.5
798.0	107.4	1,474.4
800.0	117.4	1,699.0
802.0	125.6	1,942.3
803.0	130.7	2,070.3

Table 4. Lake elevations and respective surface areas and volumes. Spillway elevation 803.0 feet. Datum is sea level.

BROOKFIELD LAKE



EXPLANATION

—790— BATHYMETRIC CONTOUR—Shows altitude of the reservoir bottom. Contour interval 2 feet. Datum is sea level.

—796— WATER SURFACE—Shows approximate elevation of water surface, July 13, 2000 (actual elevation 795.8 feet, table 4). Datum is sea level.

⊠ U.S. GEOLOGICAL SURVEY REFERENCE MARKER—Chiseled square located on northeast side of boat ramp. Elevation 804.3 feet. Datum is sea level.

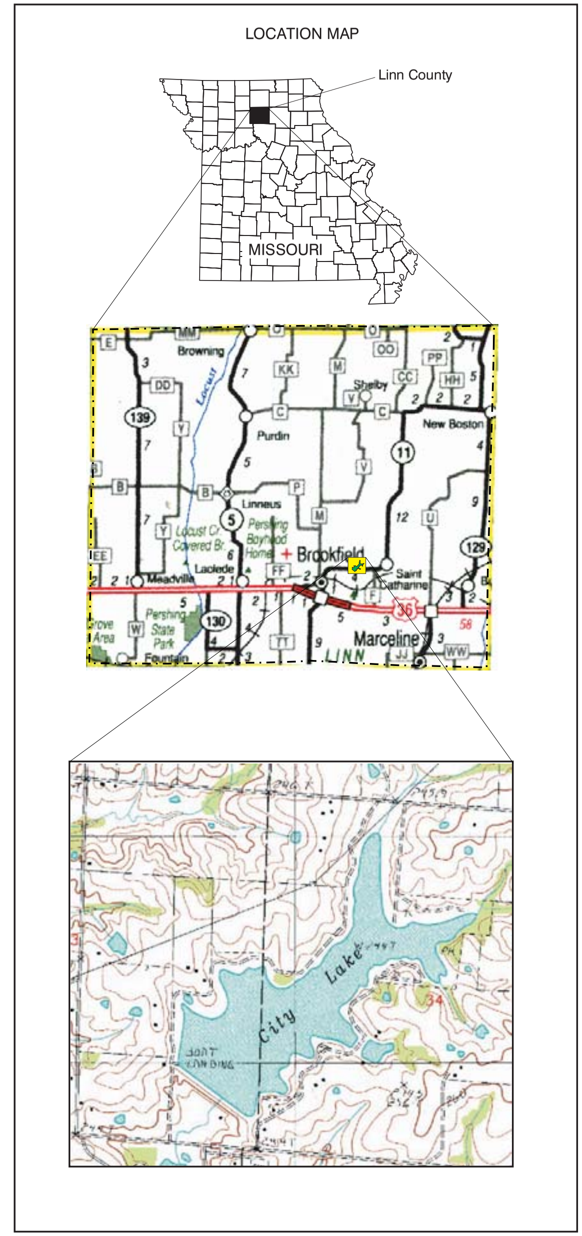


Figure 4. Bathymetric map and area/volume table for Brookfield City Lake near Brookfield, Missouri.

Butler, Missouri
Water Supply Study
City Lake

Up to the present, (January 2002), Butler Missouri has used three raw water sources. These are Miami Creek, Butler Lake, and Marais Des Cygnes River. Sometime during the year 2002, Butler will have completed a new pumping plant on the Marais Des Cygnes River. This plant will have two 2000 GPM pumps. One will be kept in reserve. Miami Creek will be taken off the system, in part because of high concentrations of agricultural chemicals.

The Marais Des Cygnes River diversion and the lake will be the sources of water supply for Butler. Pumping from the Marais Des Cygnes River is shut off when atrazine levels exceed drinking water standards. The diversion will be shut off April through June. Marais Des Cygnes River water will be pumped into the Butler Lake for storing and will then be fed to the treatment plant by gravity flow at up to 1100 GPM. The drainage area at the intake point on Marais Des Cygnes River is 3418 square miles.

Butler Lake is located on a tributary to Miami Creek, about 3 miles WSW of Butler. The lake has a drainage area of 3.11 Square Miles.

For this study, pumping was planned so that the lake level did not fall below 5 to 6 feet below the spillway in order to have a minimum reserve of 400 acre-feet. This study does not consider pumping from mid March through mid July of each year.

Pumping over the last several years has been necessary 4 to 5 months a year. Upstream dams and water uses in Kansas are intensively allocated at other upstream locations for municipal needs, wetland augmentation and cooling for power generation plants.

Upper limits of water available for use from the Marais Des Cygnes River, by Butler, on a monthly basis, was determined by use of a computer program, called STELLA.

As part of this study it was found to be beneficial to analyze base flow and runoff indexes. This was done for the State Line Gage on the Marais Des Cygnes River. The USGS computer program "HYSEP" was used to make this determination. The sliding hydrograph separation method was used. It generates median values of fixed and local hydrograph separation methods. This analysis was made for the period of record from 1959 through 2000. The results of those runs reflect a trend that the base flow is increasing over the evaluation period.

NRCS's computer program "RESOP" was used to make the analysis. Following is the procedure for derivation of data.

STO-AREA Elevation-Storage and Elevation-Area data were determined from July 2000 survey made by USGS.

Butler City Lake

Elevation (feet)	Area (acres)	Storage (ac-ft)
770	0.74	0.57
772	2.18	3.42
774	3.63	9.26
776	6.67	19.07
778	12.66	37.68
780	18.75	69.11

782	24.70	112.18	
784	31.33	1 68.24	
786	37.82	237.08	
788	44.43	319.21	
790	54.24	417.02	
792	63.17	535.91	
794	69.88	668.82	
794.3	71.74	689.95	
795.1	74.77	748.56	Spillway crest elevation
796	77.99	817.32	
798	85.22	980.40	
800	96.48	1159.77	Top of dam

Water surface elevation on 4/18/01 = 793.5

LIMITS Butler City Lake Max. Pool storage 748.56 Ac.Ft.
Minimum Pool storage 15 Ac.Ft.

GENERAL Record period of drought is in the 1950's. Analysis began in January 1951 and ended December 1959.

SEEPAGE Seepage when full was estimated to be 3.5 inches per month and when the pool is near Empty, seepage is zero.

RAINFALL Rainfall data came from the Butler, Mo. rain gage and supplemented where needed with the Appleton City rainfall data.

RUNOFF This is the runoff into the lake from its drainage area. Regional monthly runoff values were determined from stream gage data.

Monthly runoff volumes in watershed inches was determined at the Little Blue River gage near Lake City, North of Butler. Another gage on Cedar Creek near Pleasant View, Missouri was analyzed. Results at the lake were nearly the same. Because the soils and topography of Little Blue River is more nearly like that at Butler, it was selected to represent regional runoff. If runoff did not appear reasonable when compared to rainfall, it was necessary to examine daily rainfall values for that month. Antecedent moisture was estimated for each rainfall event and adjustments to NRCS runoff curve number was made to arrive at runoff for each storm.

EVAP. Pan evaporation at the Lakeside gaging station near the Lake of the Ozarks was used to determine pan evaporation. The adjustment to lake evaporation was 0.76.

DEMAND This was determined by city records. Current usage is 1.01 million gallon per day.

When water level dropped to between 5 and 6 feet below the spillway level, water was pumped to the lake from Marais Des Cygnes River.

OTHER This refers to the volume of water pumped from Marais Des Cygnes River to the Lake.

Determination of the volume of water available for pumping was made using monthly discharges volumes determined by the Computer program, STELLA. The STELLA analysis was based on the stream gage data at Trading Post Gage (drainage area 3230 square miles) and factored up based on drainage area.

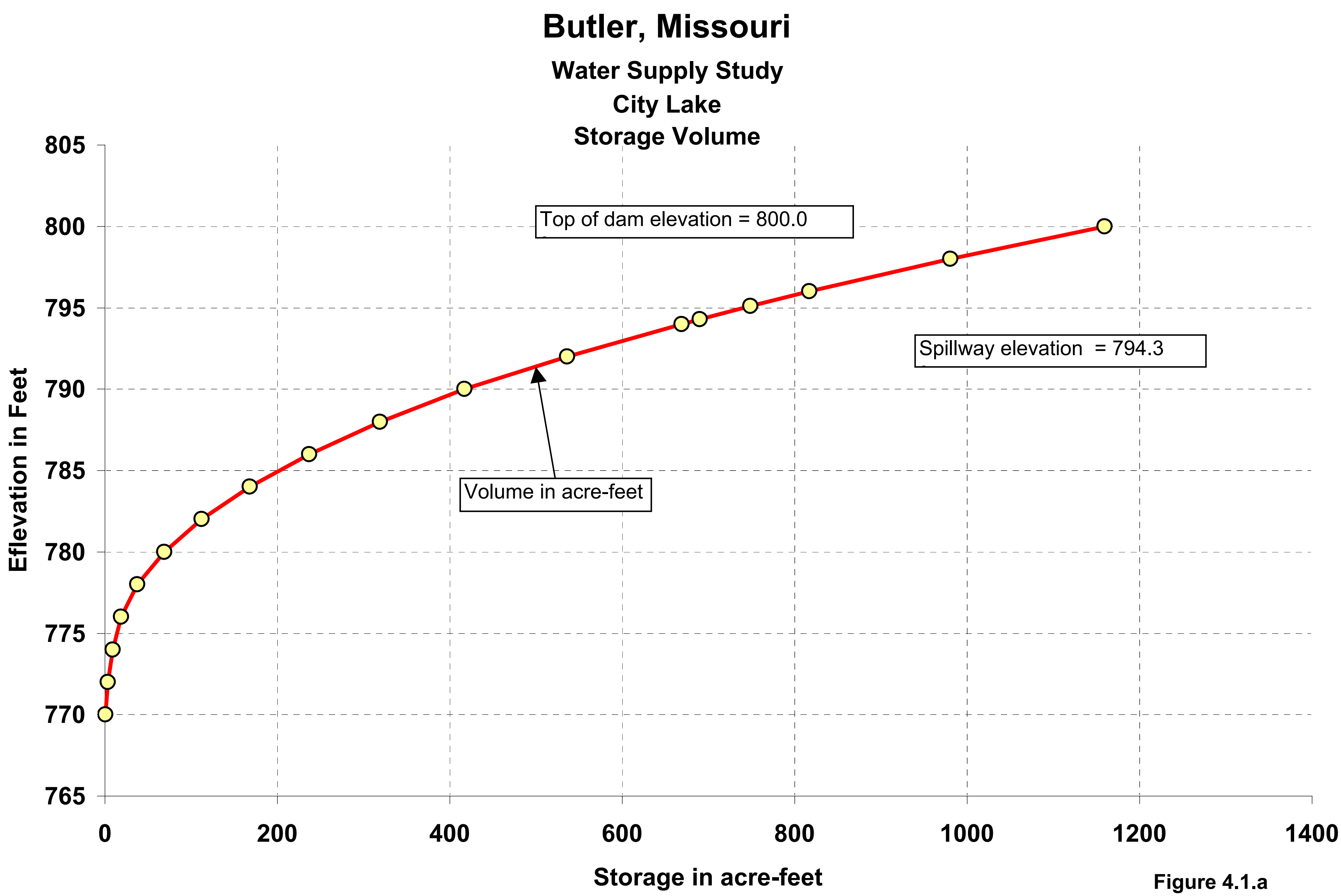
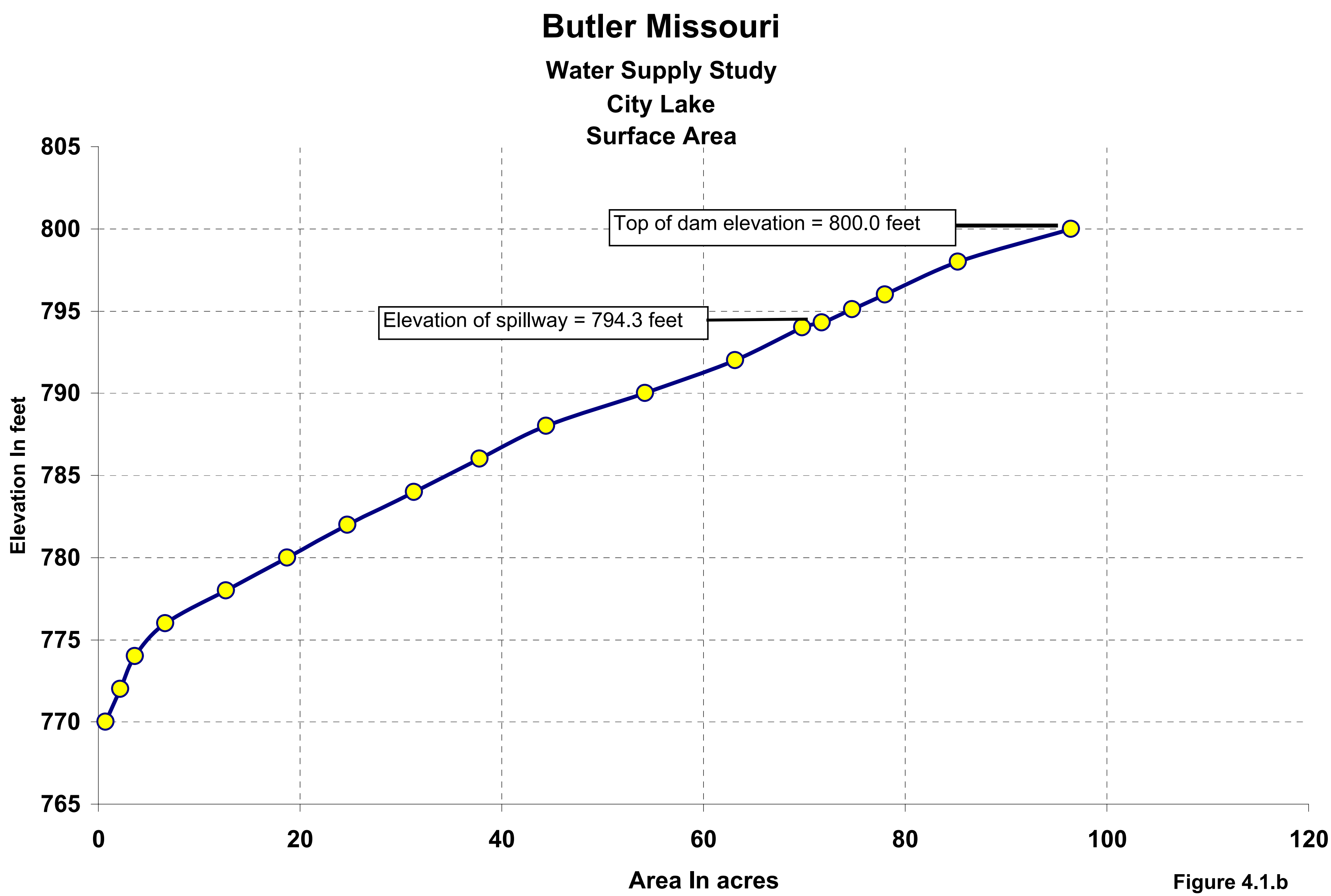
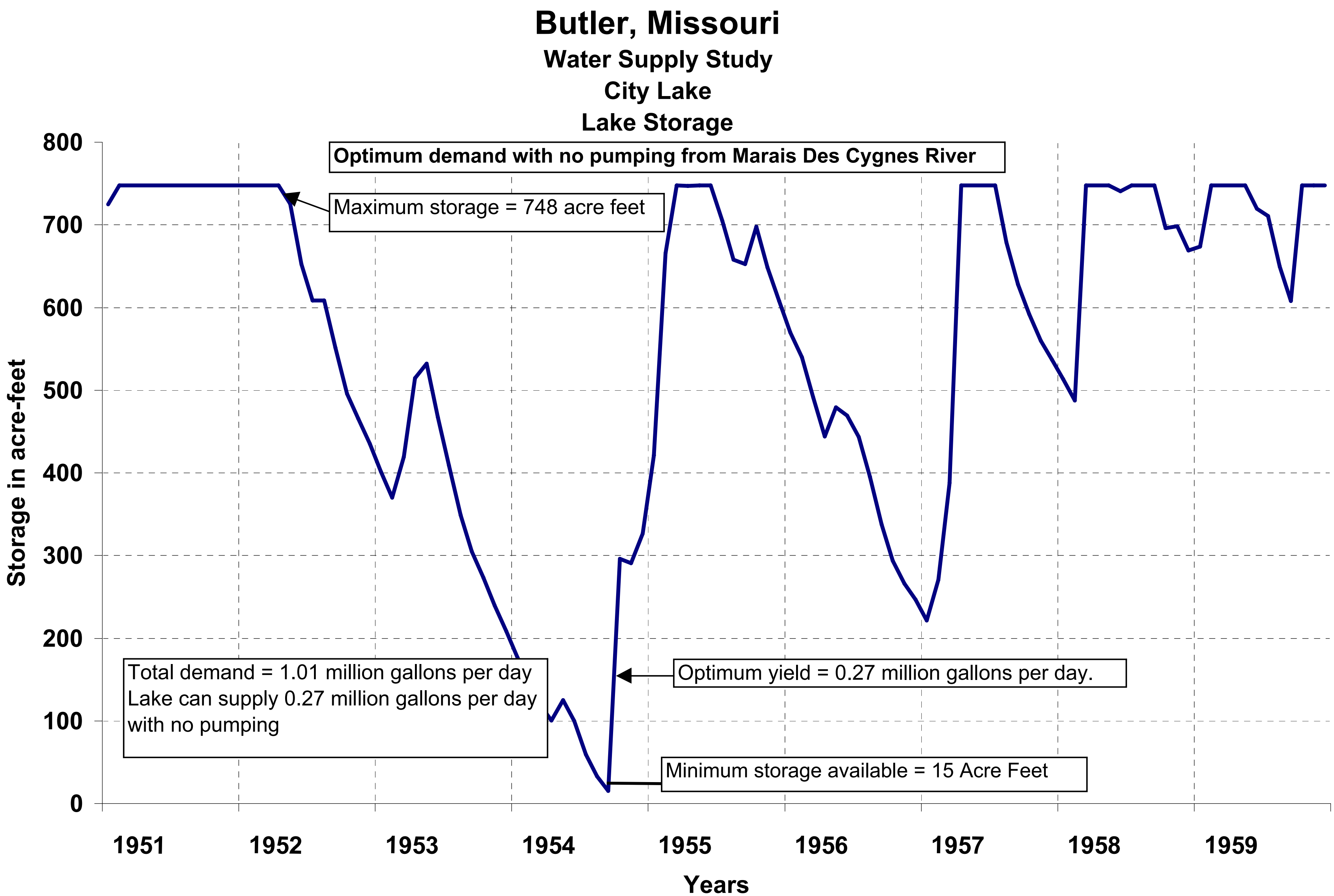

Butler, Missouri
Water Supply Study
City Lake
Storage Volume
Top of dam elevation = 800.0
Spillway elevation = 794.3
Volume in acre-feet
Eflevation in Feet
805
800
795
790
785
780
775
770
765
0
200
400
600
800
1000
1200
1400
Storage in acre-feet

Figure 4.1.a

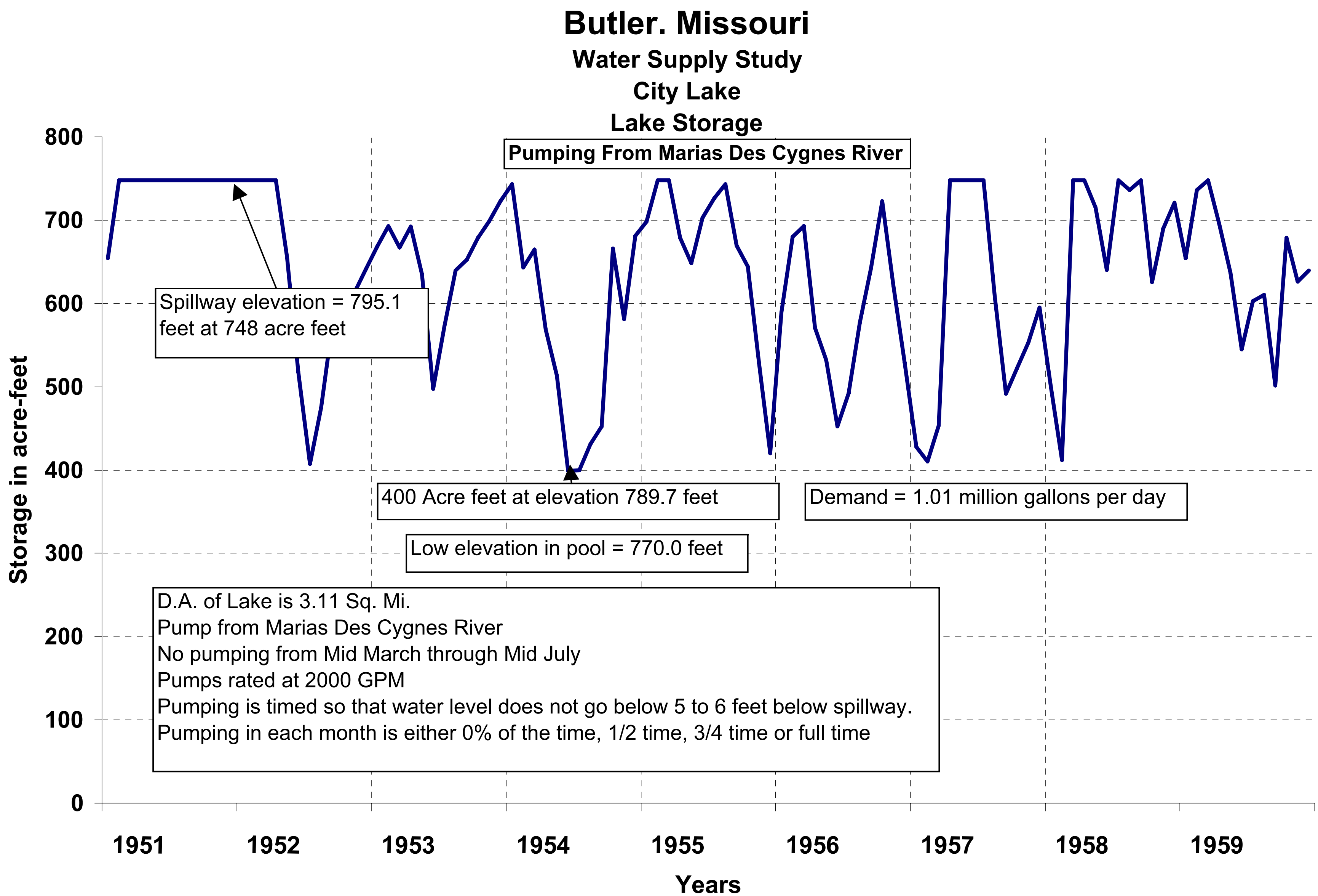


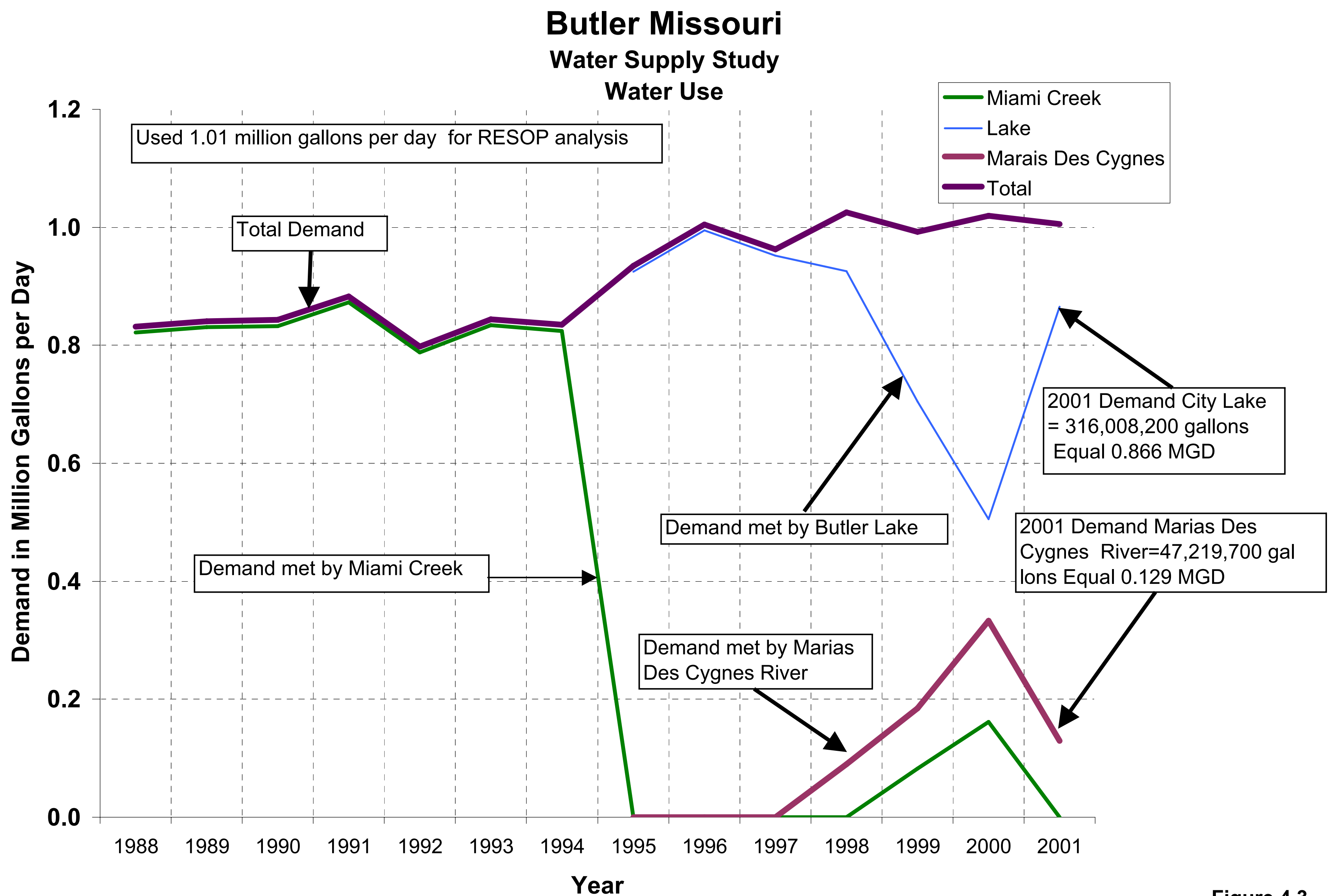
Butler Missouri
Water Supply Study
City Lake
Surface Area
805
800
795
790
785
780
775
770
765
Elevation In feet
Top of dam elevation = 800.0 feet
Elevation of spillway = 794.3 feet
0
20
40
60
80
100
120
Area In acres

Figure 4.1.b



Butler, Missouri
Water Supply Study
City Lake
Lake Storage
Optimum demand with no pumping from Marais Des Cygnes River
Maximum storage = 748 acre feet
Total demand = 1.01 million gallons per day
Lake can supply 0.27 million gallons per day
with no pumping
Optimum yield = 0.27 million gallons per day.
Minimum storage available = 15 Acre Feet
Storage in acre-feet
800
700
600
500
400
300
200
100
0
1951
1952
1953
1954
1955
1956
1957
1958
1959
Years

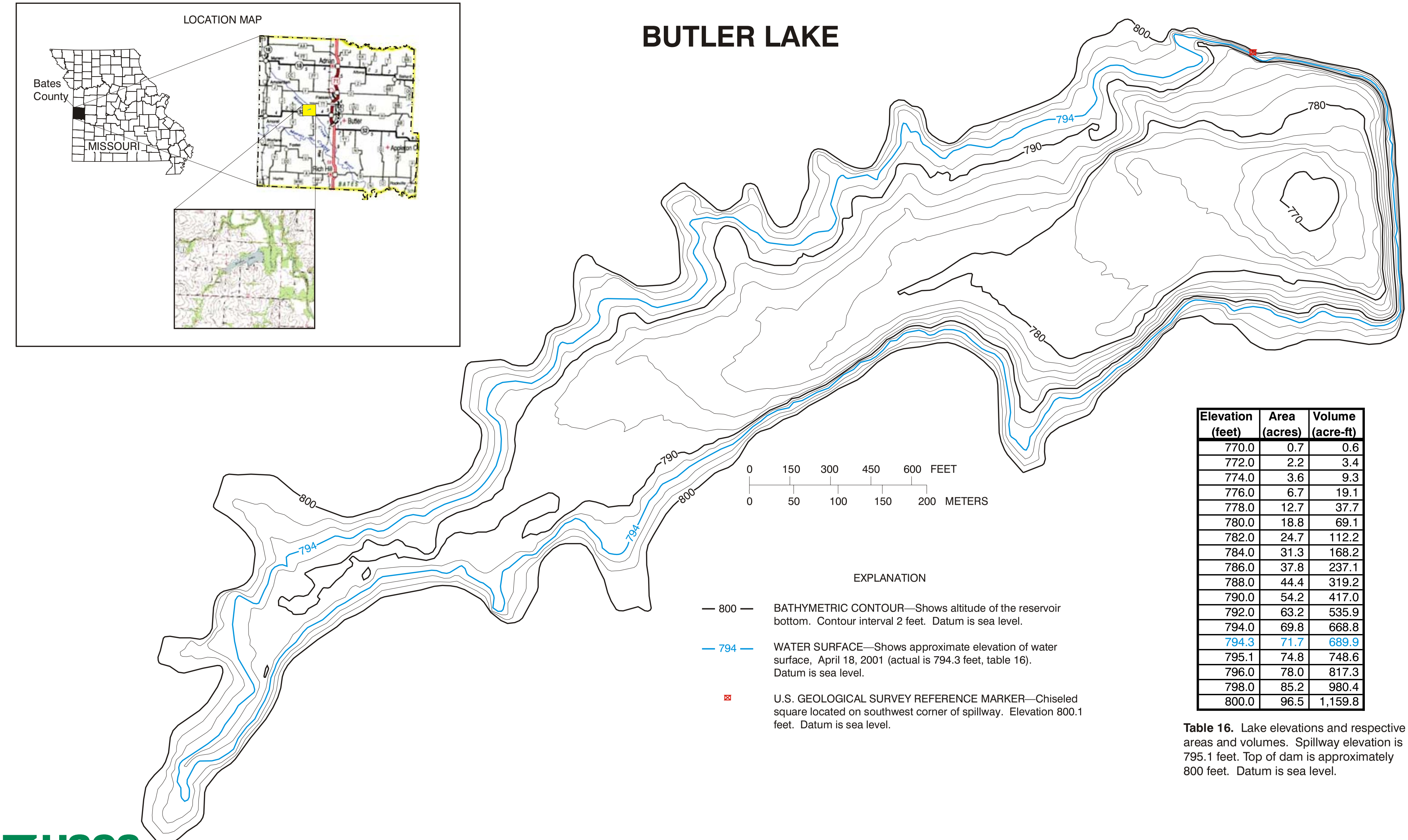

Butler. Missouri
Water Supply Study
City Lake
Lake Storage
Pumping From Marias Des Cygnes River
Spillway elevation = 795.1 feet at 748 acre feet
400 Acre feet at elevation 789.7 feet
Low elevation in pool = 770.0 feet
Demand = 1.01 million gallons per day
D.A. of Lake is 3.11 Sq. Mi.
Pump from Marias Des Cygnes River
No pumping from Mid March through Mid July
Pumps rated at 2000 GPM
Pumping is timed so that water level does not go below 5 to 6 feet below spillway.
Pumping in each month is either 0% of the time, 1/2 time, 3/4 time or full time
Storage in acre-feet
800
700
600
500
400
300
200
100
0
1951
1952
1953
1954
1955
1956
1957
1958
1959
Years



Butler Missouri
Water Supply Study
Water Use
Miami Creek
Lake
Marais Des Cygnes
Total
Used 1.01 million gallons per day for RESOP analysis
Total Demand
Demand met by Miami Creek
Demand met by Butler Lake
Demand met by Marias Des Cygnes River
2001 Demand City Lake = 316,008,200 gallons Equal 0.866 MGD
2001 Demand Marias Des Cygnes River=47,219,700 gal lons Equal 0.129 MGD
Demand in Million Gallons per Day
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
Year

Figure 4.3

BUTLER LAKE



Elevation (feet)	Area (acres)	Volume (acre-ft)
770.0	0.7	0.6
772.0	2.2	3.4
774.0	3.6	9.3
776.0	6.7	19.1
778.0	12.7	37.7
780.0	18.8	69.1
782.0	24.7	112.2
784.0	31.3	168.2
786.0	37.8	237.1
788.0	44.4	319.2
790.0	54.2	417.0
792.0	63.2	535.9
794.0	69.8	668.8
794.3	71.7	689.9
795.1	74.8	748.6
796.0	78.0	817.3
798.0	85.2	980.4
800.0	96.5	1,159.8

Table 16. Lake elevations and respective areas and volumes. Spillway elevation is 795.1 feet. Top of dam is approximately 800 feet. Datum is sea level.

USGS
science for a changing world

Figure 16. Bathymetric map and table of areas/volumes of Butler Lake near Butler, Missouri.

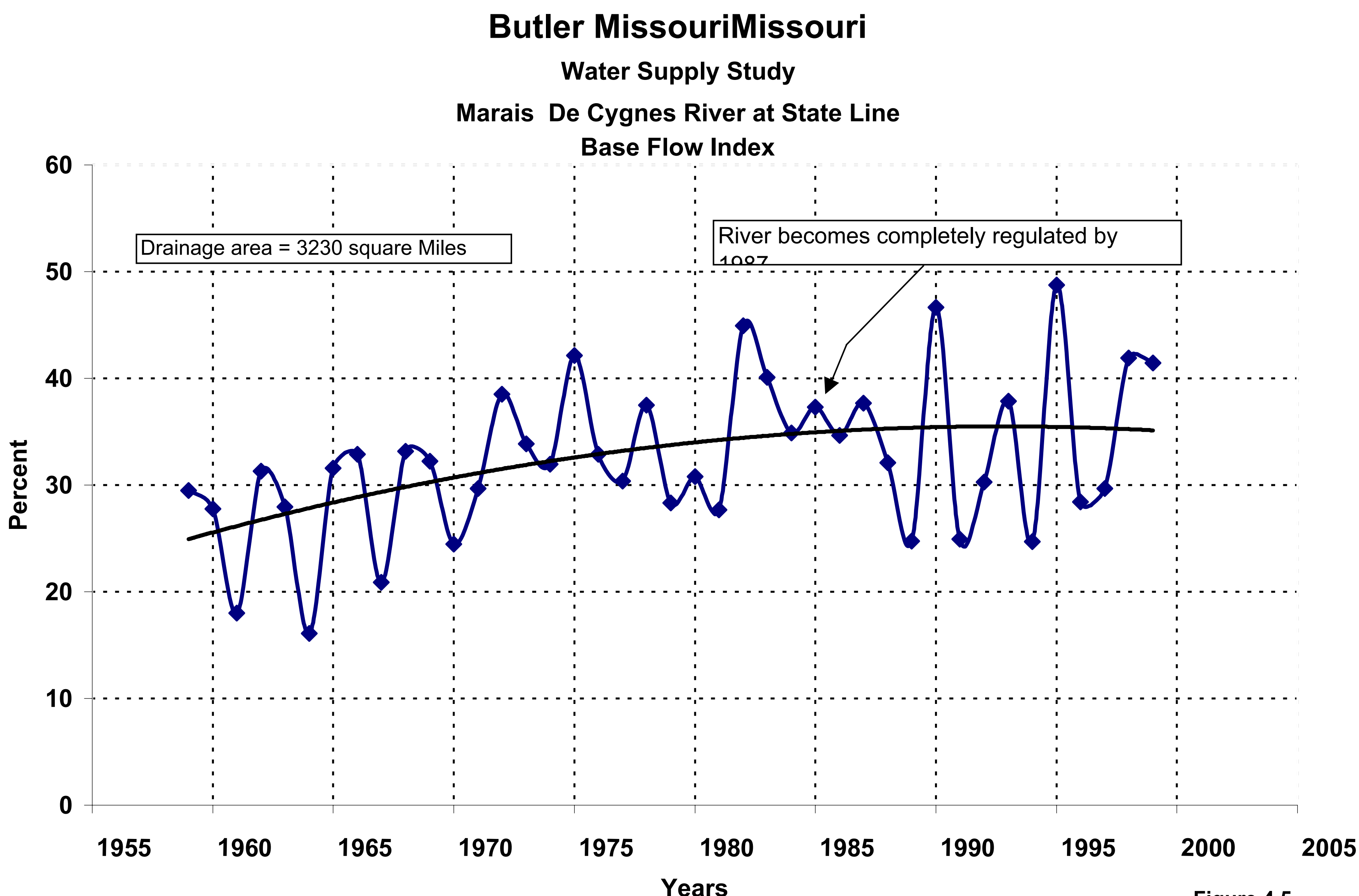

Butler MissouriMissouri
Water Supply Study
Marais De Cygnes River at State Line
Base Flow Index
Drainage area = 3230 square Miles
River becomes completely regulated by
Percent
60
50
40
30
20
10
0
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
Years

Figure 4.5

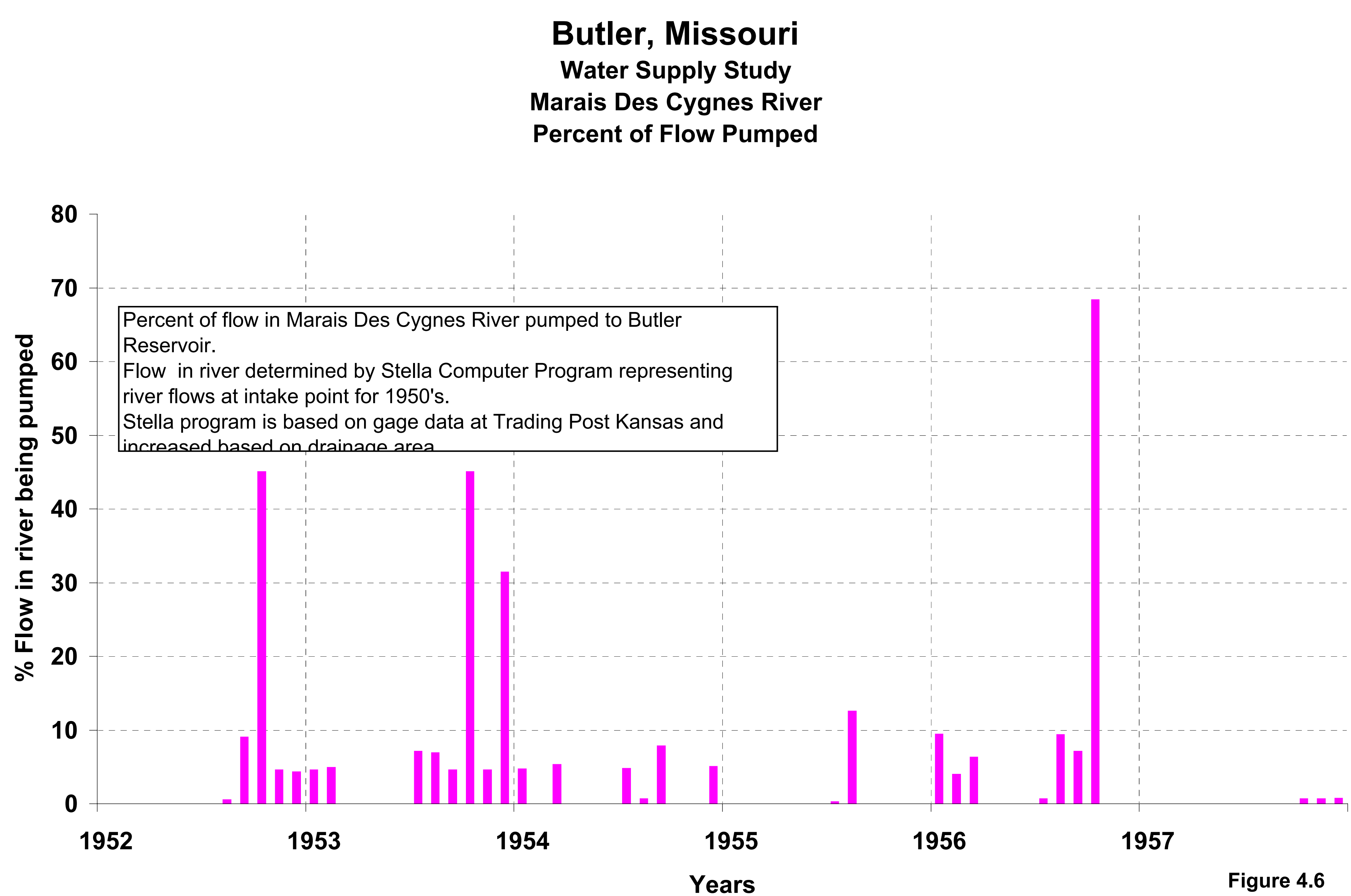

Butler, Missouri
Water Supply Study
Marais Des Cygnes River
Percent of Flow Pumped
Percent of flow in Marais Des Cygnes River pumped to Butler Reservoir.
Flow in river determined by Stella Computer Program representing river flows at intake point for 1950's.
Stella program is based on gage data at Trading Post Kansas and increased based on drainage area
% Flow in river being pumped
80
70
60
50
40
30
20
10
0
1952
1953
1954
1955
1956
1957
Years

Figure 4.6

Cameron, Missouri
Water Supply Study
Grindstone Reservoir and Three City Lakes

Cameron has a system of four lakes. The older three lakes have met their Original needs. Lake #1 and lake #2 are small lakes above lake #3 and are used primarily for sediment control. Lake #1 has approximately 110 Acre Feet of storage, Lake #2 has 310 Acre Feet and lake #3 has 950 acre feet of total storage. In addition, the Grindstone Reservoir was completed in 1992 and contains 1300 acre feet of municipal storage. Lakes #1 and #2 are used for water supply only in emergencies.

Water usage by the city of Cameron has been increasing each year. Following is the annual volume of water used:

1998 505.23 Million Gallon
1999 508.34 Million Gallon
2000 540.89 Million Gallon
2001 540.74 Million Gallon
2002 556.09 Million Gallon

Demand for this study was 1.5 million gallon per day.
Optimized demand was determined to be about 1.5 million gallon per day.

Operation of the system is for using water from Lake #3 to the treatment plant. Lake #3 inflow is runoff from the uncontrolled drainage area above lake #3 and spillage from lakes #1 and #2 as well as pumping from Grindstone Reservoir. Water in Lake #3 is then pumped into the treatment plant.

Cameron's system of lakes was analyzed using the NRCS's computer program named "RESOP". Following is the data and procedures for input to the program.

STO-AREA Elevation-Storage and Elevation-Area data were determined from the as built plans for the Grindstone Reservoir and a 1996 sediment survey of lakes #1 through #3.

Grindstone Reservoir
Constructed in 1991
Contains 569 Acre Feet of sediment storage + 1300 Acre Feet Water supply storage.

Elevation Feet	Surface Area Acres	Storage Ac.Ft.
885	75	300
890	111	850
895	156	1500
900	208	2400
905	265	3550
910	336	4950
915	415	6750
920	504	9000
925	620	12000
930	750	15300

Reservoir no. 1

Elevation Feet	Area Acres	Storage Acre Feet
925	0	0
926	0.02	0.01
928	2.03	2.06
930	4.29	8.38
932	6.77	19.44
934	9.37	35.58
936	12.02	56.97
938	14.66	83.65
940	17.04	115.35

Weir elevation = 939.75

Reservoir no. 2

Elevation Feet	Area Acres	Storage Acre Feet
917	0	0
918	0.1	0.05
920	0.44	0.59
922	1.18	2.21
924	2.27	5.66
926	4.15	12.08
928	6.05	22.28
930	8.56	36.89
932	11.16	56.61
934	13.73	81.50
936	16.59	111.82
938	20.31	148.72
940	22.64	191.67
942	25.27	239.58
944	28.58	293.43

Weir elevation = 945.2

Reservoir no. 3

Elevation Feet	Area Acres	Storage Acre Feet
887	0	0
888	0.24	0.12
890	1.75	2.11
892	4.89	8.75
894	12.56	26.20
896	19.03	57.79
898	24.55	101.37
900	31.06	156.98
902	41.53	229.57
904	54.92	326.02
906	66.19	447.13
908	73.52	586.84
910	80.20	740.56
912	88.10	908.86

Weir elevation = 912.5

LIMITS

Grindstone Reservoir
Maximum Pool storage = 1869 Ac.Ft. (569 Ac.Ft. sediment and 1300 acre feet municipal water supply storage).
Minimum Pool storage 569 Ac.Ft.

Starting storage was considered at maximum pool.

The Drainage area of the lake is 13,382 acres (20.91 Sq. Mi.).

Lake #1
Maximum pool storage = 110 Acre Feet at elevation 939.75 feet.
Minimum Pool storage = 2 Acre Feet at elevation 928 feet.

Starting storage was considered at maximum pool.

The drainage area = 1056 Acres (1.65 Square Miles)

Lake #2
Maximum pool storage = 310 Acre Feet at elevation 945.2 feet.
Minimum Pool storage = 6 Acre Feet at elevation 924 feet.

Starting storage was considered at maximum pool.

The drainage area = 1152 Acres (1.80 Square Miles)

Lake #3
Maximum pool storage = 950 Acre Feet at elevation 912.5 feet.
Minimum Pool storage = 100 Acre Feet at elevation 898.0 feet.

Starting storage was considered at maximum pool.

The drainage area = 1106 Acres (1.73 Square Miles)
Total drainage area including #1 and #2 is 3314 acres.
(5.18 Square Miles)

GENERAL The adjustment to convert from pan evaporation to lake evaporation was made before entering evaporation data. The factor was 0.76. As a result a factor of 100.0 was used here.

The record period of drought is in the 1950's.
Analysis began in January 1951 and ended December 1959

SEEPAGE The reservoir seepage varied for each lake. For the GLM lake seepage varied from 0 seepage near empty to a maximum of 1.1 inch per month when at full pool. This lake was built using controlled construction procedures with the core of the dam being clay material so that the dam would be impermeable. Lakes #1, #2 and #3 have less static pressure because the water is not as deep against the dam but were built under less controlled conditions. The material in each dam is compacted earth of clayey soils. These lakes are shallow so that static pressure is low, as a result seepage was lower for smaller depths. Lake #3 values varied from 1.0 inches per month to near 0 inches when the pool was low. Lakes #1 and #2 would have very little seepage for RESOP runs because any seepage through the dam would drain into lake #3.

RAINFALL There were no rainfall records for the Cameron area until 1998. Records from Hamilton were available and used for the period June 1954 through 1959. Prior to that date(1951 through 1954) the Rainfall data at Gallatin, Mo. was used. Gallatin is located 14 miles north of Hamilton. Rainfall data came from the Gallatin, Mo. rain gage for the period 1951 through May 1954.

RUNOFF This is the runoff into the lake from its drainage area. Monthly runoff volumes in watershed inches. Three gage runoff data were examined, one at Jenkins Branch, a tributary to Platte River. Crooked river at Richmond with a drainage area of 159 square miles and the other gage was on East Fork Big Creek at Bethany having a drainage area of 95 square miles. East Fork Big Creek Gage data best fit the rainfall data. As a result it was selected to represent the runoff from the watersheds for the period 1951 through 1959. Monthly runoff was compared to the rainfall and if the results did not appear reasonable, adjustments were made for that month by looking at individual rains and estimating antecedent moisture then adjusting runoff based on NRCS's runoff curve numbers.

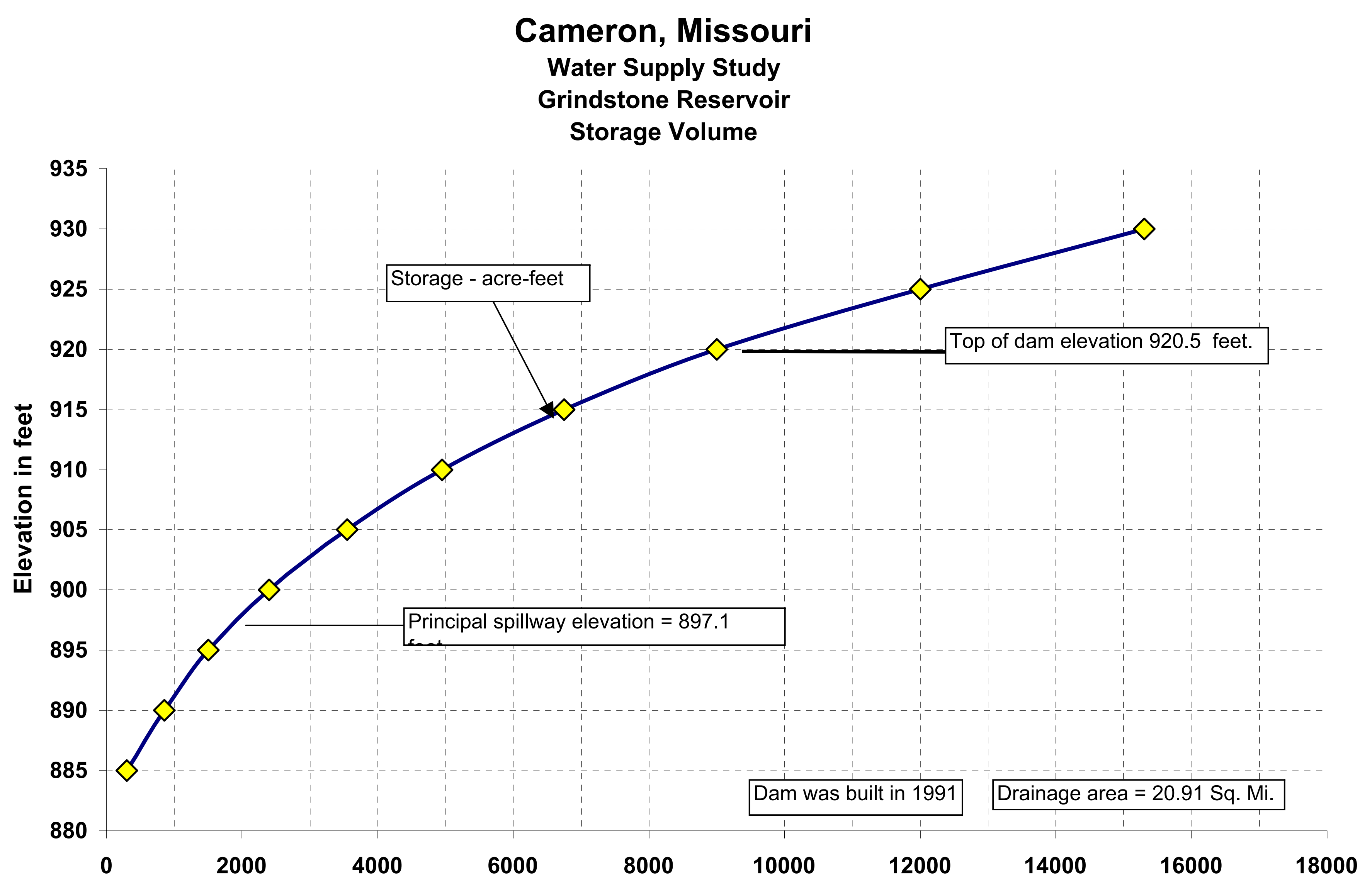
EVAP. Pan evaporation at the Lakeside gaging station was used as a base because it has data for year around evaporation. This data was updated with gage data from stations at Spickard, New Franklin, and Columbia. Depending on the latest data for the station nearest to Cameron. The adjustment factor of 0.76 to convert from pan to lake evaporation was applied at this step.

DEMAND This was determined by city records. Cameron's 2002 water use was approximately 1.5 million gallons per Day.

OTHER This refers to the volume of water that entered the system from other sources.

The Grindstone Reservoir had no other inflows beyond rainfall and runoff.
Lakes #1 and #2 had no other inflows.

Lake #3 received spillage from #1 and #2 as well as pumped inflow from the GLM lake. To simplify the input to the program, lake #2 spillage was treated as upper site inflow and Lake #1 spillage plus the Grindstone Reservoir demand were added together and entered as OTHER.



Cameron, Missouri
Water Supply Study
Grindstone Reservoir
Storage Volume
Storage - acre-feet
Top of dam elevation 920.5 feet.
Principal spillway elevation = 897.1
Dam was built in 1991
Drainage area = 20.91 Sq. Mi.
Elevation in feet
935
930
925
920
915
910
905
900
895
890
885
880
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
Storage in acre-feet

Figure 5.1.a

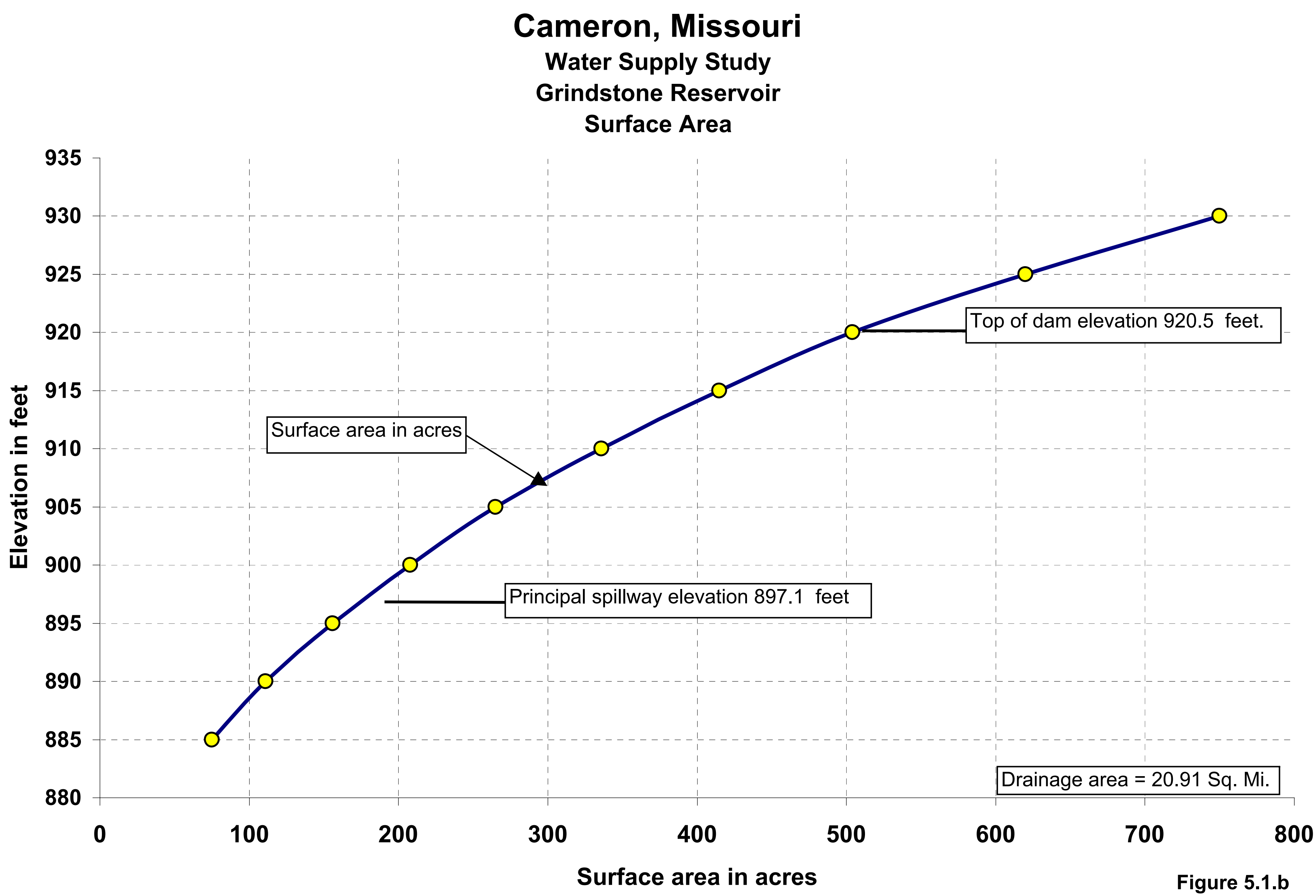

Cameron, Missouri
Water Supply Study
Grindstone Reservoir
Surface Area
Elevation in feet
935
930
925
920
915
910
905
900
895
890
885
880
0
100
200
300
400
500
600
700
800
Surface area in acres
Top of dam elevation 920.5 feet.
Surface area in acres
Principal spillway elevation 897.1 feet
Drainage area = 20.91 Sq. Mi.

Figure 5.1.b

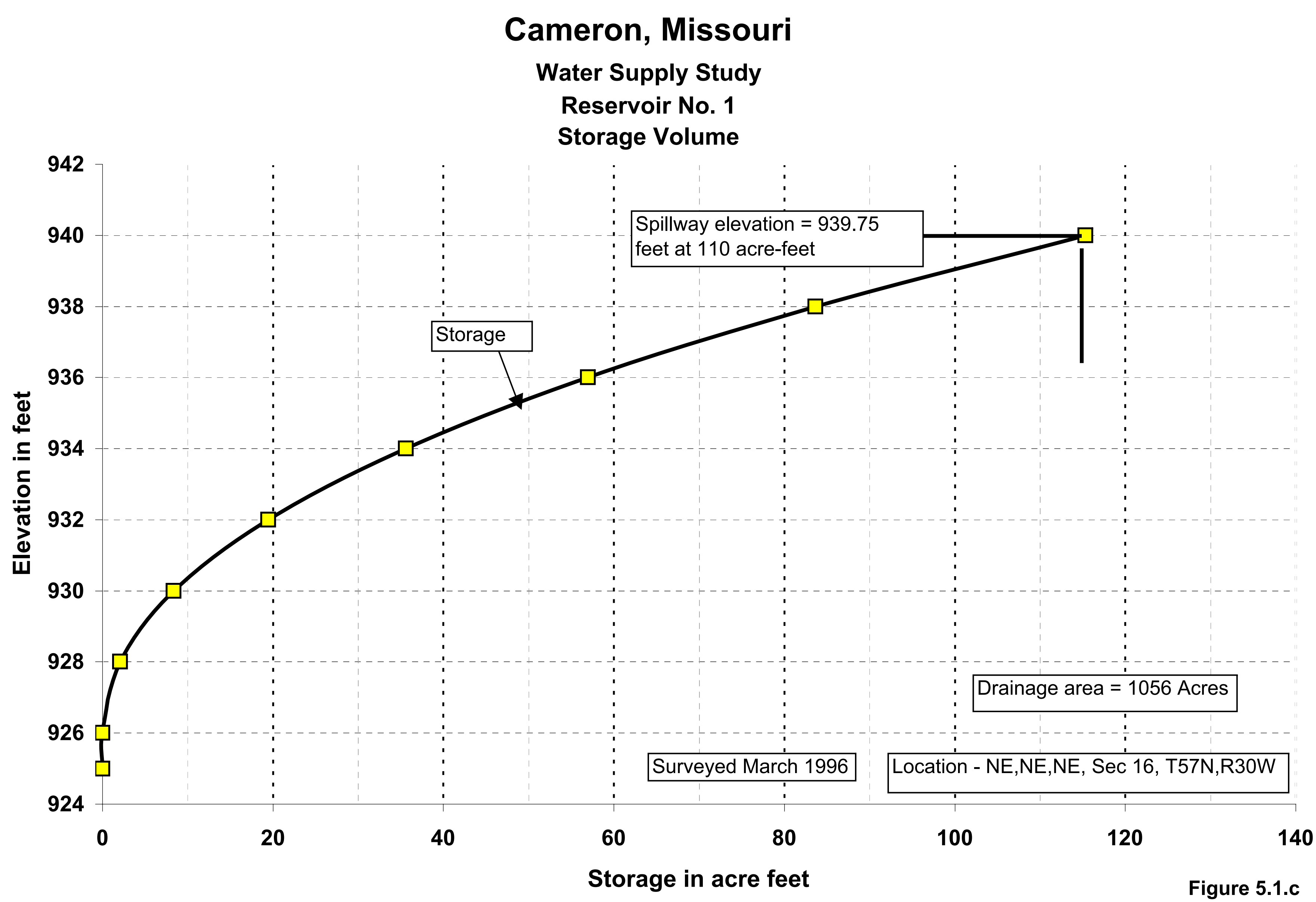

Cameron, Missouri
Water Supply Study
Reservoir No. 1
Storage Volume
Elevation in feet
942
940
938
936
934
932
930
928
926
924
0
20
40
60
80
100
120
140
Storage in acre feet
Spillway elevation = 939.75
feet at 110 acre-feet
Storage
Drainage area = 1056 Acres
Surveyed March 1996
Location - NE,NE,NE, Sec 16, T57N,R30W

Figure 5.1.c

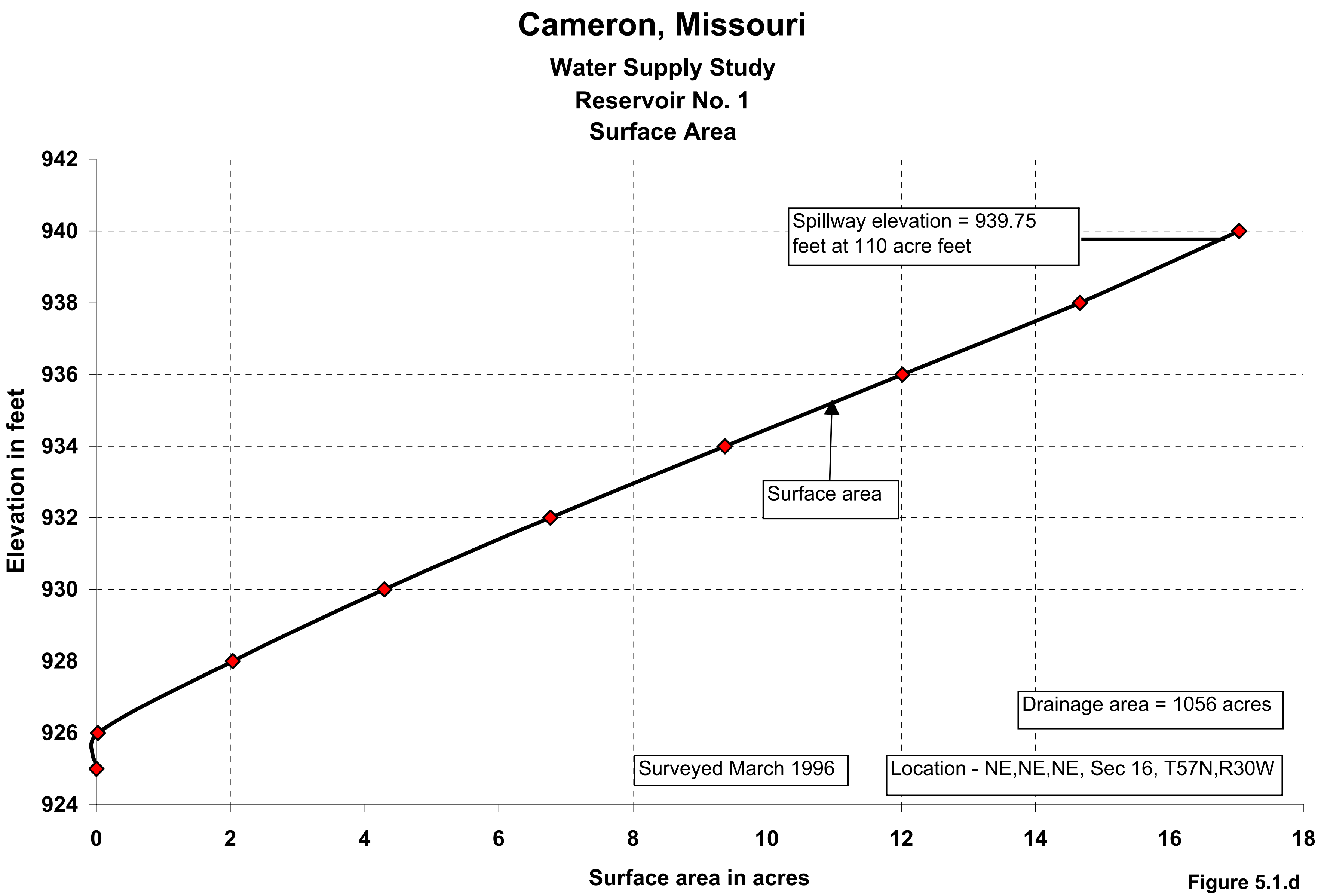

Cameron, Missouri
Water Supply Study
Reservoir No. 1
Surface Area
Elevation in feet
942
940
938
936
934
932
930
928
926
924
0
2
4
6
8
10
12
14
16
18
Surface area in acres
Spillway elevation = 939.75
feet at 110 acre feet
Surface area
Drainage area = 1056 acres
Surveyed March 1996
Location - NE,NE,NE, Sec 16, T57N,R30W

Figure 5.1.d

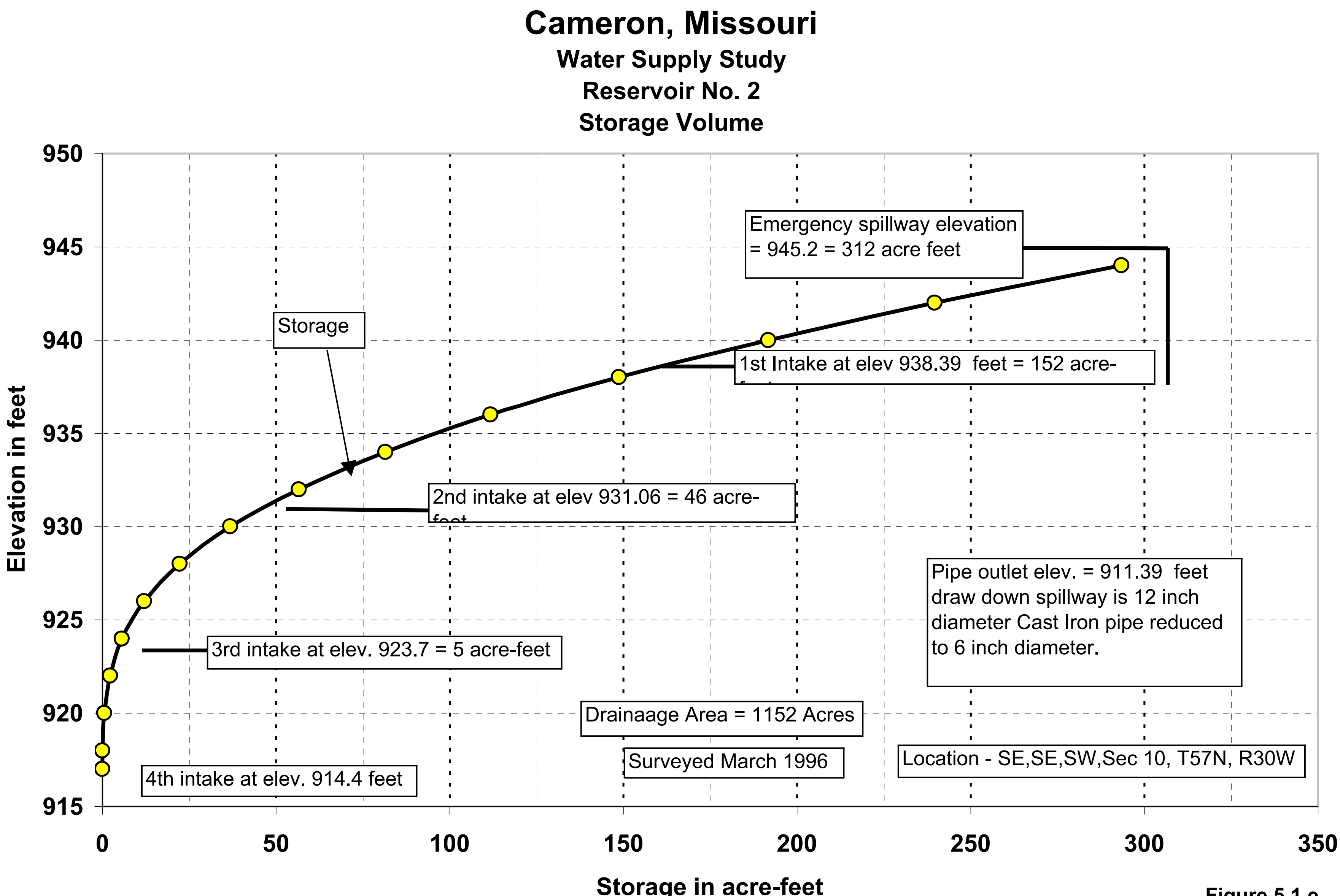

Cameron, Missouri
Water Supply Study
Reservoir No. 2
Storage Volume
Elevation in feet
950
945
940
935
930
925
920
915
0
50
100
150
200
250
300
350
Storage in acre-feet
Emergency spillway elevation = 945.2 = 312 acre feet
Storage
1st Intake at elev 938.39 feet = 152 acre-
2nd intake at elev 931.06 = 46 acre-
3rd intake at elev. 923.7 = 5 acre-feet
4th intake at elev. 914.4 feet
Pipe outlet elev. = 911.39 feet draw down spillway is 12 inch diameter Cast Iron pipe reduced to 6 inch diameter.
Drainaage Area = 1152 Acres
Surveyed March 1996
Location - SE,SE,SW,Sec 10, T57N, R30W

Figure 5.1.e

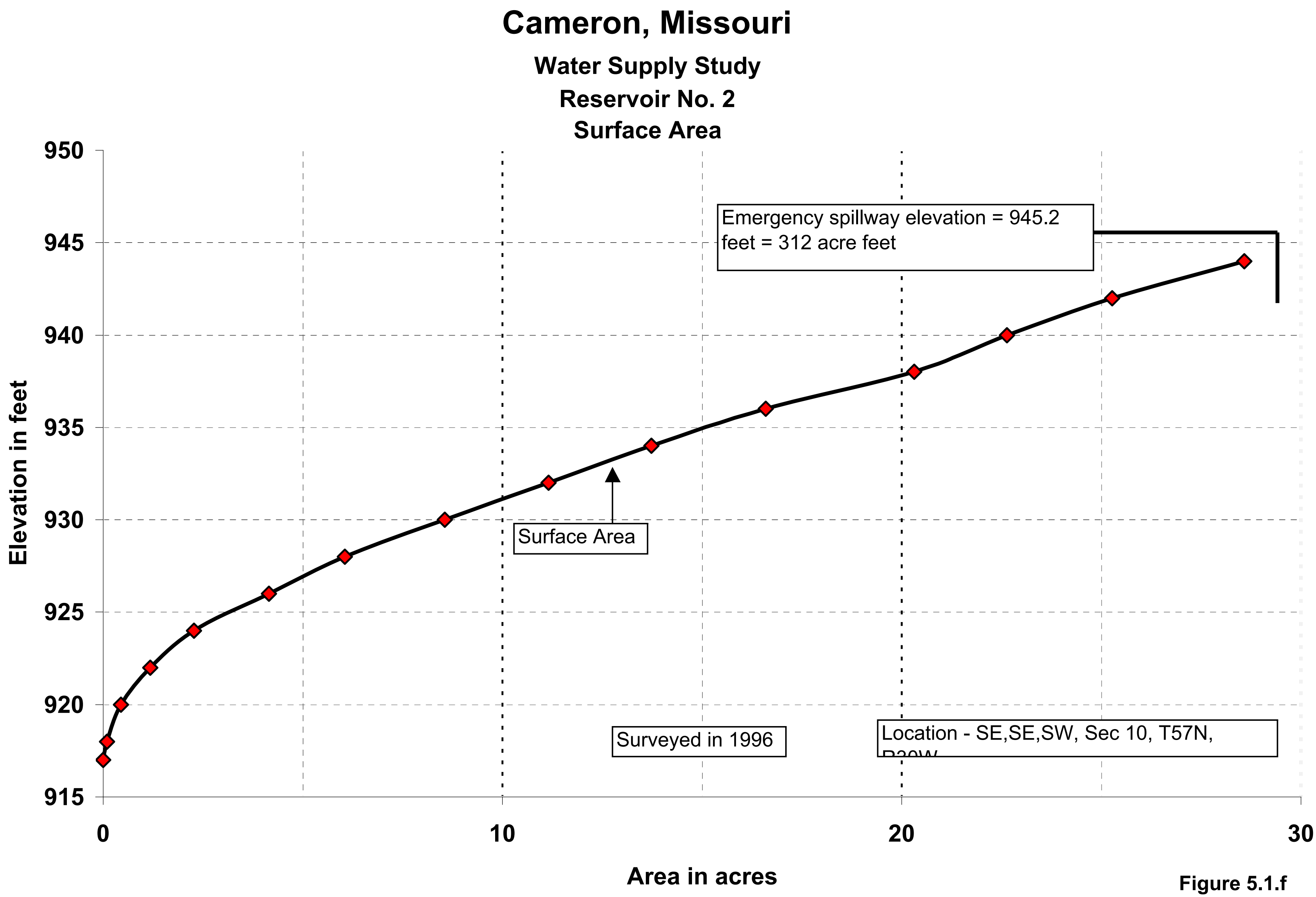

Cameron, Missouri
Water Supply Study
Reservoir No. 2
Surface Area
Elevation in feet
950
945
940
935
930
925
920
915
0
10
20
30
Area in acres
Emergency spillway elevation = 945.2 feet = 312 acre feet
Surface Area
Surveyed in 1996
Location - SE,SE,SW, Sec 10, T57N,

Figure 5.1.f

Cameron, Missouri

Water Supply Study
Reservoir No. 3
Storage Volume

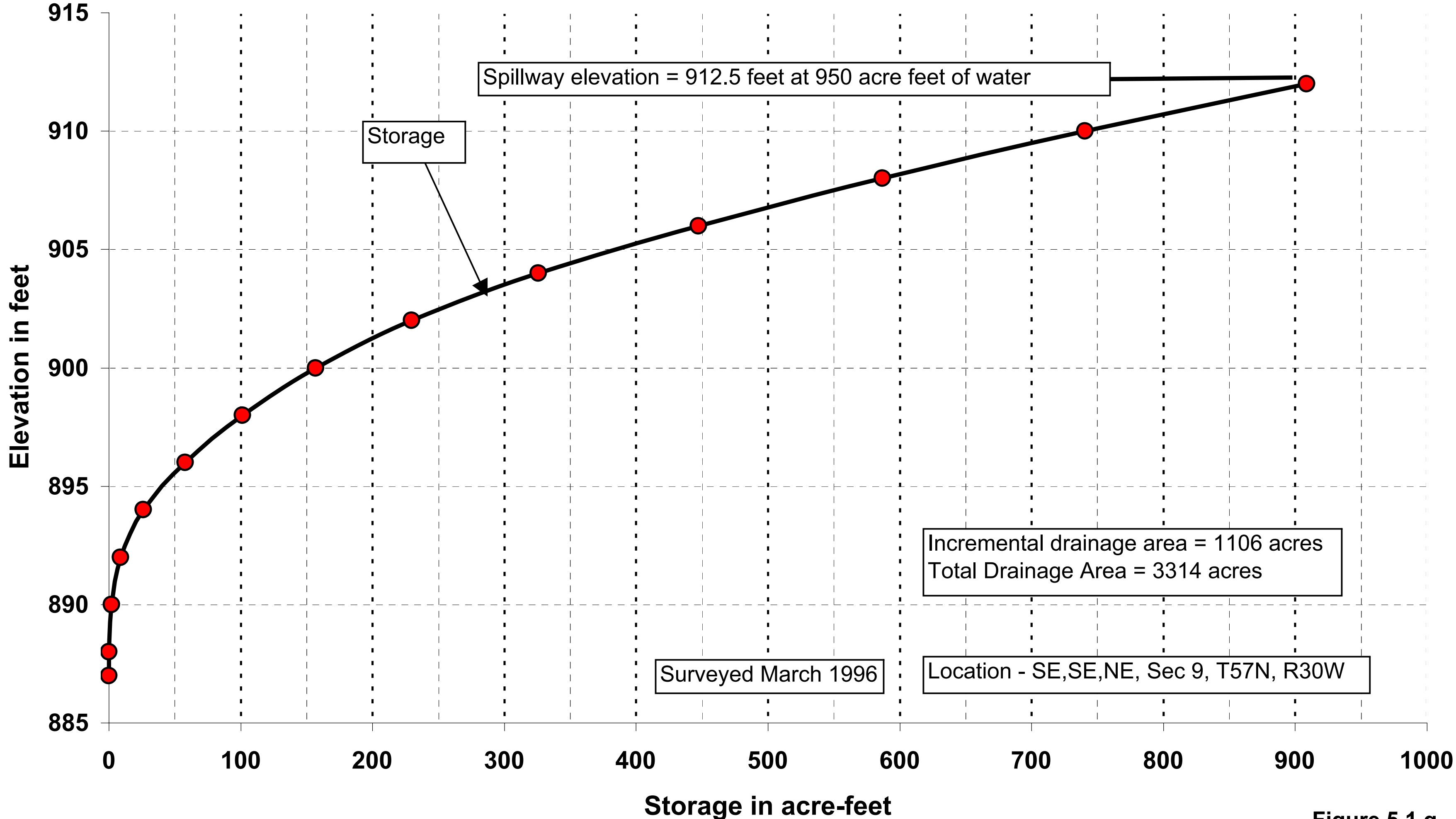


Figure 5.1.g

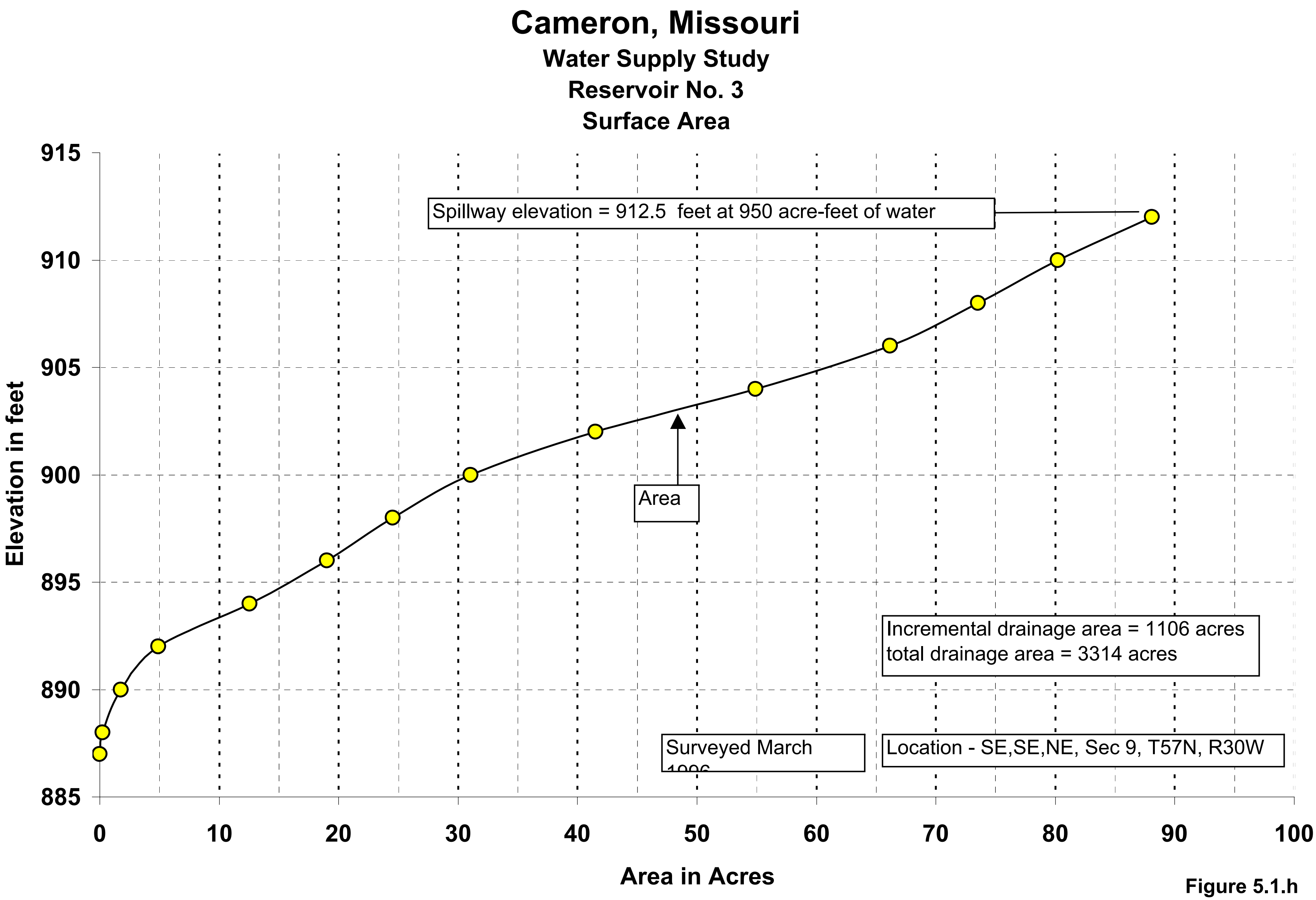

Cameron, Missouri
Water Supply Study
Reservoir No. 3
Surface Area
915
910
905
900
895
890
885
Elevation in feet
0
10
20
30
40
50
60
70
80
90
100
Area in Acres
Spillway elevation = 912.5 feet at 950 acre-feet of water
Area
Incremental drainage area = 1106 acres
total drainage area = 3314 acres
Surveyed March
Location - SE,SE,NE, Sec 9, T57N, R30W

Figure 5.1.h

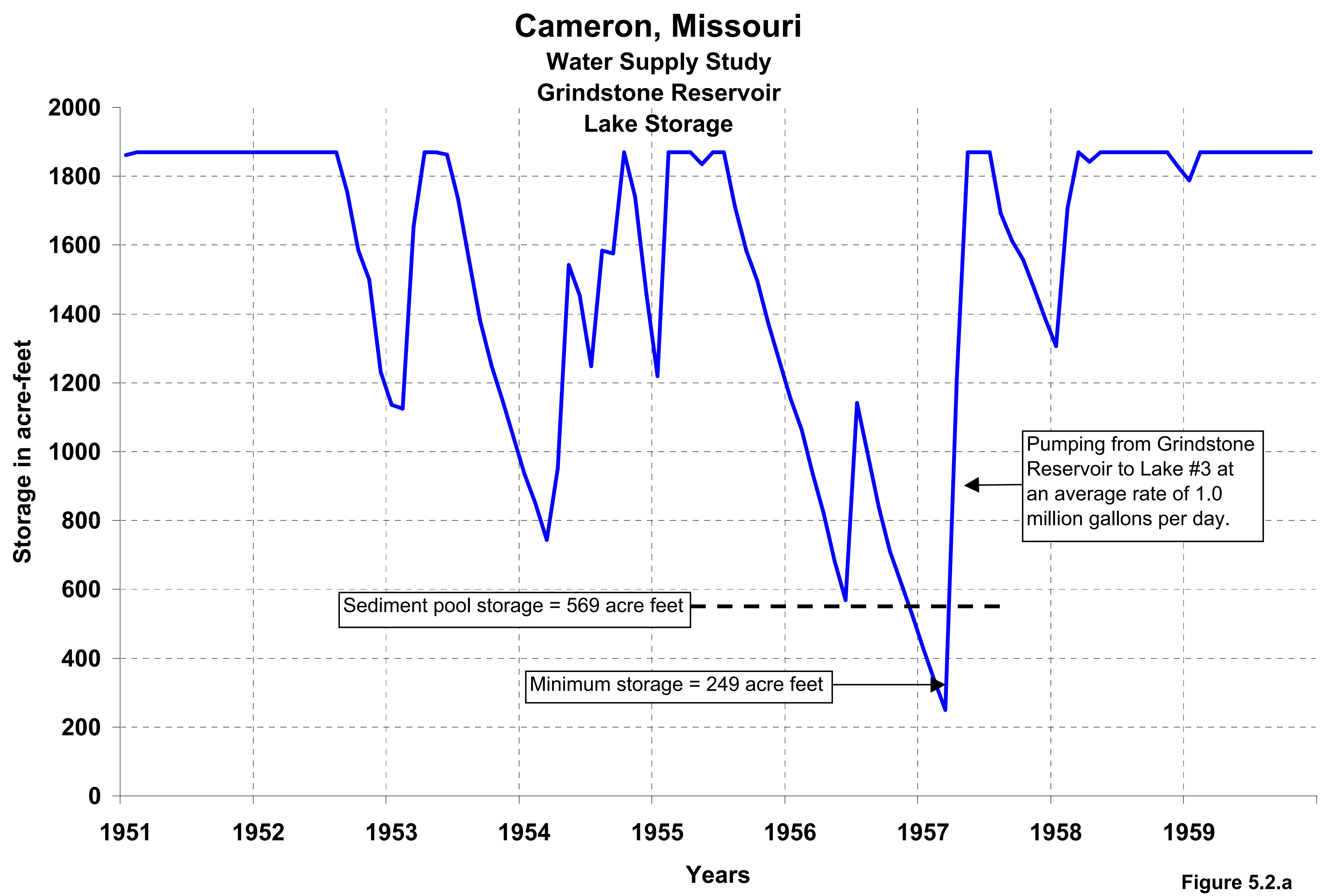

Cameron, Missouri
Water Supply Study
Grindstone Reservoir
Lake Storage
Storage in acre-feet
2000
1800
1600
1400
1200
1000
800
600
400
200
0
1951
1952
1953
1954
1955
1956
1957
1958
1959
Years
Sediment pool storage = 569 acre feet
Minimum storage = 249 acre feet
Pumping from Grindstone Reservoir to Lake #3 at an average rate of 1.0 million gallons per day.

Figure 5.2.a

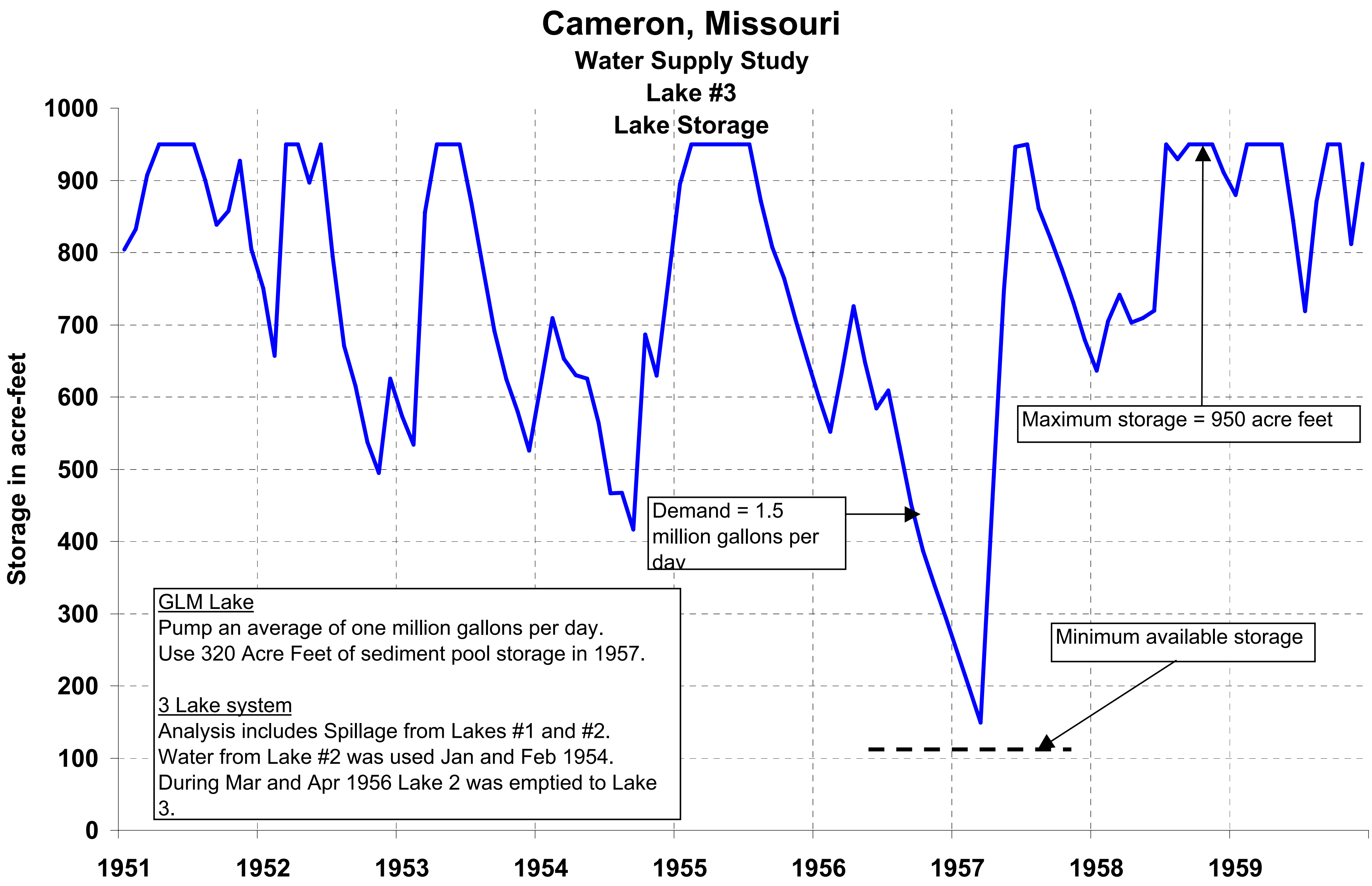

Cameron, Missouri
Water Supply Study
Lake #3
Lake Storage
Storage in acre-feet
1000
900
800
700
600
500
400
300
200
100
0
1951
1952
1953
1954
1955
1956
1957
1958
1959
Years
Maximum storage = 950 acre feet
Demand = 1.5 million gallons per day
Minimum available storage
GLM Lake
Pump an average of one million gallons per day.
Use 320 Acre Feet of sediment pool storage in 1957.
3 Lake system
Analysis includes Spillage from Lakes #1 and #2.
Water from Lake #2 was used Jan and Feb 1954.
During Mar and Apr 1956 Lake 2 was emptied to Lake 3.

Figure 5.2.b

Cameron, Missouri
Water Supply Study
Water Use

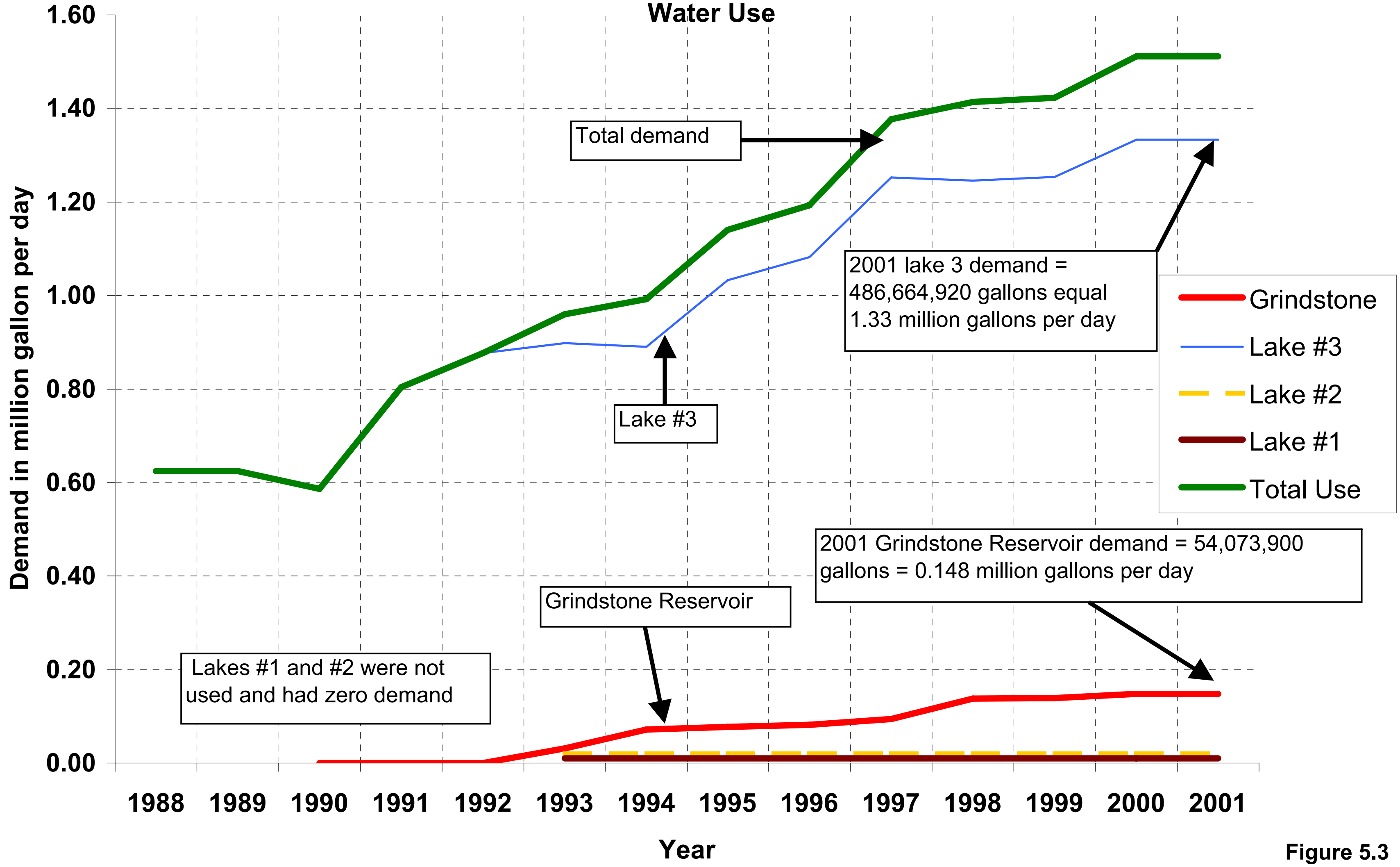
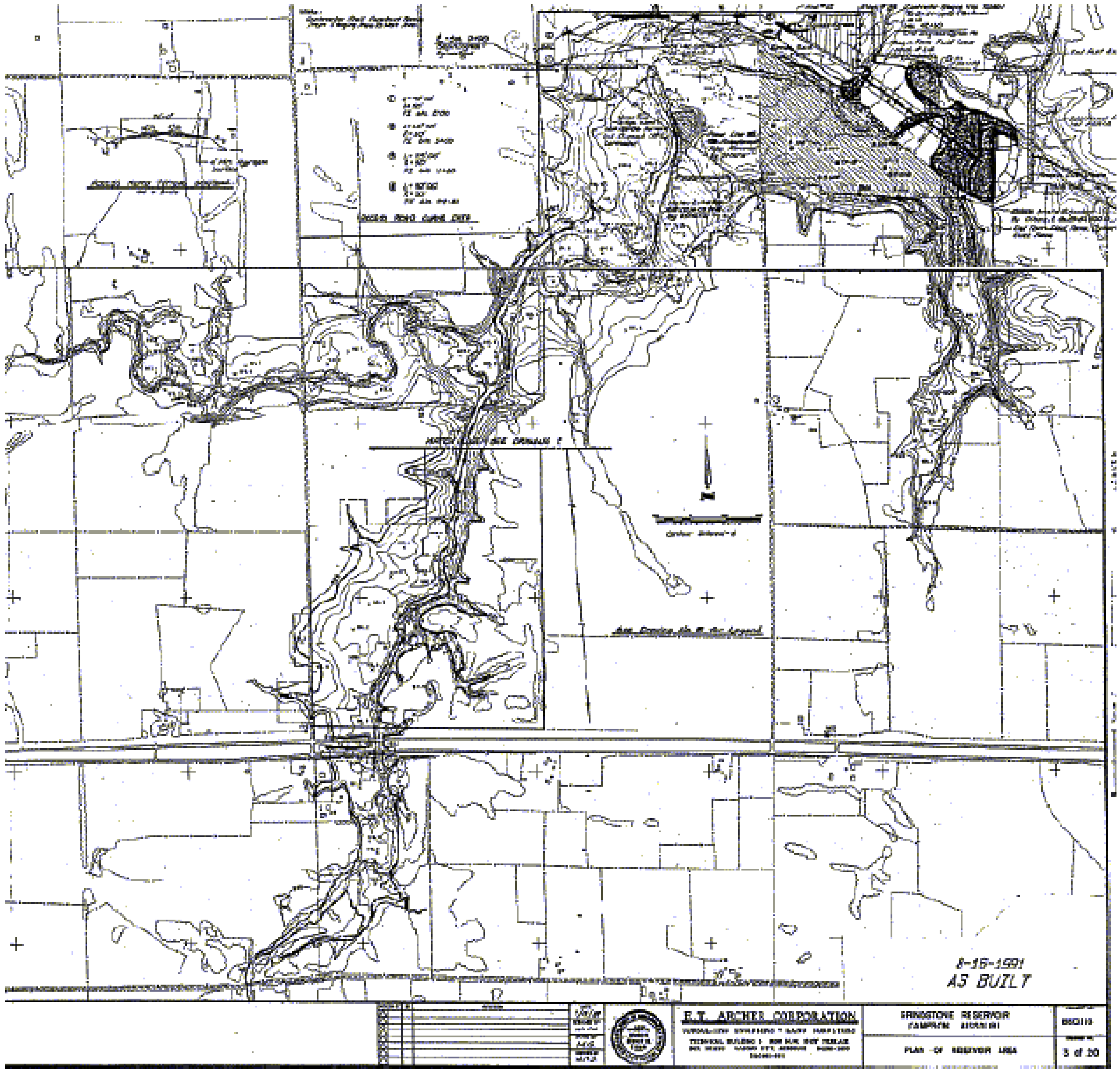
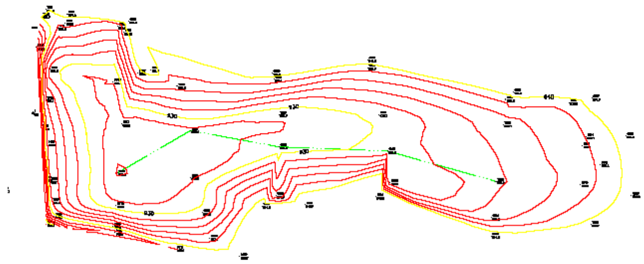


Figure 5.3

GLM - A2 Lake


8-15-1991
AS BUILT
E.T. ARCHER CORPORATION
GRINDSTONE RESERVOIR
PLAN OF RESERVOIR AREA
3 of 20

Title: SCSBD-G.DWG



Cameron Reservoir #1 Weir Elev. 939.75

Elev.	Sq. Ft.	Acres
926	730.5	0.02
928	88,776.9	2.03
930	187,062.5	4.29
932	295,237.3	6.77
934	408,061.8	9.37
936	523,576.6	12.02
938	638,752.2	14.66
940	742,055.9	17.04

100 50 0 100 200
Scale in Feet

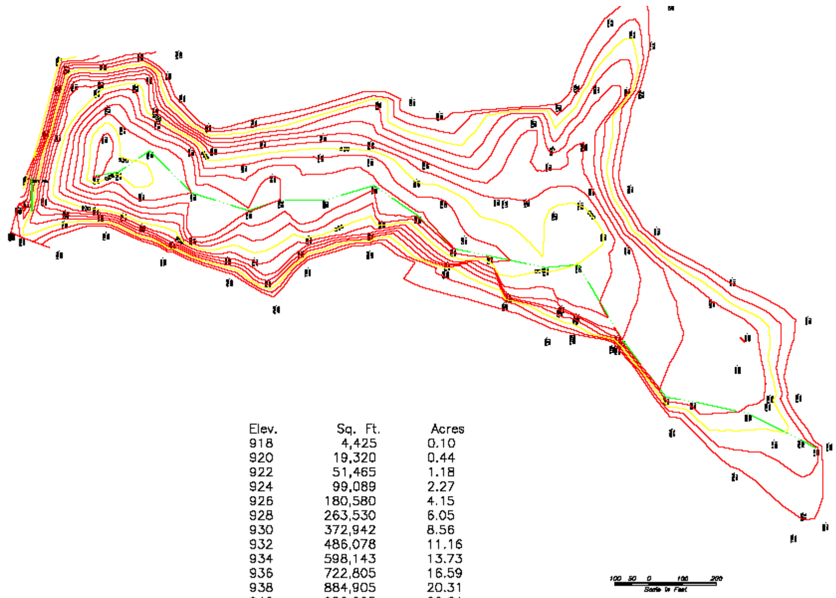
Figure 5.4.b Bathymetric map and area/volume table of Cameron #1, Missouri

City of Cameron Resevoir No. 1
Cameron, Missouri

CAD FILE NO.
DRAWING NO.
SHEET NO. OF

Title: SCSBD-G.DWG

Figure 5.4.c Bathymetric map and area/volume table of Cameron #2, Missouri



Elev.	Sq. Ft.	Acres
918	4,425	0.10
920	19,320	0.44
922	51,465	1.18
924	99,089	2.27
926	180,580	4.15
928	263,530	6.05
930	372,942	8.56
932	486,078	11.16
934	598,143	13.73
936	722,805	16.59
938	884,905	20.31
940	986,295	22.64
942	1,100,682	25.27
944	1,245,012	28.58

City of Cameron Resevoir No. 2
Cameron, Missouri

U.S. DEPARTMENT OF AGRICULTURE, NATURAL RESOURCES CONSERVATION SERVICE

Designed .... Date
Drawn ....
Traced ....
Checked ....
Approved by .... Date
Title ....
Title ....

CAD FILE NO.
DRAWING NO.
SHEET NO. 2 OF 3

Title: SCSBD–G.DWG

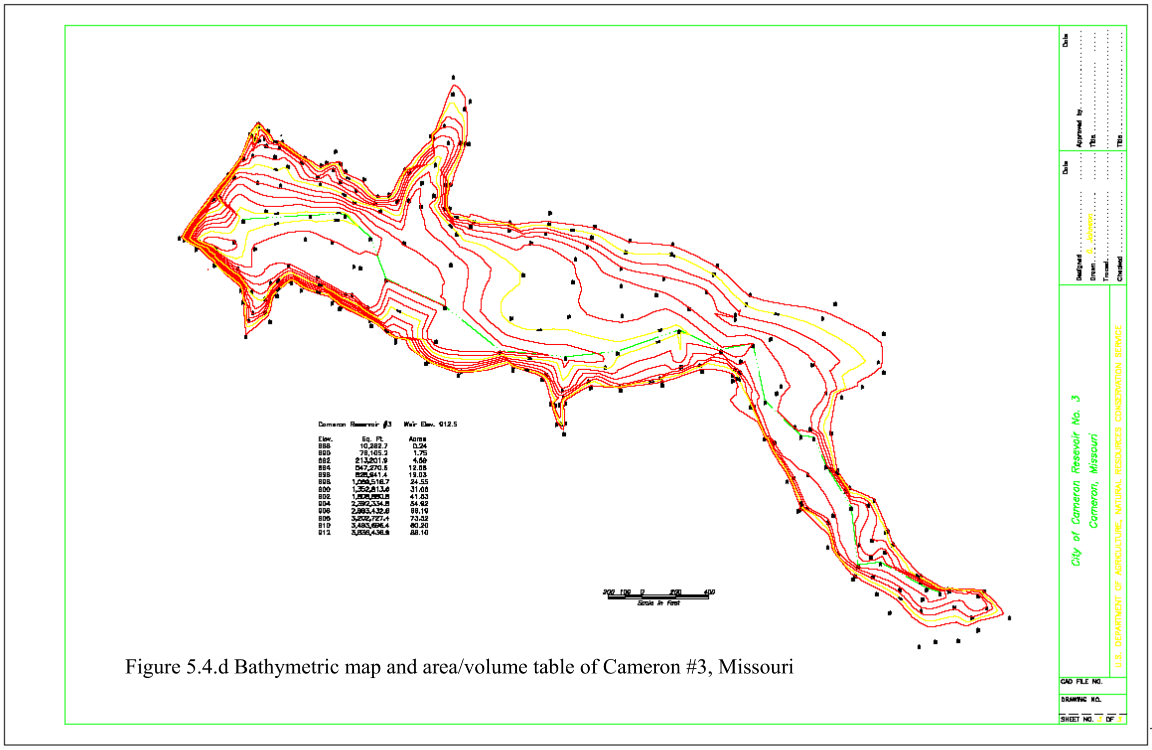


Figure 5.4.d Bathymetric map and area/volume table of Cameron #3, Missouri

Concordia, Missouri
Water Supply Study
E. A. PAPE LAKE

E. A. Pape Lake is located on a tributary to Blackwater River approximately 3 miles South of Concordia. Concordia is located in the Southeast corner of Lafayette County Missouri.

The record period of drought is the 1950's. Average annual rainfall is 37.2 inches. Annual rainfall for 1953 through 1957 is 24.1, 33.6, 39.4, 25.59, and 47.1 inches.

Two analysis were made:

1. First run was with the 2001 demand.
2. The lake was analyzed for the optimum daily use without emptying the lake during the evaluation period.

The 2001 demand was 0.494 million gallon per day.
Optimized demand is 0.839 million gallon per day.

Concordia Lake analysis consisted of using the NRCS's computer program "RESOP". This program analyses remaining stored water at the end of each month by summing gains and losses.

Following is the data and procedures for input to the "RESOP" program.

STO-AREA Elevation-Storage and Elevation-Area data were determined from June, 26, 2002 survey made by USGS.

E. A. Pape Lake

Elevation (feet)	Area (acres)	Storage (ac-ft)	
684.0	0.42	0.08	
686.0	4.71	3.28	
688.0	19.66	26.23	
690.0	32.74	78.18	
692.0	50.89	161.92	
694.0	70.71	281.88	
696.0	89.19	439.30	
698.0	111.02	639.15	
700.0	135.28	886.82	
702.1	156.02	1178.24	
704.0	179.15	1512.56	
706.0	205.59	1896.67	
708.0	238.20	2337.17	
709.3	261.55	2660.11	Water Surface on 6/26/2002
709.6	269.16	2740.18	Spillway Elevation

LIMITS Full Pool storage 2740 Ac.Ft.
Minimum Pool storage 60 Ac.Ft.

Starting storage was considered at full pool elevation.
The Drainage area of the lake is 8.48 Square Miles.

GENERAL The adjustment factor of 0.76 to convert from Pan evaporation to Lake evaporation was applied prior to entering the data for the control word EVAP. As a result a factor of 100 was applied.

The record period of drought is in the 1950's.
Analysis began in January 1951 and ended December 1959.

SEEPAGE The reservoir seepage varied from 0 seepage near empty to a maximum of 2.0 inch per month when at full pool. The material in the dam is compacted earth of clayey soils.

RAINFALL Rainfall data came from the Lexington, Mo. rain gage for the period 1951 through 1959.

RUNOFF This is the runoff into the lake from its drainage area. Monthly runoff volumes in watershed inches were determined and comparisons were made for the Blackwater River Gage at Blue Lick, South Fork Blackwater River near Elm and Shiloh Creek near Marshall. The three gages yielded similar monthly runoff volumes with Shiloh Creek being the highest. However The Shiloh creek drainage has a higher percentage of cropland than the other gages and also Concordia Lake. The Blackwater River Gage was used for 1951 to June 1954, when data from South Fork Blackwater River near Elm became available and was used. The drainage area at the South Fork gage is 16.6 square miles. This gage is located upstream of Concordia. The soils and land use in the drainage area of the gage and the lake are similar.

In cases where rainfall to runoff values did not appear reasonable, adjustments were made for that month by looking at individual rainfall events and estimating antecedent moisture and then, adjusting runoff based on NRCS's runoff curve numbers.

EVAP. Pan evaporation at the Lakeside gaging station was used as a base because it has data for year around evaporation. All other stations only measure data between April through November. Lakeside data was updated during these months with gage data from stations at New Franklin, and Columbia. Depending on the latest data for the station nearest to Concordia.

DEMAND This was determined by city historical water use records. The total use in 2001 was 180,424,873 Gallons which amounts to 494,315 gallon per day.

Concordia, Missouri

Water Supply Study
E. A. Pape Lake
Storage Volume

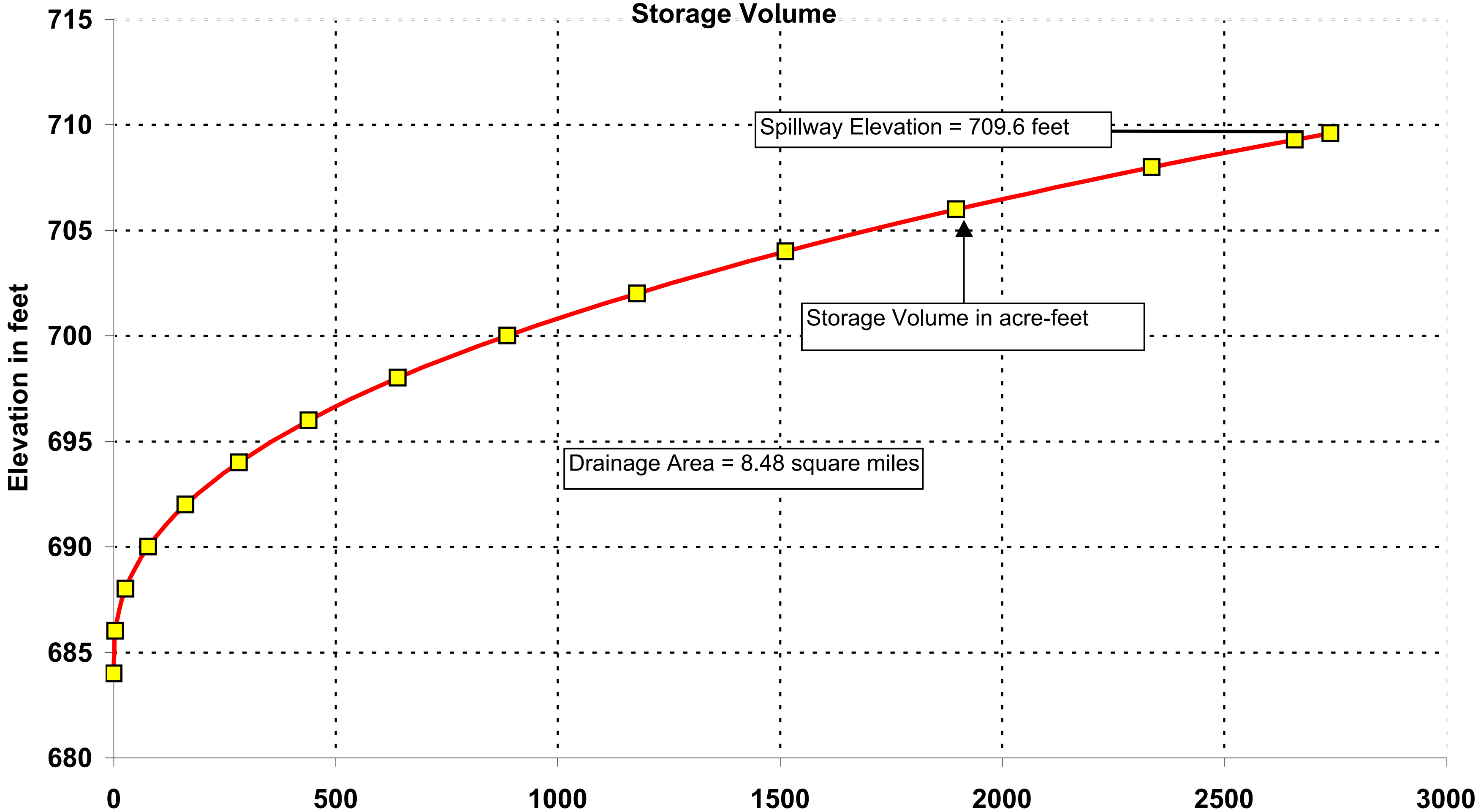


Figure 6.1.a

Concordia, Missouri

Water Supply Study
E. A. Pape Lake
Surface Area

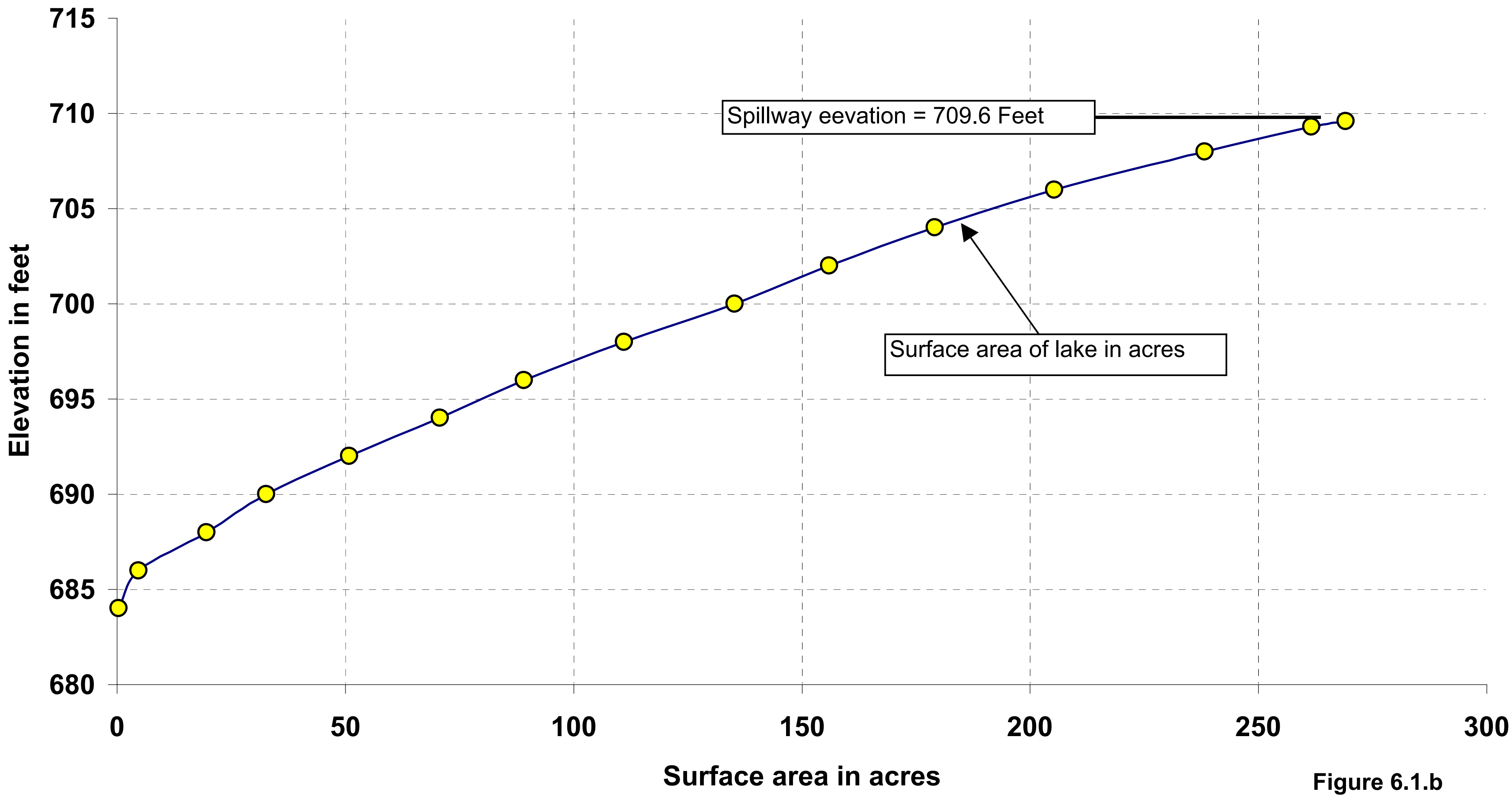


Figure 6.1.b

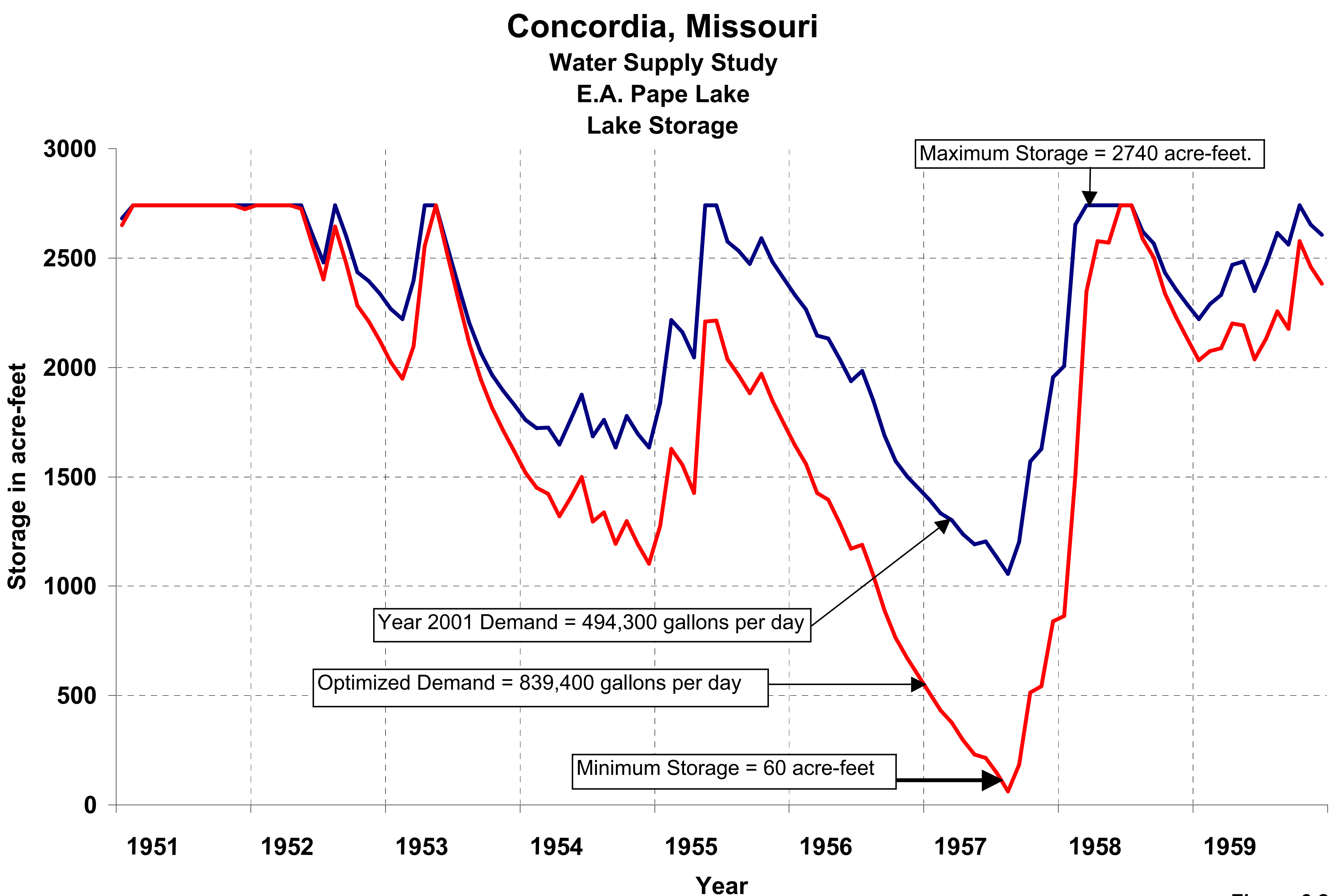
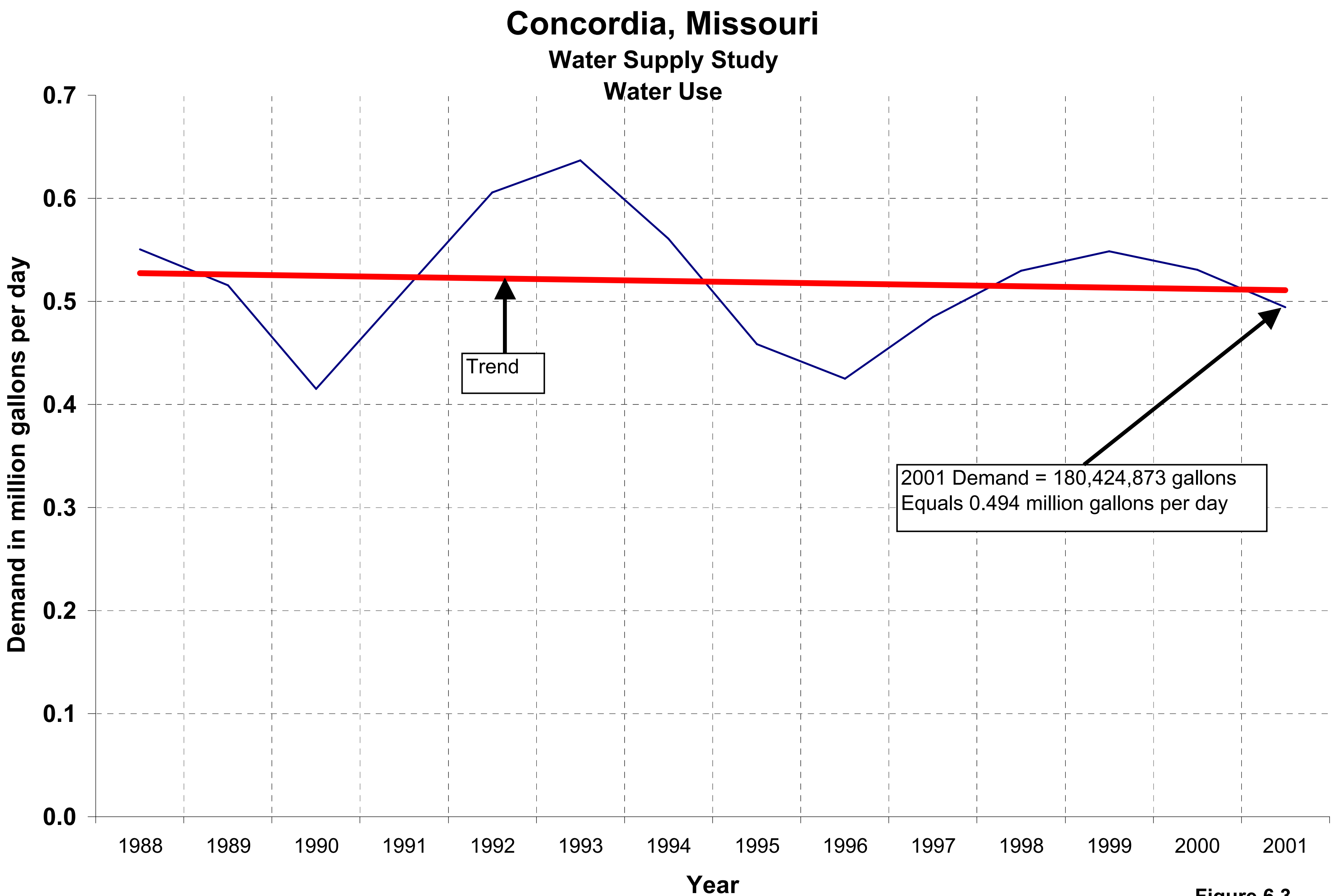
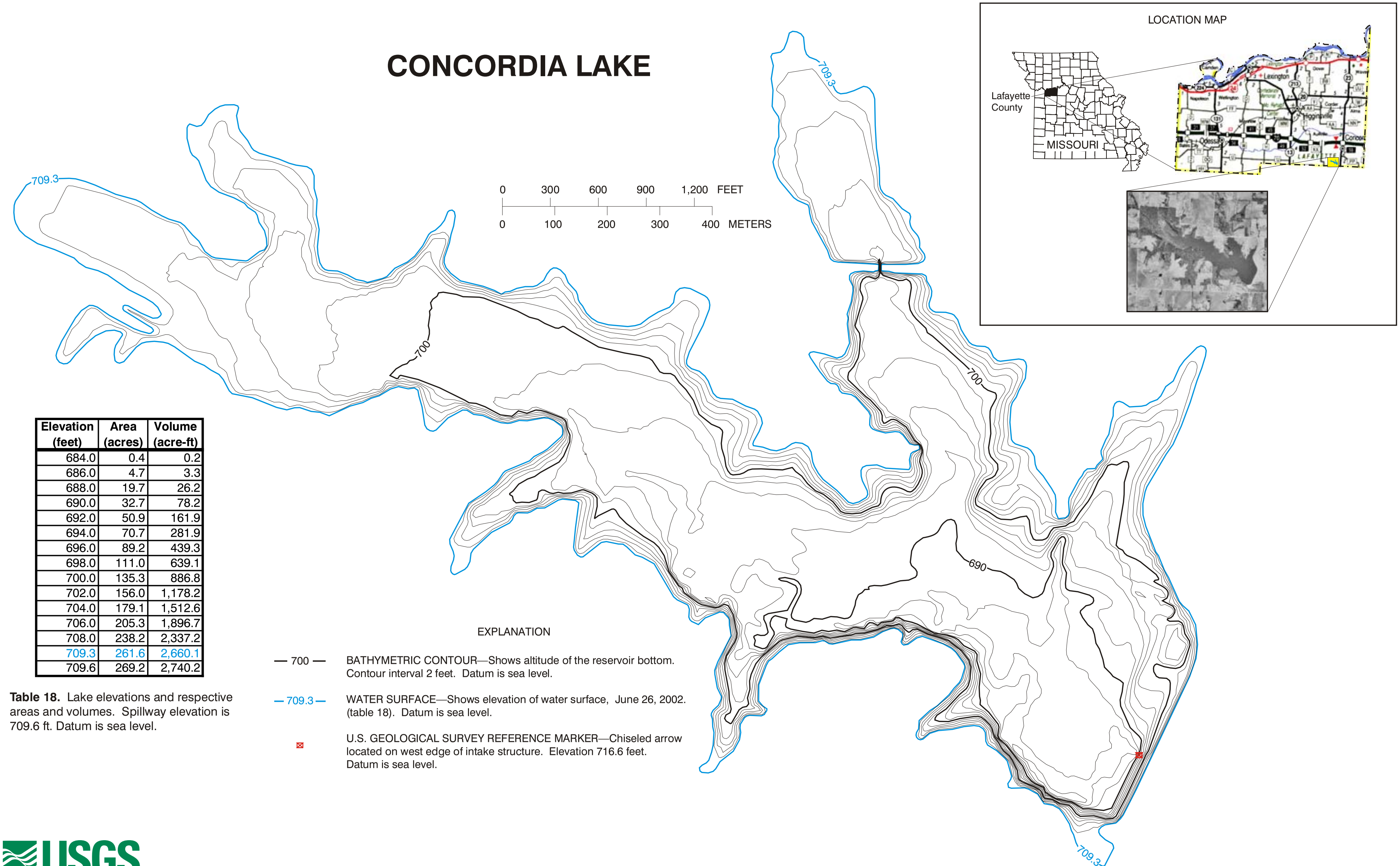

Concordia, Missouri
Water Supply Study
E.A. Pape Lake
Lake Storage
Storage in acre-feet
3000
2500
2000
1500
1000
500
0
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year
Maximum Storage = 2740 acre-feet.
Year 2001 Demand = 494,300 gallons per day
Optimized Demand = 839,400 gallons per day
Minimum Storage = 60 acre-feet

Figure 6.2


Concordia, Missouri
Water Supply Study
Water Use
Demand in million gallons per day
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Trend
2001 Demand = 180,424,873 gallons
Equals 0.494 million gallons per day
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
Year
Figure 6.3

CONCORDIA LAKE



Elevation (feet)	Area (acres)	Volume (acre-ft)
684.0	0.4	0.2
686.0	4.7	3.3
688.0	19.7	26.2
690.0	32.7	78.2
692.0	50.9	161.9
694.0	70.7	281.9
696.0	89.2	439.3
698.0	111.0	639.1
700.0	135.3	886.8
702.0	156.0	1,178.2
704.0	179.1	1,512.6
706.0	205.3	1,896.7
708.0	238.2	2,337.2
709.3	261.6	2,660.1
709.6	269.2	2,740.2

Table 18. Lake elevations and respective areas and volumes. Spillway elevation is 709.6 ft. Datum is sea level.

Figure 18. Bathymetric map and table of areas/volumes of the Concordia Lake near Concordia, Missouri.

Creighton, Missouri
Water Supply Study
City Lake

Creighton is located in the South East corner of Cass County, Missouri.

The record period of drought was used to estimate if Creighton water supply was adequate to provide ample water for the city. The 1950's were determined to be that period.

The 30-year average rainfall is 42.05 inches. Rainfall at the Harrisonville gage was used in this analysis. For the period 1953 through 1957, annual rainfall was 28.8, 35.7, 28.4, 21.3, and 37.5 inches.

Creighton is not a major water user and they are not currently reporting their water use. Usage in the Safe Drinking Water Information System (SDWIS) database indicates they are using an average of 28,000 gallon per day. The plant capacity is reported at 36,000 gallon per day and the maximum day reported was at a rate of 35,000 gallon per day.

Demand for year 2000 was 28,000 gallon per day.
Optimized demand is 65,584 gallon per day.

Creighton's Lake analysis consisted of using the NRCS's computer program "RESOP". This program analyzes remaining stored water at the end of each month by summing gains and losses.

Following is the data and procedures for input to the "RESOP" program.

STO-AREA -- Elevation-Storage and Elevation-Area data were determined from June, 28, 2003 survey made by USGS.

Creighton City Lake

Elevation Feet	Area Acres	Volume Acre-Ft.	
806	0.09	0.03	
808	0.4	0.4	
810	1.0	1.7	
812	2.2	4.6	
814	5.0	11.7	
816	7.6	24.5	
818	10.0	41.9	
820	12.6	64.5	
820.2	13.0	67.06	Water Surface on 6/28/2003
822	16.6	93.8	
823	18.9	111.4	
823.2	19.4	112.9	Spillway Elevation

LIMITS
Full Pool storage 112.9 Ac.Ft.
Minimum Pool storage 15 Ac.Ft.

Starting storage was considered at full pool elevation.

The drainage area of the lake is 0.83 square miles.

GENERAL	The adjustment factor of 0.76 to convert from pan evaporation to lake evaporation was applied prior to entering the data for the control word EVAP. As a result a factor of 100 is applied. The record period of drought is in the 1950's. Analysis began in January 1951 and ended December 1959.
SEEPAGE	The reservoir seepage varied from 0 seepage near empty to a maximum of 0.75 inch per month at full pool. The material in the dam is compacted earth of clayey soils.
RAINFALL	Rainfall data came from the Harrisonville, Mo. rain gage for the period 1951 through 1959.
RUNOFF	This is the runoff into the lake from its drainage area. Regional monthly runoff values were determined from stream gage data. Monthly runoff volumes in watershed inches was determined at the Little Blue River gage near Lake City, North East of Drexel. Another gage on Cedar Creek near Pleasant View, Missouri was analyzed. Results at the lake were nearly the same. Because Little Blue River watershed is nearer to Creighton, and the soils and topography of Little Blue River is more nearly like that at Creighton, it was selected to represent regional runoff. If runoff did not appear reasonable when compared to rainfall, it was necessary to examine daily Rainfall values for that month. Anticedent moisture was estimated for each rainfall event and adjustments to NRCS runoff curve number was made to arrive at runoff for each storm.
EVAP	Pan evaporation at the Lakeside gaging station near the Lake of the Ozarks was used to determine pan evaporation. The adjustment to lake evaporation was 0.76.
DEMAND	Creighton has not been reporting their water use because they are not considered to be major water users. This RESOP run was for the daily use recorded in the SDWIS data base. The daily amount recorded is 0.028 MGD. The optimized use would be 0.069 million gallon per day.

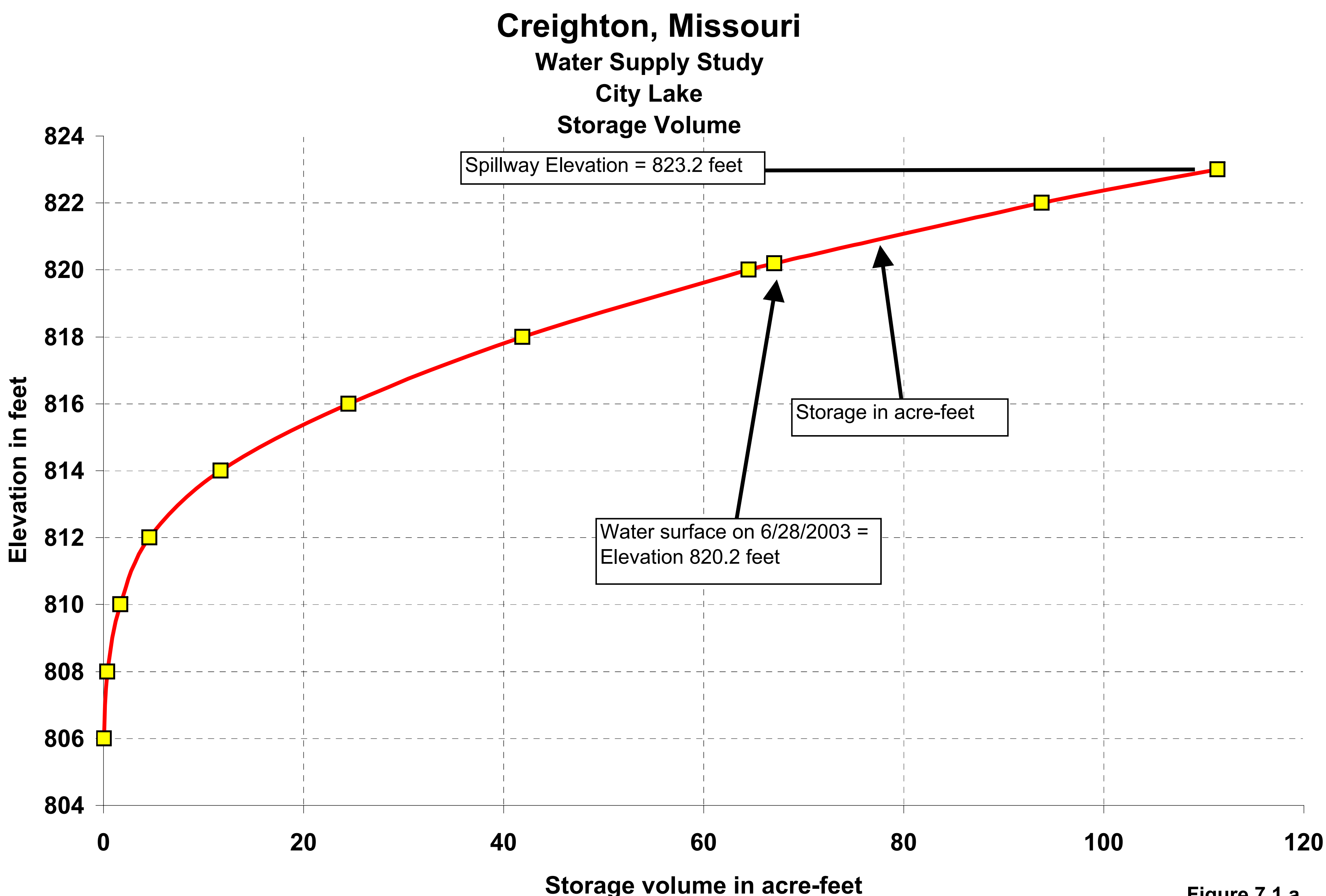

Creighton, Missouri
Water Supply Study
City Lake
Storage Volume
Spillway Elevation = 823.2 feet
Storage in acre-feet
Water surface on 6/28/2003 =
Elevation 820.2 feet
Elevation in feet
824
822
820
818
816
814
812
810
808
806
804
0
20
40
60
80
100
120
Storage volume in acre-feet

Figure 7.1.a

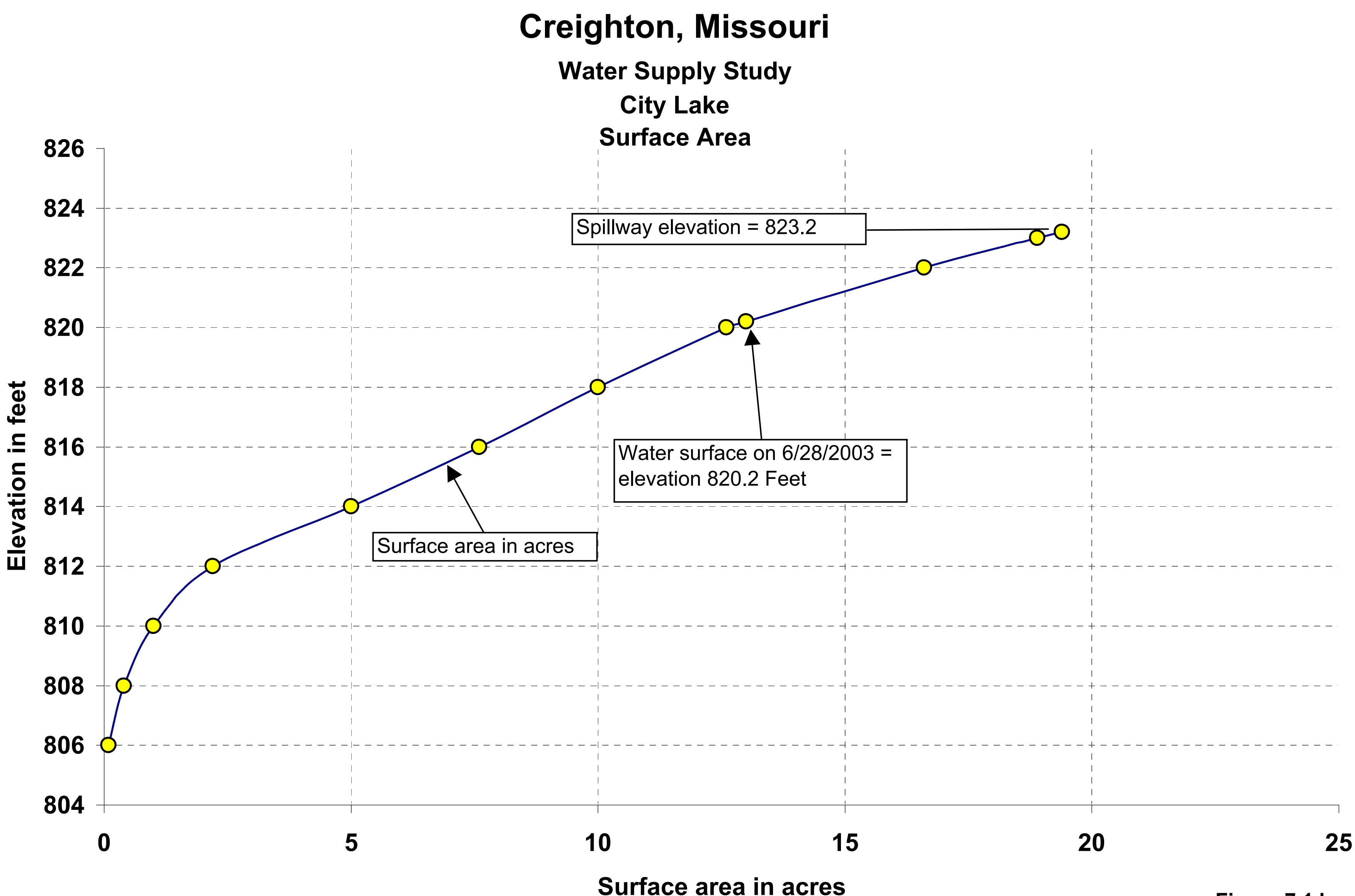
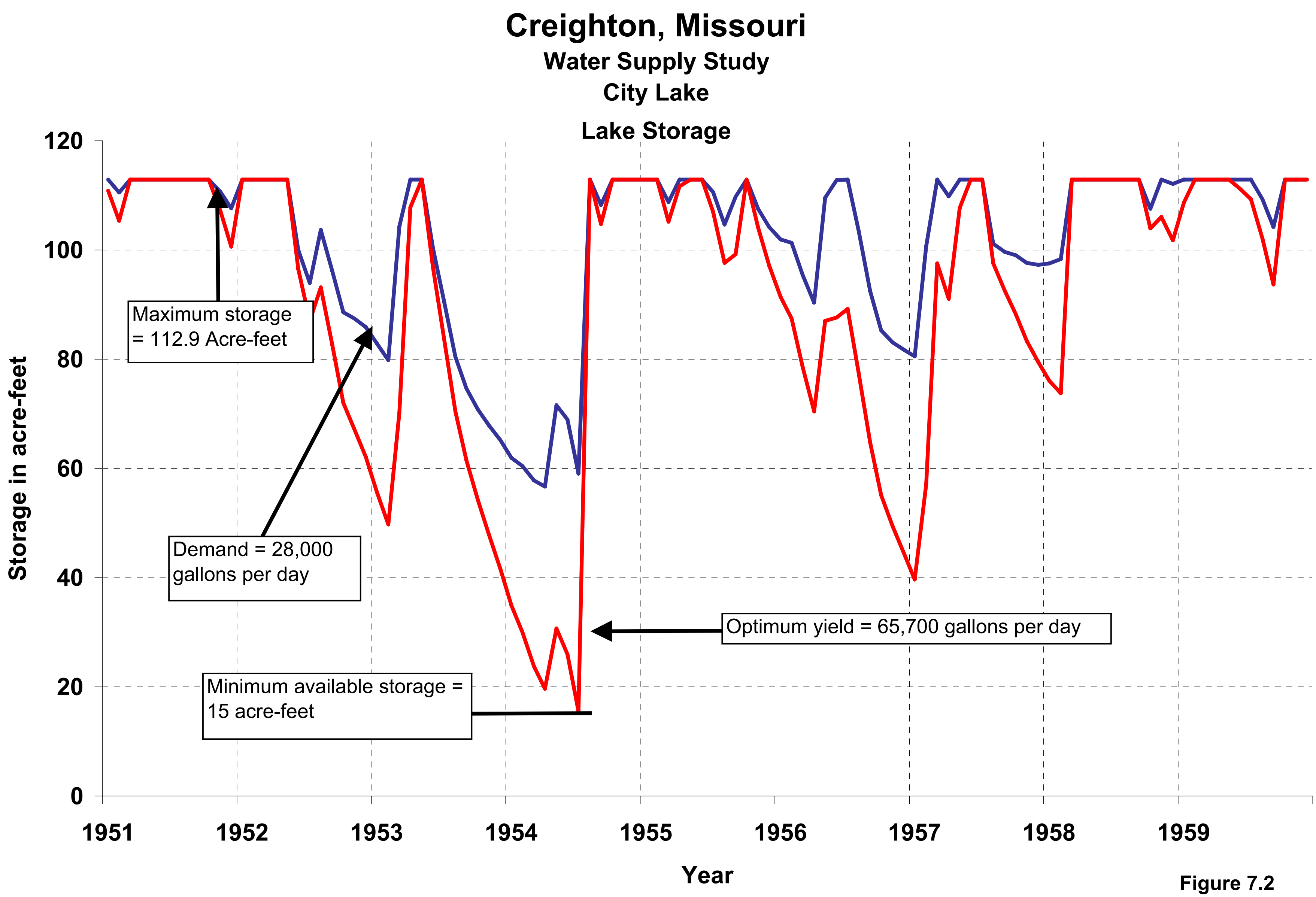

Creighton, Missouri
Water Supply Study
City Lake
Surface Area
Elevation in feet
826
824
822
820
818
816
814
812
810
808
806
804
0
5
10
15
20
25
Surface area in acres
Spillway elevation = 823.2
Water surface on 6/28/2003 = elevation 820.2 Feet
Surface area in acres

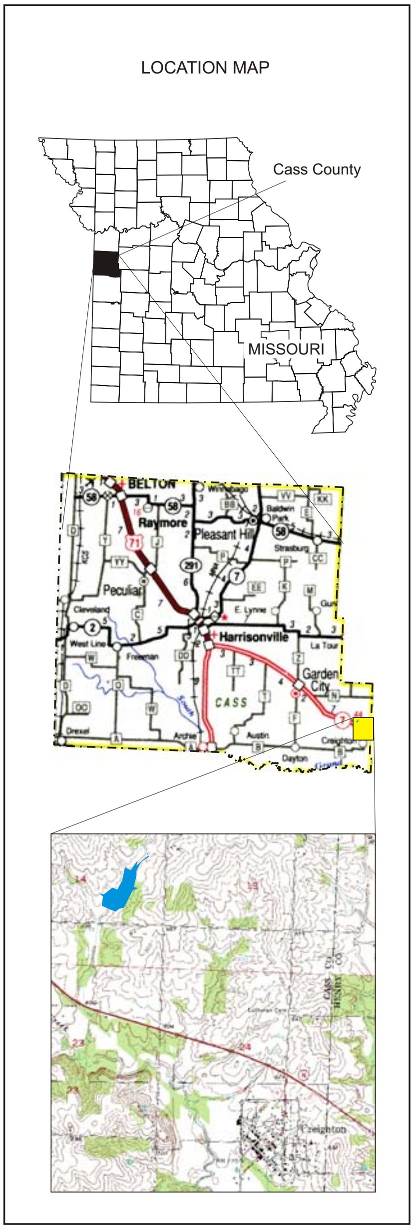
Figure 7.1.b



Creighton, Missouri
Water Supply Study
City Lake
Lake Storage
Storage in acre-feet
120
100
80
60
40
20
0
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year
Maximum storage = 112.9 Acre-feet
Demand = 28,000 gallons per day
Minimum available storage = 15 acre-feet
Optimum yield = 65,700 gallons per day

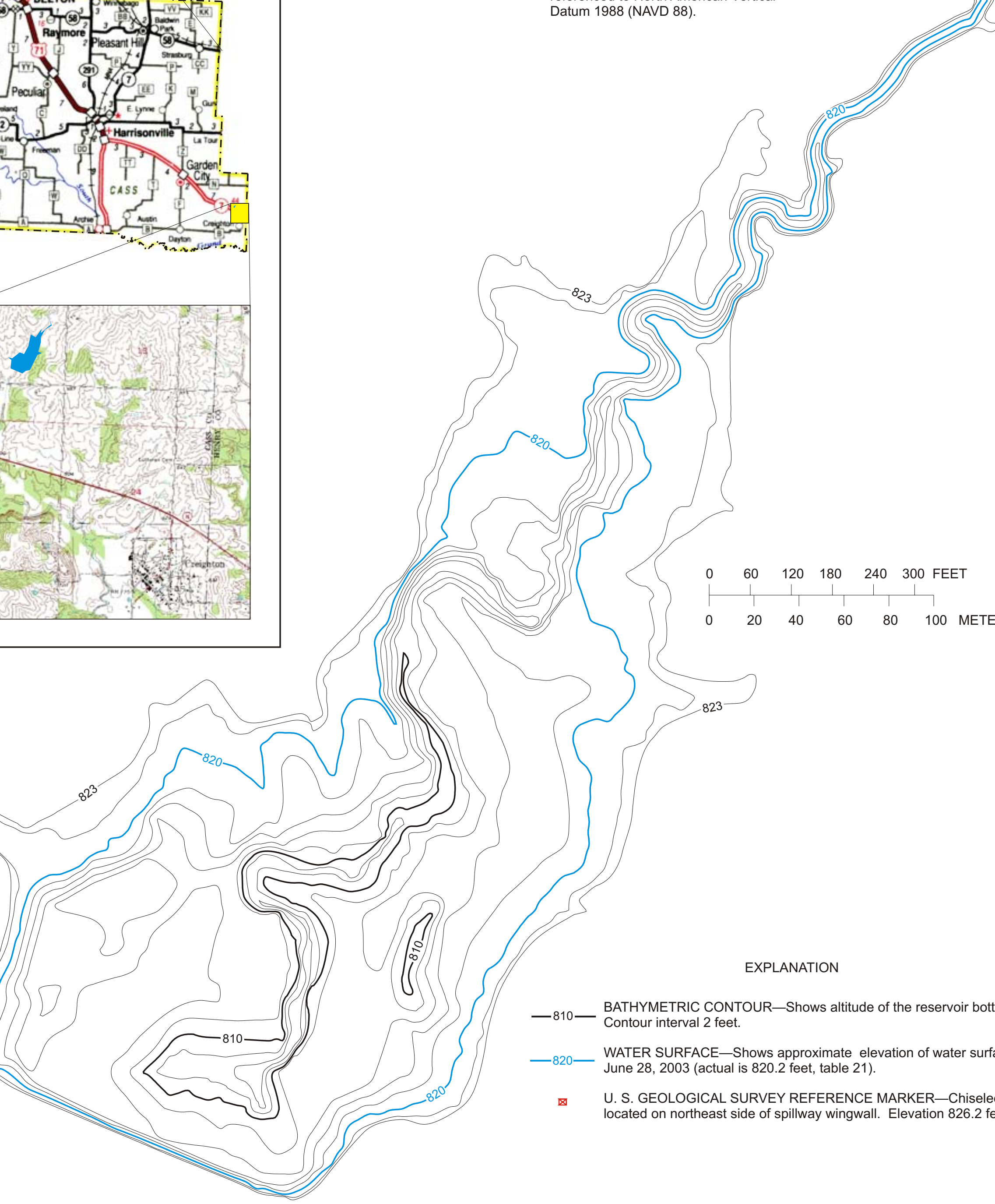
Figure 7.2

CREIGHTON LAKE



Elevation (feet)	Area (acres)	Volume (acre-ft)
806.0	0.09	0.03
808.0	0.4	0.4
810.0	1.0	1.7
812.0	2.2	4.6
814.0	5.0	11.7
816.0	7.6	24.5
818.0	10.0	41.9
820.0	12.6	64.5
822.0	16.6	93.8
823.0	18.9	111.4

Table 25. Lake elevations and respective surface areas and volumes. Top of spillway structure is 823.2 feet. Elevations referenced to North American Vertical Datum 1988 (NAVD 88).



EXPLANATION

—810— BATHYMETRIC CONTOUR—Shows altitude of the reservoir bottom. Contour interval 2 feet.

—820— WATER SURFACE—Shows approximate elevation of water surface, June 28, 2003 (actual is 820.2 feet, table 21).

⊠ U. S. GEOLOGICAL SURVEY REFERENCE MARKER—Chiseled arrow located on northeast side of spillway wingwall. Elevation 826.2 feet.

USGS science for a changing world

Figure 25. Bathymetric map and table of areas/volumes of the Creighton Lake near Creighton, Missouri.

In cooperation with Missouri Department of Natural Resources

Dearborn, Missouri
Water Supply Study
City Lake

Dearborn is located in South Central Buchanon County Missouri.

Dearborn Lake is about one-half mile north of the city. The lake is small and will not support their needs During periods of dry weather. It is necessary to pump water from Bee creek most of the year. They use a portable six inch pump to pump from Bee Creek to the Lake. They have plans to abandon the lake sometime during the year 2002 and purchase water from Kansas City. Pumping into the lake at this rate resulted in 2 months of water shortage during the evaluation period.

The Drainage area of the lake is 350 acres (0.55 Sq. Mi.).

Dearborn's 1999 water use was 2,234,800 gallon or and average of 0.062 million gallon per day.

Optimized demand without pumping from Bee Creek is 9670 gallon per day

Dearborn Lake analysis consisted of using the NRCS's computer program "RESOP". This program analyses remaining stored water at the end of each month by summing gains and losses.

Three analysis were made:

1. First run was the entire demand was taken from the lake with no pumping. This resulted in an extended period of water shortage.
2. The lake was analyzed for the optimum daily use without pumping or emptying the lake during the evaluation period 1951 through 1959.
3. The existing plan of pumping from Bee Creek into the lake.

STO-AREA -- Elevation-Storage and Elevation-Area data were determined from July 27, 2000 survey made by USGS.

Dearborn Lake

Elevation (feet)	Area (acres)	Storage (ac-ft)	
906	0.36	0.05	
908	1.84	2.4	
910	3.12	7.4	
912	4.66	15.2	
914	6.38	26.3	
916	7.14	40.2	
917	7.98	47.9	Water surface on 7/27
917.5	8.63	52.0	Top of spillway

LIMITS Full Pool storage 52 Ac.Ft.
Minimum Pool storage 5 Ac.Ft.

Starting storage was considered at full pool.
The Intake elevation is not known.

GENERAL The adjustment factor of 0.76 to convert from pan evaporation to Lake evaporation was applied prior to entering the data for the control word EVAP. As a result a factor of 100 was used.

The record period of drought is in the 1950's.
Analysis began in January 1951 and ended December 1959.

SEEPAGE The reservoir seepage varied from 0 seepage near empty to a maximum of 2.0 inches per month at full pool. The seepage rate is a best estimate based on history of the reservoir, soil type, material of the core of the dam and compaction of the earth fill. The material in the dam is compacted earth of silty clay soils. The lake is shallow so that static pressure is low. As a result seepage is small.

RAINFALL Rainfall data came from the Edgerton, Mo. rain gage. If data was missing for a month, the Rainfall for that period was obtained from the St. Joseph records. Edgerton is located fourteen miles east of Dearborn and St. Joseph is about 25 miles north.

RUNOFF This is the runoff into the lake from its drainage area. Monthly runoff volumes in watershed inches were determined at the Jenkins Branch stream gage, a tributary to Platte River. The drainage area is 2.72 Sq. Mi. Jenkins Br. gage is located approximately 26 miles NE from Dearborn. This Monthly runoff was compared to the rainfall and if the results did not appear reasonable, adjustments were made for that month by looking at individual rains and estimating antecedent moisture then adjusting runoff based on NRCS's runoff curve numbers.

EVAP. Pan evaporation at the Lakeside gaging station was used as a base because it has data for year around evaporation. This data was updated with gage data from stations at Spickard, New Franklin, and Columbia. Depending on the latest data for the station nearest to Hamilton.

DEMAND This was determined by city records. Dearborn had a daily use of 62,300 gallon per day.(22,724,800 gallon in 1999)

OTHER This refers to the volume of water pumped from Marrowbone creek into Dearborn Reservoir.

Determination of the volume of water available for pumping was made using daily discharges at the Crooked River stream gage near Richmond. The Crooked River gage is about 40 miles South West of Dearborn. The drainage area is 159 square miles and the drainage area at the point of pumping on Bee Creek is 38 square miles. The daily discharge rates for Crooked River were reduced by a ratio of 38/159 to determine potential pumping volumes. Pumping was only planned for flows above 2 cfs. This was determined from agreements on Locust Creek. Pumping on Locust Creek began at 10 cfs for 225 square miles drainage area. This is 10/225=0.044 cubic feet per second per square miles drainage area. 38 square miles times 0.044 = 1.7 cubic feet per second rounded up to 2 cubic feet per second.

The maximum rate of pumping, for this analysis, was 500 gallons per minute or 1.1 cubic feet per second. It was estimated that this was the best sustainable pumping rate.

Some months had pumping reduced from available flow because the pool filled and there was flow through the spillway.

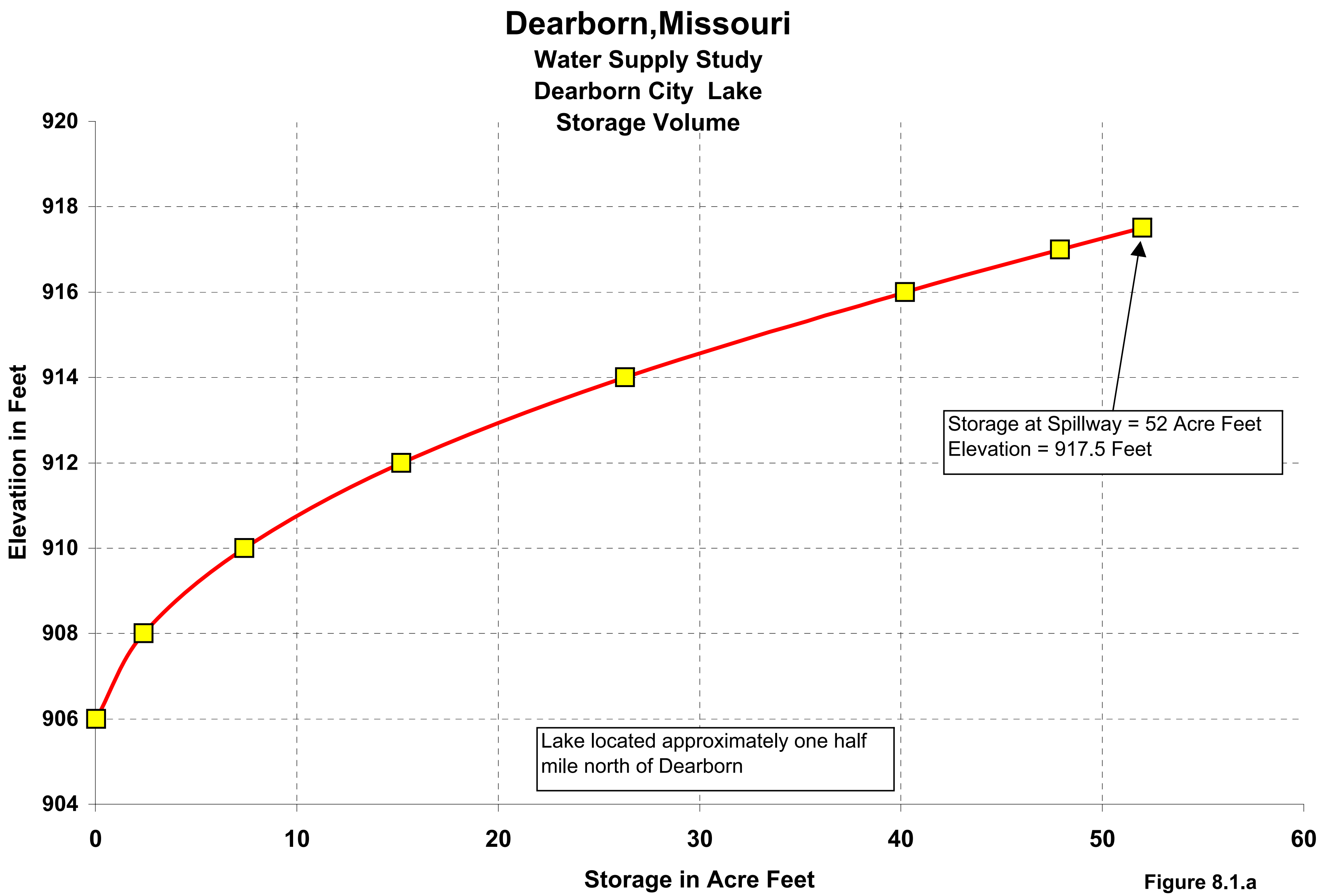
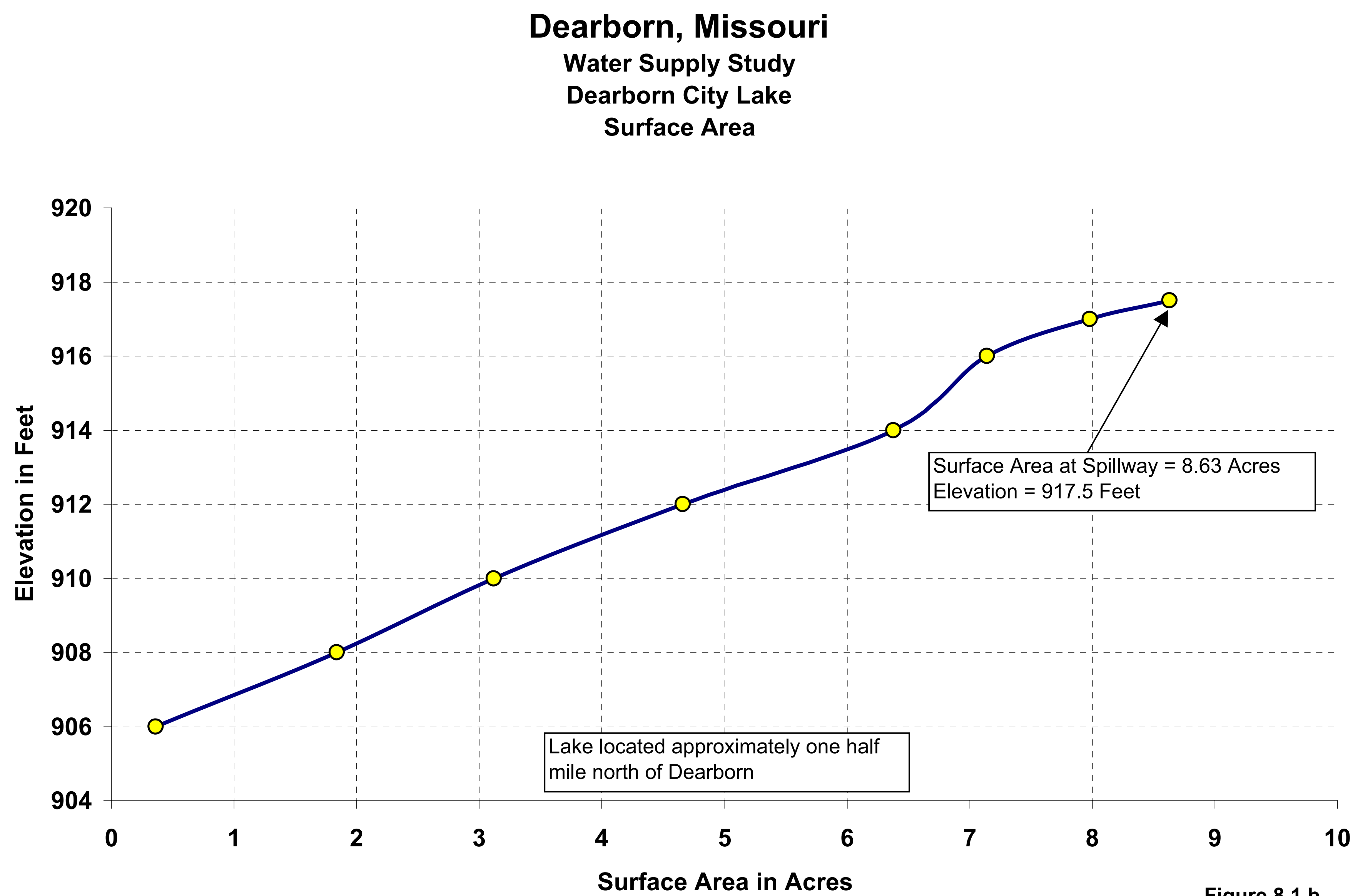

Dearborn,Missouri
Water Supply Study
Dearborn City Lake
Storage Volume
Elevatiion in Feet
920
918
916
914
912
910
908
906
904
0
10
20
30
40
50
60
Storage in Acre Feet
Storage at Spillway = 52 Acre Feet
Elevation = 917.5 Feet
Lake located approximately one half
mile north of Dearborn

Figure 8.1.a



Dearborn, Missouri
Water Supply Study
Dearborn City Lake
Surface Area
Elevation in Feet
920
918
916
914
912
910
908
906
904
0
1
2
3
4
5
6
7
8
9
10
Surface Area in Acres
Surface Area at Spillway = 8.63 Acres
Elevation = 917.5 Feet
Lake located approximately one half
mile north of Dearborn

Figure 8.1.b

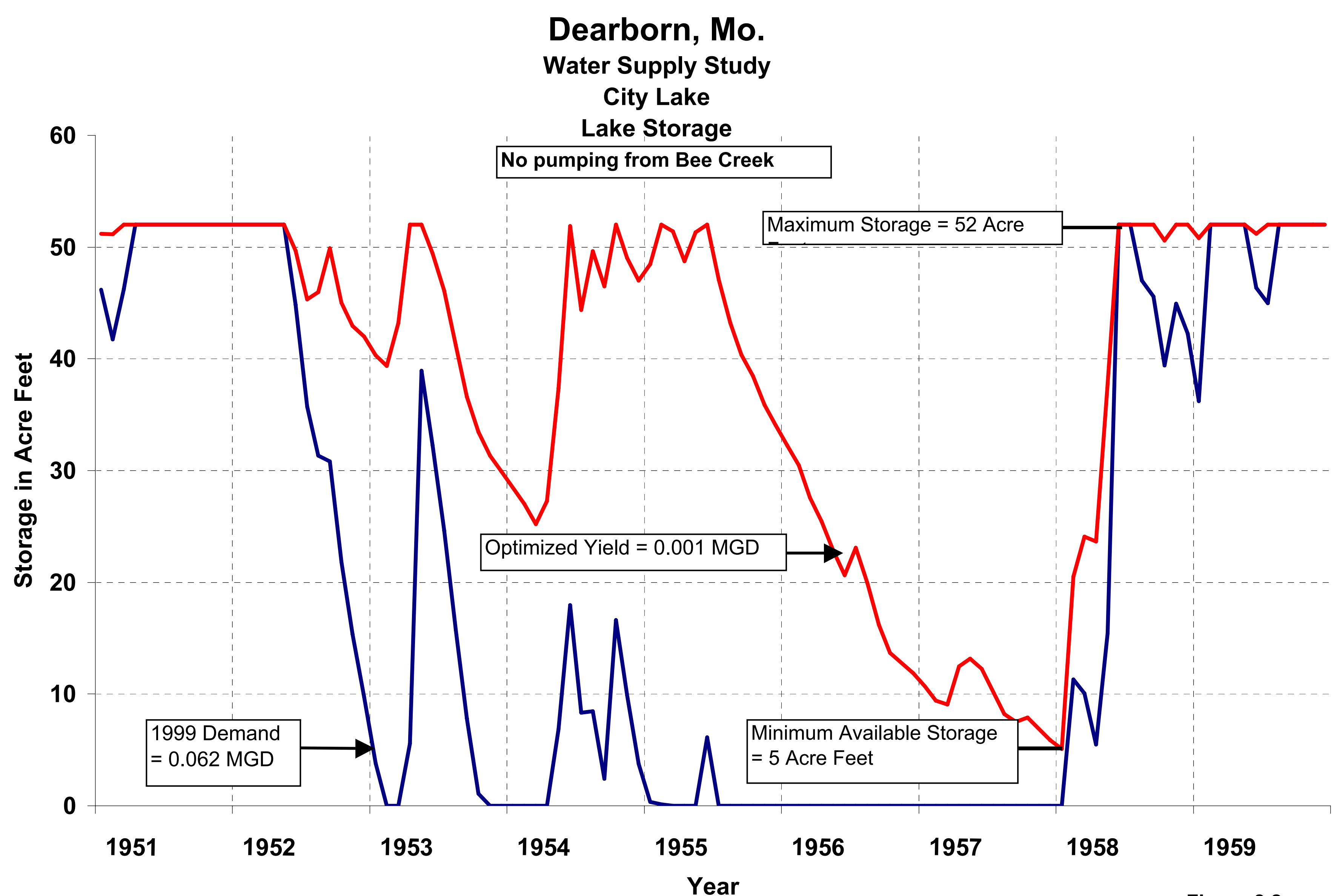

Dearborn, Mo.
Water Supply Study
City Lake
Lake Storage
No pumping from Bee Creek
Maximum Storage = 52 Acre
Optimized Yield = 0.001 MGD
1999 Demand
= 0.062 MGD
Minimum Available Storage
= 5 Acre Feet
Storage in Acre Feet
0
10
20
30
40
50
60
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year

Figure 8.2.a

Dearborn, Missouri

Water Supply Study
City Lake
Lake Storage

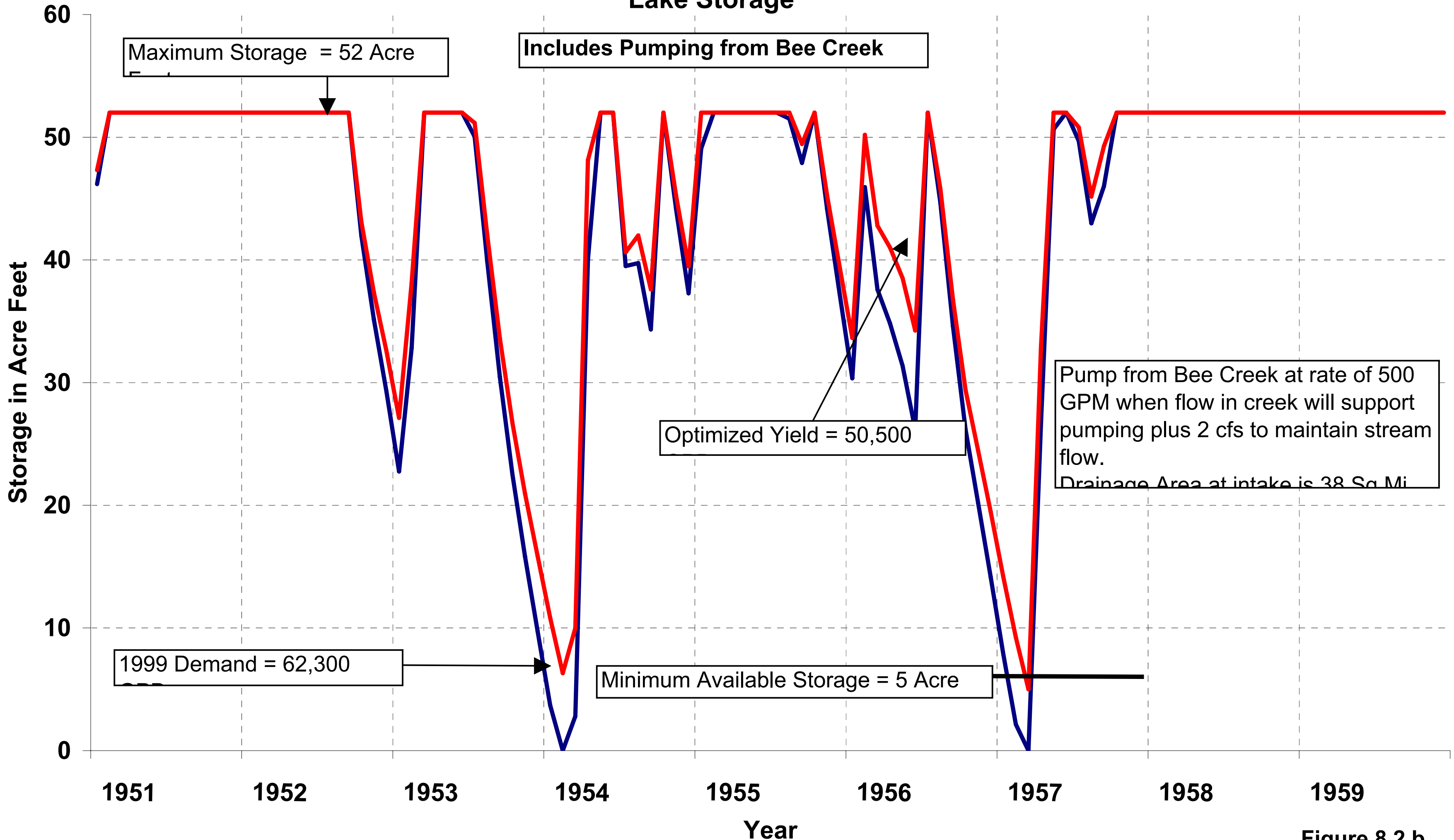


Figure 8.2.b

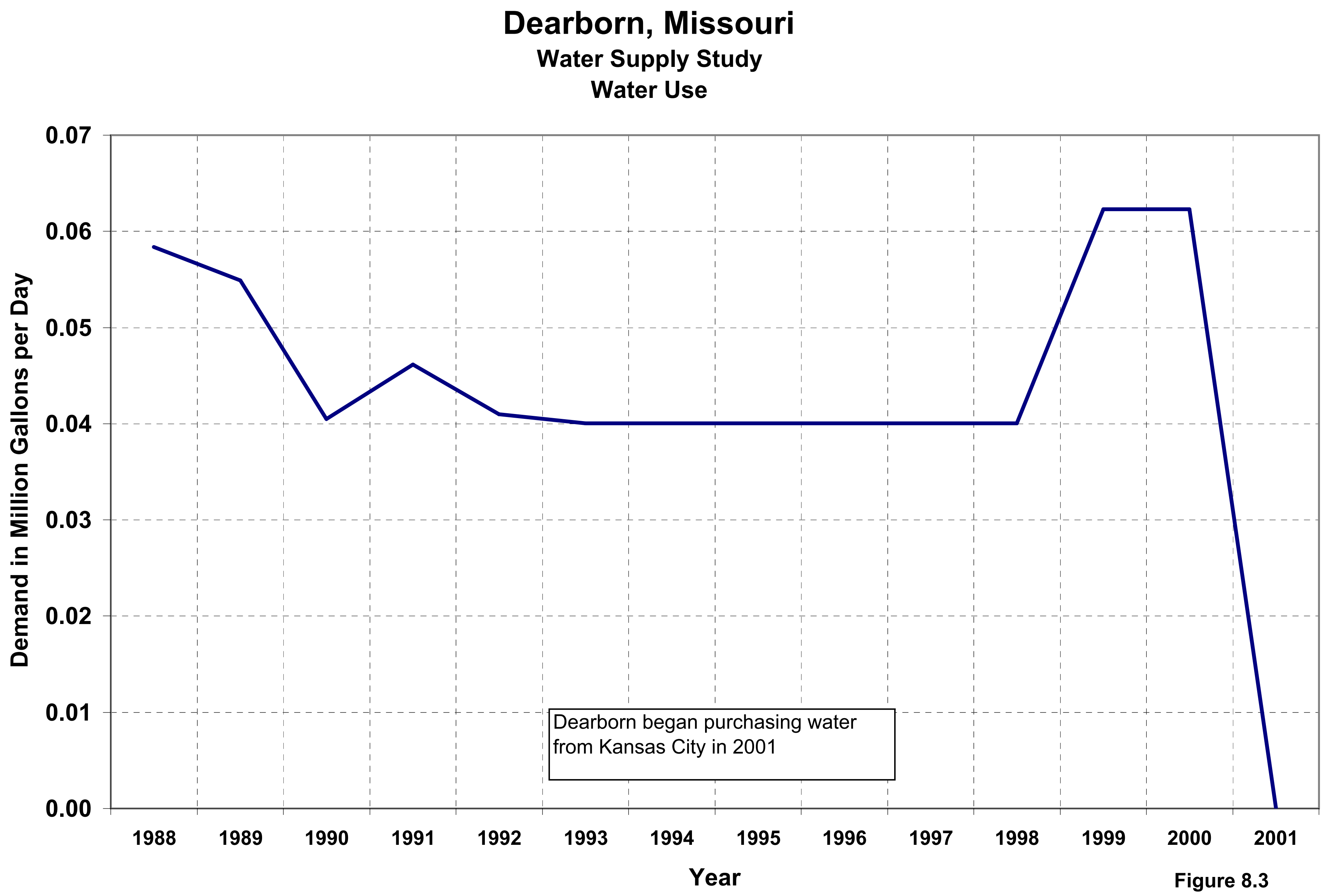
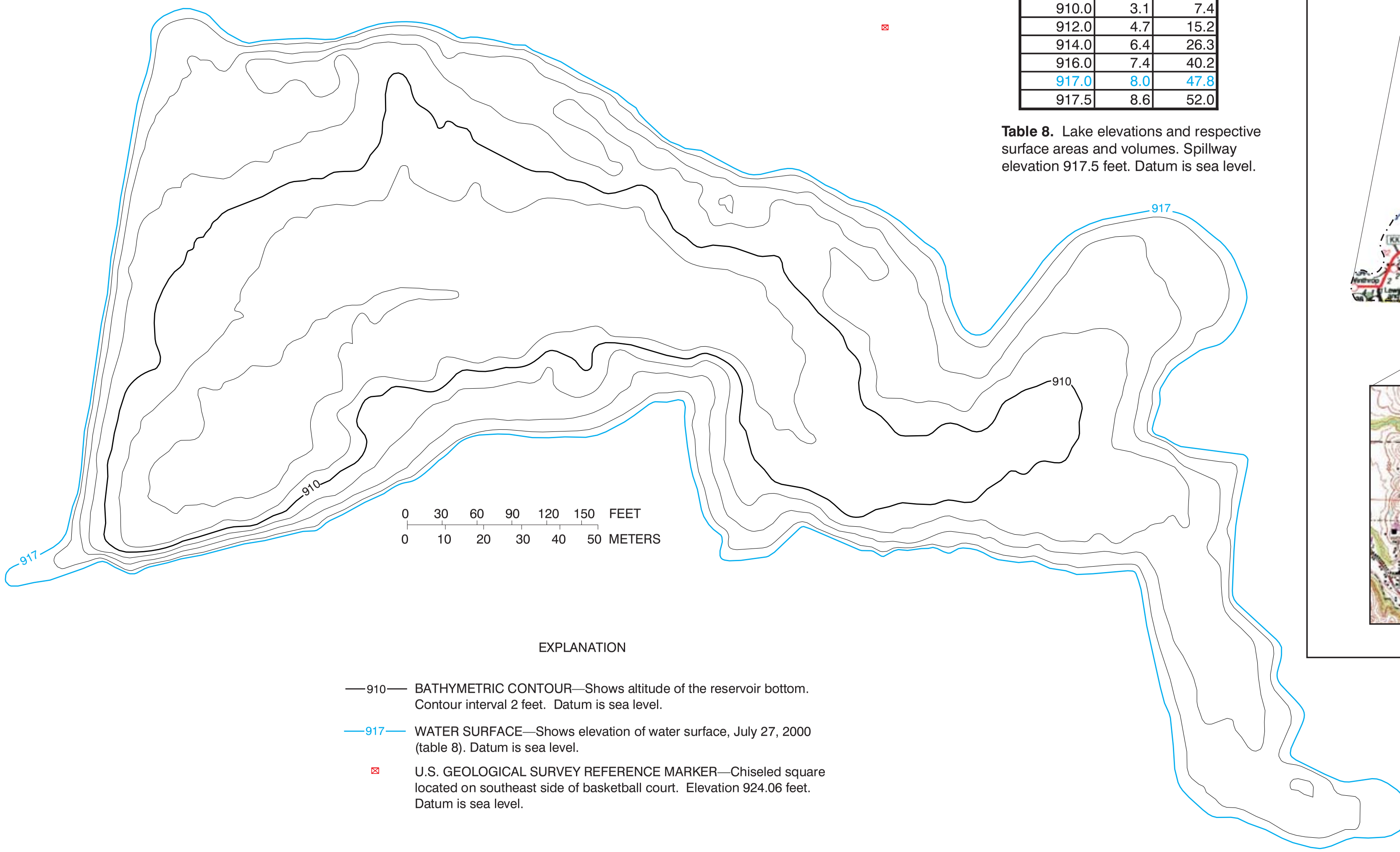

Dearborn, Missouri
Water Supply Study
Water Use
Demand in Million Gallons per Day
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
Year
Dearborn began purchasing water
from Kansas City in 2001

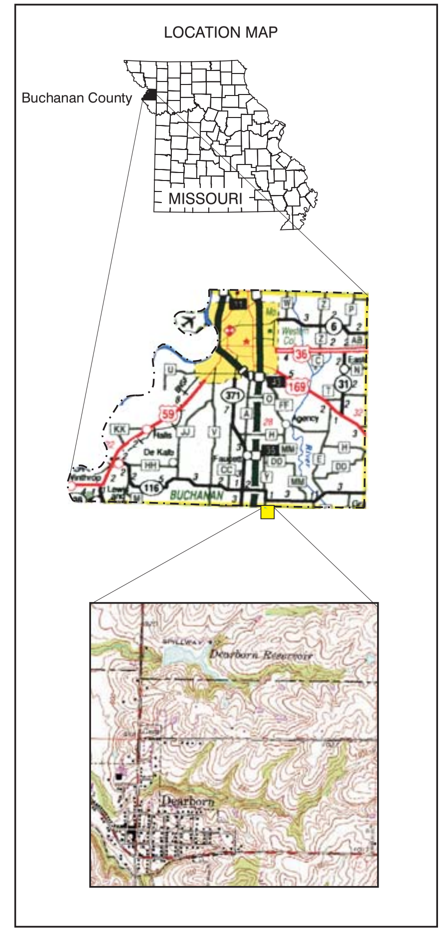
Figure 8.3

DEARBORN RESERVOIR



Elevation (feet)	Area (acres)	Volume (acre-ft)
906.0	0.4	0.0
908.0	1.8	2.4
910.0	3.1	7.4
912.0	4.7	15.2
914.0	6.4	26.3
916.0	7.4	40.2
917.0	8.0	47.8
917.5	8.6	52.0

Table 8. Lake elevations and respective surface areas and volumes. Spillway elevation 917.5 feet. Datum is sea level.



EXPLANATION

—910— BATHYMETRIC CONTOUR—Shows altitude of the reservoir bottom. Contour interval 2 feet. Datum is sea level.

—917— WATER SURFACE—Shows elevation of water surface, July 27, 2000 (table 8). Datum is sea level.

⊠ U.S. GEOLOGICAL SURVEY REFERENCE MARKER—Chiseled square located on southeast side of basketball court. Elevation 924.06 feet. Datum is sea level.

USGS science for a changing world

Figure 8. Bathymetric map and area/volume table for Dearborn Reservoir near Dearborn, Missouri.

Drexel, Missouri
Water Supply Study
City Lake #2

Drexel has 2 lakes. Only lake number 2 was surveyed and included in this analysis. Drexel is located in the South West corner of Cass County, Missouri.

The record period of drought was used to estimate if Drexel's water supply was adequate to provide ample water during extreme drought. The 1950's were determined to be that period.

The 30-year average rainfall is 42.05 inches. Rainfall at the Harrisonville gage was used in this analysis. For the period 1953 through 1957, annual rainfall was 28.8, 35.7, 28.4, 21.3, and 37.5 inches.

Drexel has not been considering themselves to be a major water user. As a result they have not been reporting their water use. They are now using enough water to be considered a major water user and will be reporting their usage. The Safe Drinking Water Information System (SDWIS) database indicates they are currently using an average of 102,600 gallon per day. The Maximum day usage reported is 161,000 gallon.

Optimized demand is 119,200 gallon per day.

Drainage area of the lake is 534 acres.

Drexel's Lake analysis consisted of using the NRCS's computer program "RESOP". This program analyzes remaining stored water at the end of each month by summing gains and losses.

Following is the data by control word for input to the "RESOP" program.

STO-AREA Elevation-Storage and Elevation-Area data were determined from June, 5, 2003 survey made by USGS.

Drexel Lake #2

ELEV Feet	AREA Acres	VOLUME Ac-Ft	
952	0.12	0.04	
954	1.0	1.0	
956	2.4	4.3	
958	4.5	11.1	
960	7.3	22.6	
962	11.2	40.9	
964	16.6	68.5	
966	23.4	108.3	
967	26.8	133.3	
968	30.8	162.1	
968.1	31.3	165.2	Water Surface on 6/5/2003
970	40.2	233.4	
972	46.7	321.5	
972.5	47.9	345.1	Spillway

LIMITS Full Pool storage 345.1 Ac.Ft.
Minimum Pool storage 10 Ac.Ft.
Starting storage was considered at full pool elevation.
The drainage area of the lake is 0.83 square miles.

GENERAL — The adjustment factor of 0.76 to convert from pan evaporation to lake evaporation was applied prior to entering the data for the control word EVAP. As a result a factor of 100 is applied.

The record period of drought is in the 1950's.
Analysis began in January 1951 and ended December 1959.

SEEPAGE — The reservoir seepage varied from 0 seepage near empty to a maximum of 1.0 inch per month at full pool. The material in the dam is compacted earth of clayey soils.

RAINFALL — Rainfall data came from the Harrisonville, Mo. rain gage for the period 1951 through 1959.

RUNOFF — This is the runoff into the lake from its drainage area. Regional monthly runoff values were determined from stream gage data.

Monthly runoff volumes in watershed inches was determined at the Little Blue River gage near Lake City, North East of Drexel. Another gage on Cedar Creek near Pleasant View, Missouri was analyzed. Because Little Blue River watershed is nearer to Drexel, and the soils and topography of Little Blue River is more nearly like that at Drexel, it was selected to represent regional runoff. If runoff did not appear reasonable when compared to rainfall, it was necessary to examine daily rainfall values for that month. Antecedent moisture was estimated for each rainfall event and adjustments to NRCS runoff curve number was made to arrive at runoff for each storm.

EVAP. — Pan evaporation at the Lakeside gaging station near the Lake of the Ozarks was used to determine pan evaporation. The adjustment to lake evaporation was 0.76.

DEMAND — Drexel has not been reporting their water use because they had not considering themselves to be major water users. They will be reporting their use in the future. This RESOP run was for the daily use recorded in the SDWIS data-base. The daily amount recorded is 0.1026 MGD. The optimized use would be 0.1192 million gallon per day.

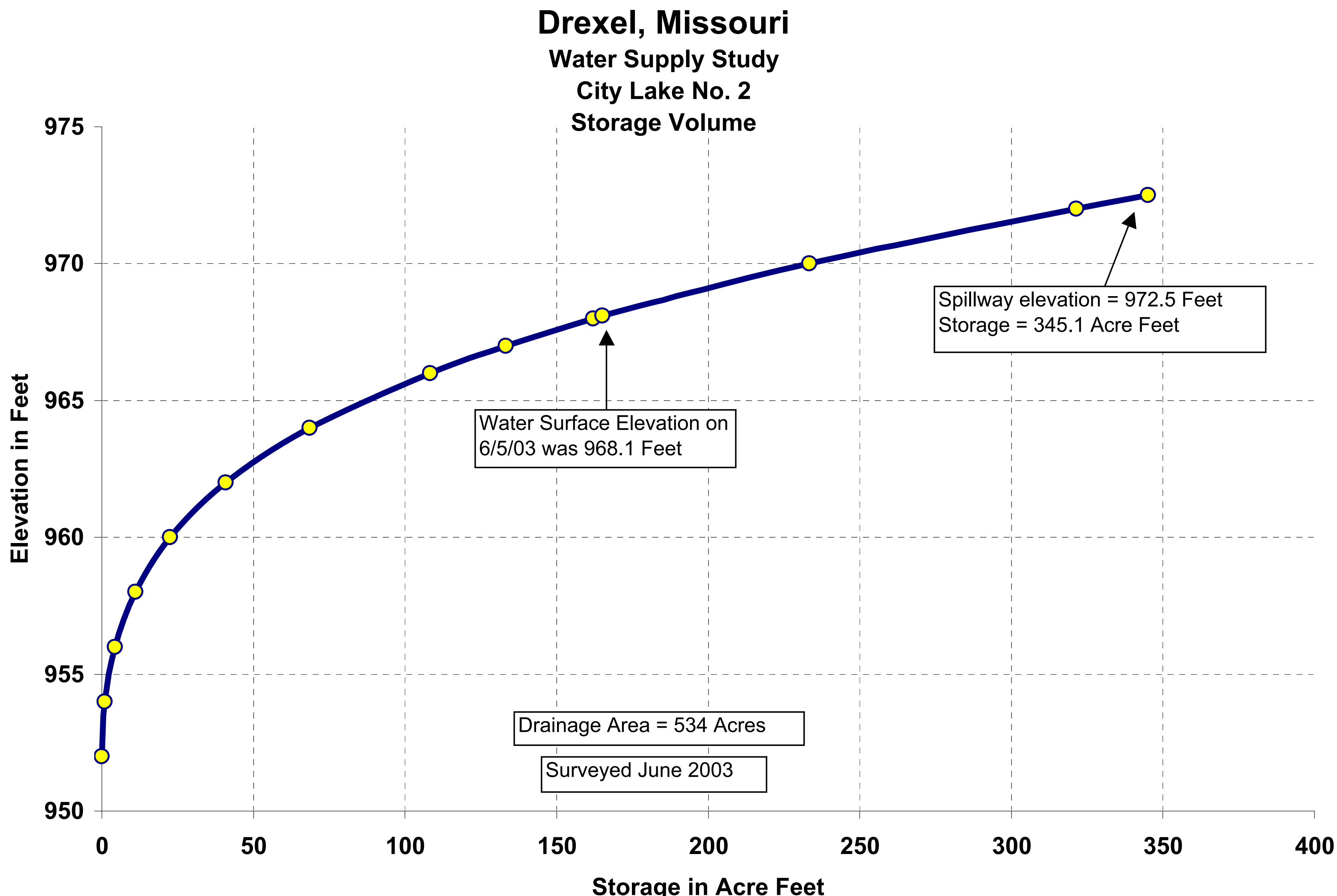

Drexel, Missouri
Water Supply Study
City Lake No. 2
Storage Volume
Elevation in Feet
975
970
965
960
955
950
0
50
100
150
200
250
300
350
400
Storage in Acre Feet
Water Surface Elevation on
6/5/03 was 968.1 Feet
Spillway elevation = 972.5 Feet
Storage = 345.1 Acre Feet
Drainage Area = 534 Acres
Surveyed June 2003

Figure 9.1.a

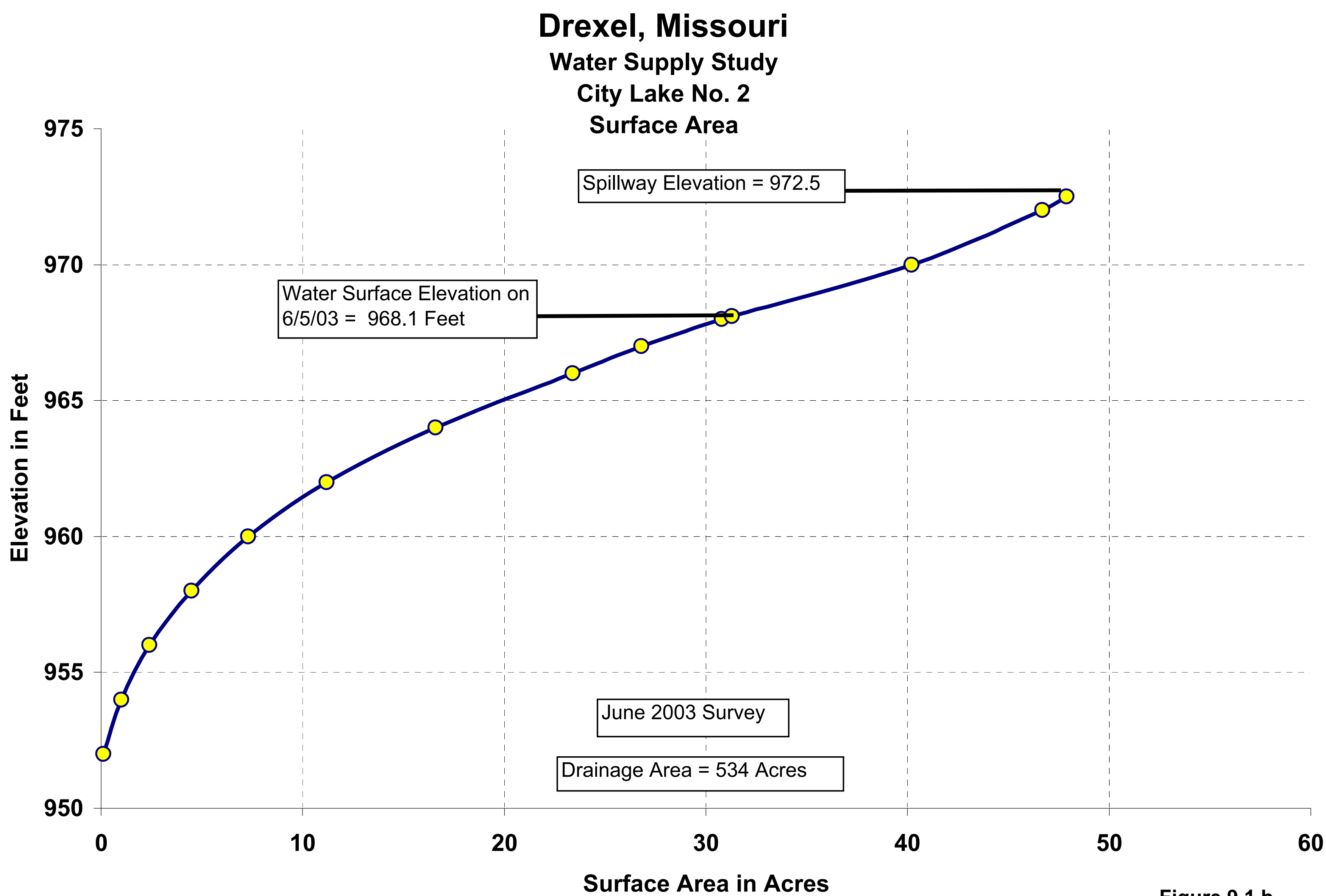

Drexel, Missouri
Water Supply Study
City Lake No. 2
Surface Area
Spillway Elevation = 972.5
Water Surface Elevation on
6/5/03 = 968.1 Feet
June 2003 Survey
Drainage Area = 534 Acres
Elevation in Feet
975
970
965
960
955
950
0
10
20
30
40
50
60
Surface Area in Acres

Figure 9.1.b

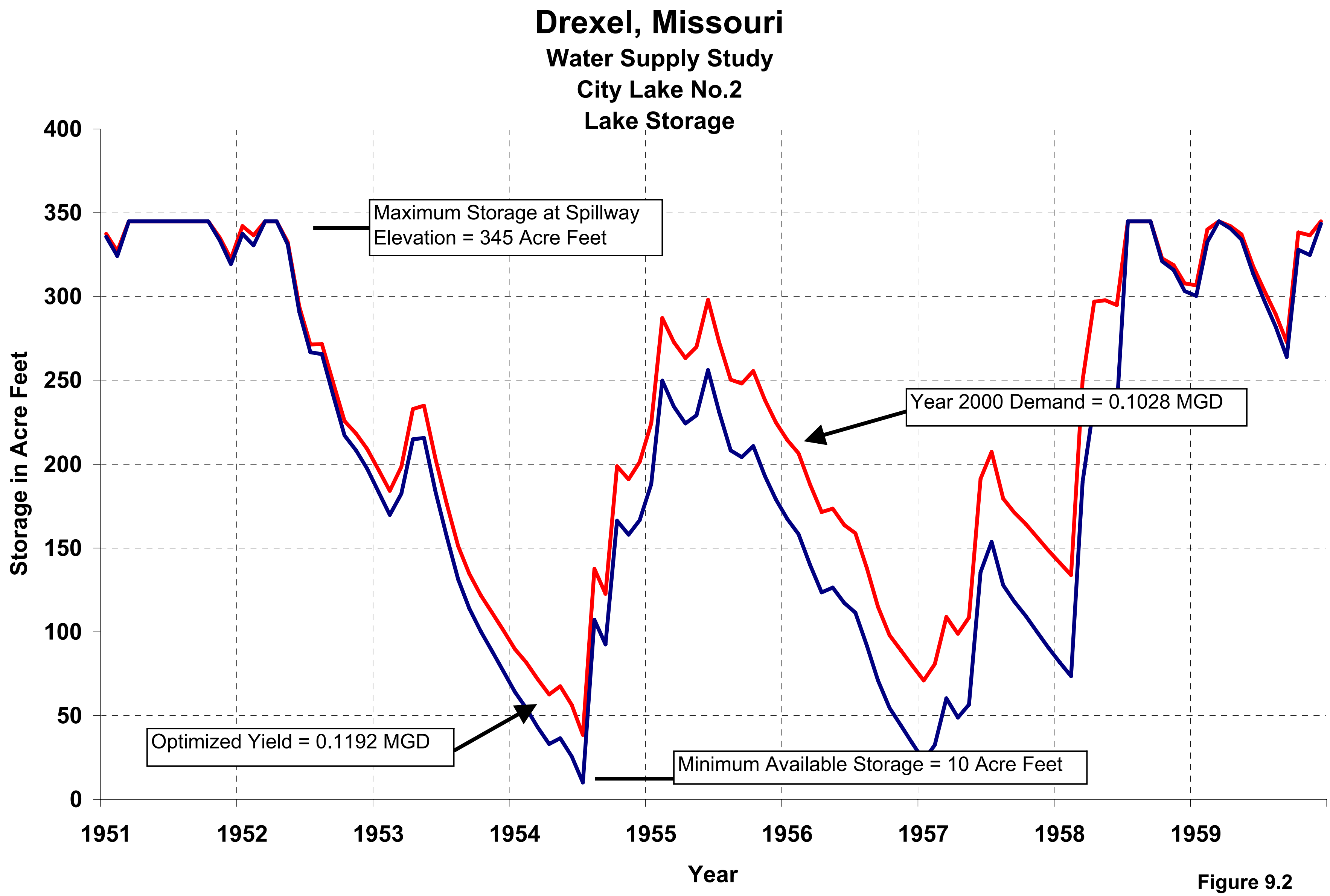
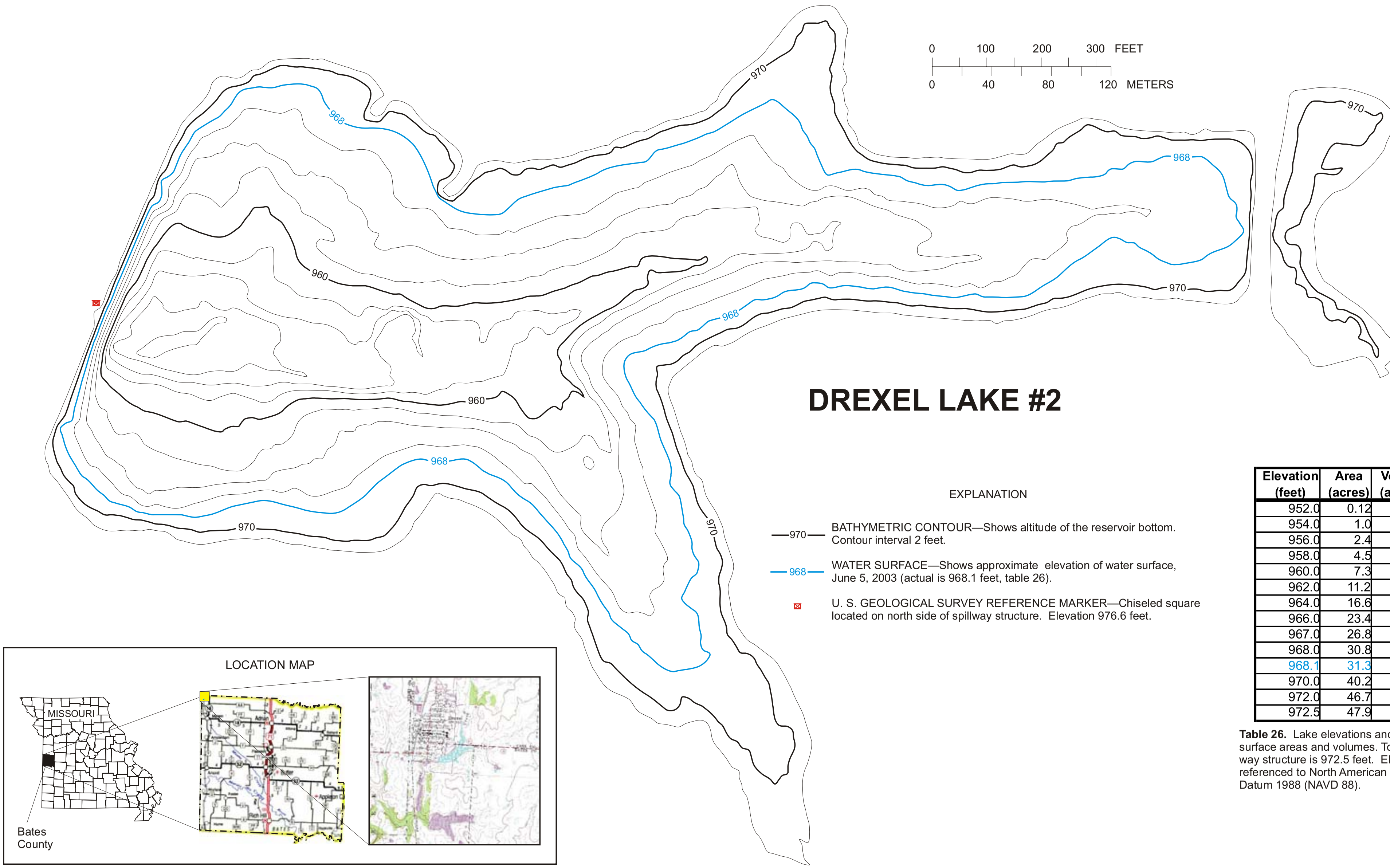

Drexel, Missouri
Water Supply Study
City Lake No.2
Lake Storage
Storage in Acre Feet
400
350
300
250
200
150
100
50
0
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year
Maximum Storage at Spillway
Elevation = 345 Acre Feet
Year 2000 Demand = 0.1028 MGD
Optimized Yield = 0.1192 MGD
Minimum Available Storage = 10 Acre Feet

Figure 9.2



Elevation (feet)	Area (acres)	Volume (acre-ft)
952.0	0.12	0.04
954.0	1.0	1.0
956.0	2.4	4.3
958.0	4.5	11.1
960.0	7.3	22.6
962.0	11.2	40.9
964.0	16.6	68.5
966.0	23.4	108.3
967.0	26.8	133.3
968.0	30.8	162.1
968.1	31.3	165.2
970.0	40.2	233.4
972.0	46.7	321.5
972.5	47.9	345.1

Table 26. Lake elevations and respective surface areas and volumes. Top of spillway structure is 972.5 feet. Elevations referenced to North American Vertical Datum 1988 (NAVD 88).

USGS science for a changing world

Figure 26. Bathymetric map and table of areas/volumes of Drexel Lake #2 near Drexel, Missouri.

In cooperation with Missouri Department of Natural Resources

Garden City, Missouri
Water Supply Study
City Lake

Garden City is located in the Southeast corner of Cass County, Missouri. It is 10 miles South East of Harrisonville on Highway 7.

The record period of drought was used to estimate if Garden City water supply is adequate to provide ample water for the city. The 1950's were determined to be the drought of record.

The 30-year average rainfall is approximately 42 inches. Rainfall at the Harrisonville gage was used in this analysis. For the period of the severest part of the drought of 1953 through 1957, annual rainfall was 28.8, 35.7, 28.4, 21.3, and 37.5 inches.

Garden City has two lakes, an older lake and their new lake. The new lake was constructed 1992 and the city began using the water in 1994. This lake is located 2 miles south and 1 1/4 mile East of Garden City. Its drainage area is 1.70 square miles. The old lake is located 1 mile east of town and has a drainage area of 0.67 square miles. Prior to 1994 the old lake was the main source of water for the community. The operating plan is to use whichever lake has a supply that meets their needs.

In year 2000 the older lake provided 20,311,090 gallon of water or 55,646 gallons per day and the new lake provided 29,889,810 gallons or 81,890 gallons per day. The total was 50,200,900 gallons for an average daily use of 137,536 gallons per day.

The optimized demand for Year 2000 was 69,000 gallons per day for the old lake and 182,000 gallons per day for the new lake.

Garden City's Lake analysis consisted of using the NRCS's computer program "RESOP". This program analyzes remaining stored water at the end of each month by summing gains and losses.

Following is the data and procedures for input to the "RESOP" program.

STO-AREA Elevation-Storage and Elevation-Area data were determined from April 6, 2004 surveys of both lakes made by USGS.

Garden City (Old) Lake

Elevation Feet	Area Acres	Volume Acre Feet	
878	0.15	0.02	
880	1.7	1.7	
882	5.1	7.8	
884	10.2	24.4	
886	13.6	48.2	
888	19.3	81.4	
890	23.4	124.7	
892	26.1	174.3	
892.1	27.1	177.0	Spillway Elevation
893	30.4	202.9	Emergency Spillway Elevation
894	33.5	234.9	
895	36.8	270.0	Top of Dam

Garden City (New) Lake

Elevation Feet	Area Acres	Volume Acre Feet	
842	0.3	0.2	
844	2.5	2.9	
846	5.0	10.5	
848	7.9	23.4	
850	12.4	43.7	
852	16.2	72.6	
854	20.1	108.8	
856	23.8	152.7	
858	27.7	203.7	
860	33.7	264.7	
862	39.3	337.7	
862.4	40.5	353.7	Water Surface 6/2004
864	8.8	426.1	
864.3	49.9	440.9	Spillway Elevation
866	57.4	532.0	
867.2	63.0	604.2	Top of Dam

		New Lake	Old Lake
LIMITS	Full Pool storage	440.9 Ac.Ft.	177.0 Ac.Ft.
	Minimum Pool storage	50 Ac.Ft.	10 Ac.Ft.
	Drainage Area	1.70 Sq.Mi.	0.67 Sq.Mi.

Starting storage was considered at full pool elevation.

GENERAL The adjustment factor of 0.76 to convert from pan evaporation to lake evaporation was applied prior to entering the data for the control word EVAP. As a result a factor of 100 is applied.

The record period of drought is in the 1950's.
Analysis began in January 1951 and ended December 1959

SEEPAGE The reservoir seepage varied from 0 seepage near empty to a maximum of 1.00 inch per Month at full pool for each lake. The material in each dam is compacted earth of clayey soils.

RAINFALL Rainfall data came from the Harrisonville, Mo. rain gage for the period 1951 through 1959.

RUNOFF This is the runoff into the lake from its drainage area. Regional monthly runoff values were determined from stream gage data.

Monthly runoff volumes in watershed inches was determined at the Little Blue River gage near Lake City, Another gage on Cedar Creek near Pleasant View, Missouri was analyzed. Results at the lake were nearly the same. Because Little Blue River watershed is nearer to Garden City, and the soils and topography of Little Blue River is more nearly like that at Garden City, it was selected to present regional runoff.

If runoff did not appear reasonable when compared to rainfall, it was necessary to examine daily rainfall values for that month. Anticedent moisture was estimated for each rainfall event and adjustments to NRCS runoff curve number was made to arrive at runoff for each storm.

EVAP.	Pan evaporation at the Lakeside gaging station near the Lake of the Ozarks was used to determine Pan evaporation. The adjustment to Lake Evaporation was 0.76.
DEMAND	Garden City demand came from their reporting as a major water user to the department of natural Resources. In year 2000 they reported using a total of 50,200,900 gallons, (0.138 MGD) from the two lakes.

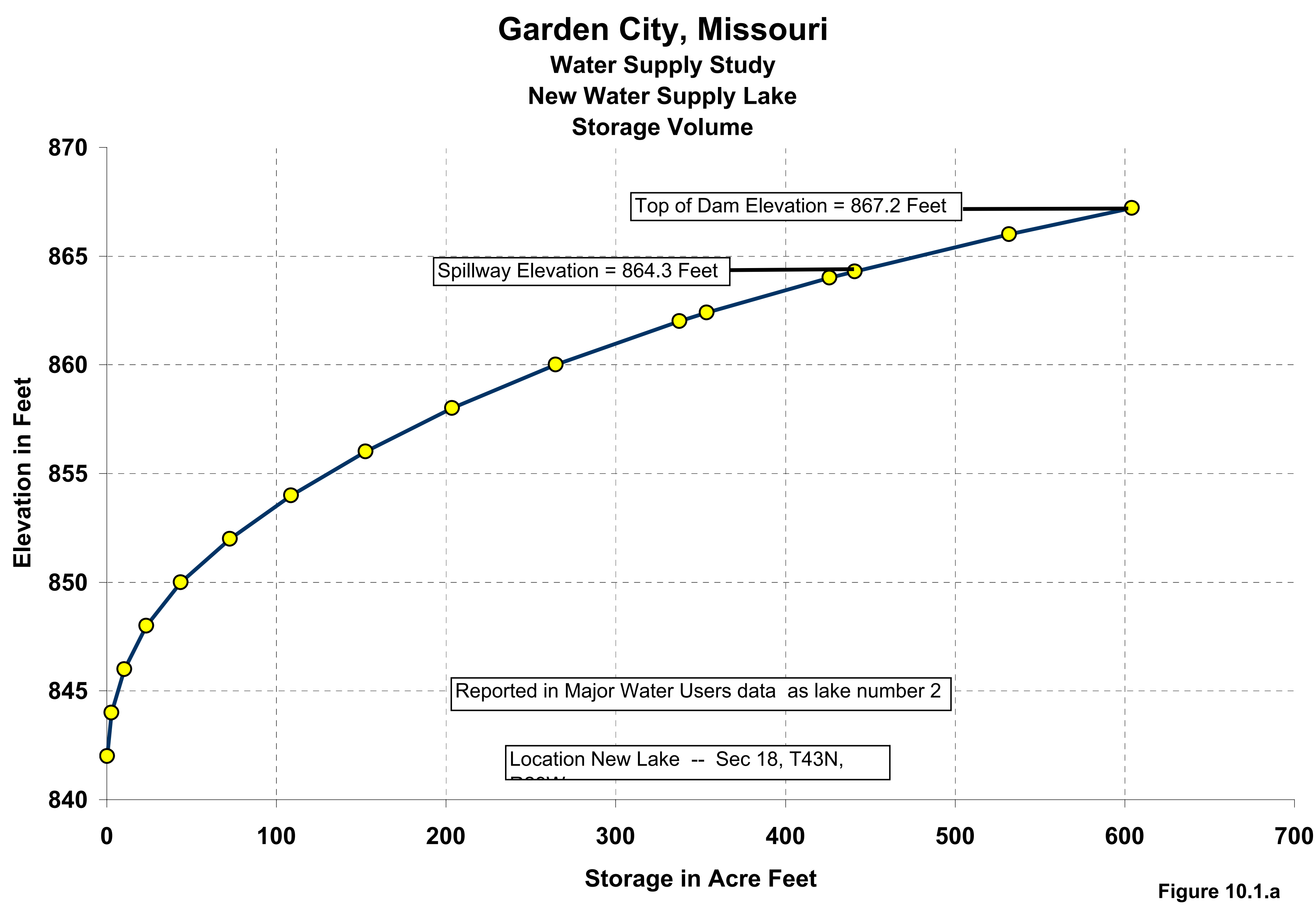

Garden City, Missouri
Water Supply Study
New Water Supply Lake
Storage Volume
Top of Dam Elevation = 867.2 Feet
Spillway Elevation = 864.3 Feet
Reported in Major Water Users data as lake number 2
Location New Lake -- Sec 18, T43N,
Elevation in Feet
870
865
860
855
850
845
840
0
100
200
300
400
500
600
700
Storage in Acre Feet

Figure 10.1.a

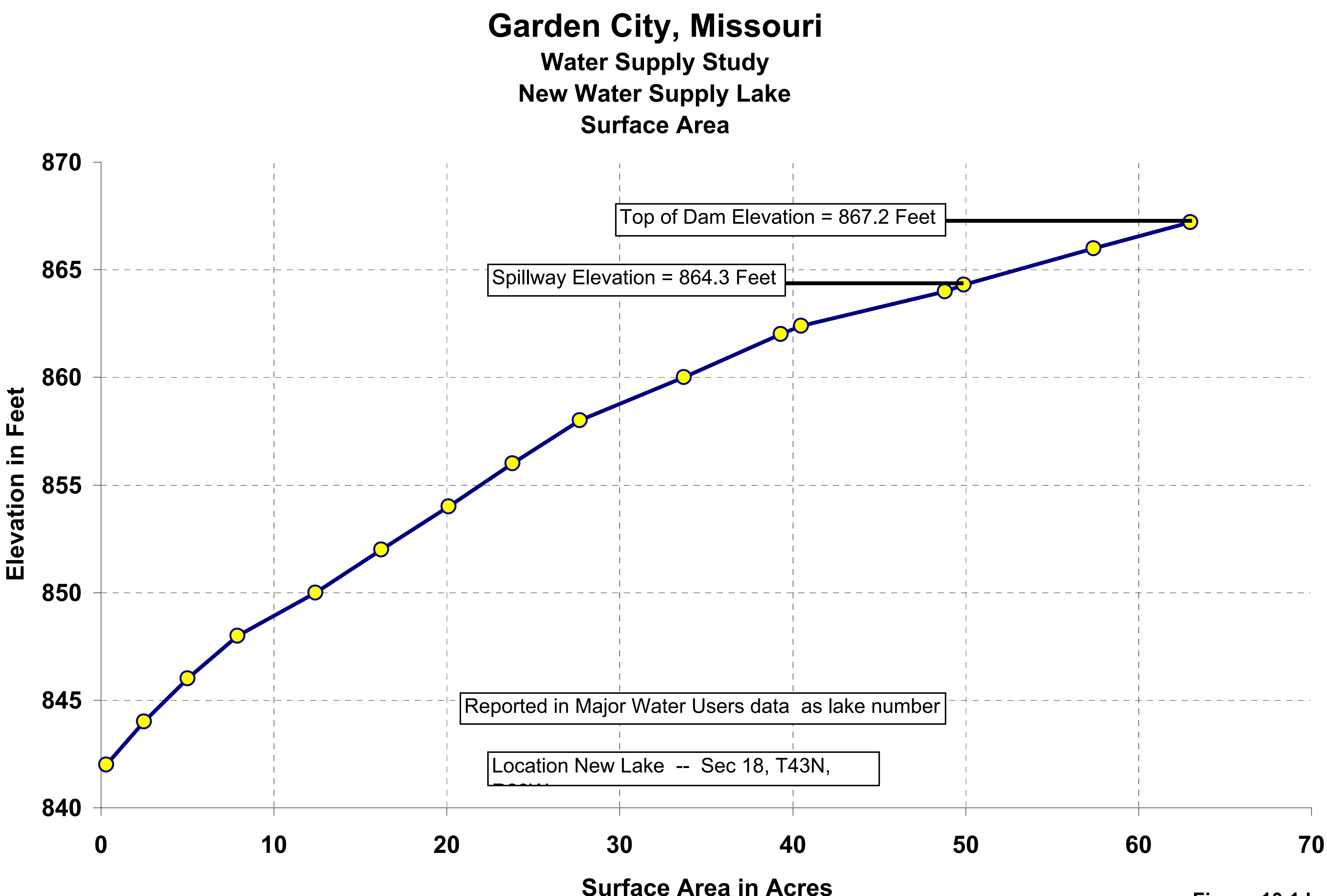

Garden City, Missouri
Water Supply Study
New Water Supply Lake
Surface Area
Top of Dam Elevation = 867.2 Feet
Spillway Elevation = 864.3 Feet
Reported in Major Water Users data as lake number
Location New Lake -- Sec 18, T43N,
870
865
860
855
850
845
840
Elevation in Feet
0
10
20
30
40
50
60
70
Surface Area in Acres

Figure 10.1.b

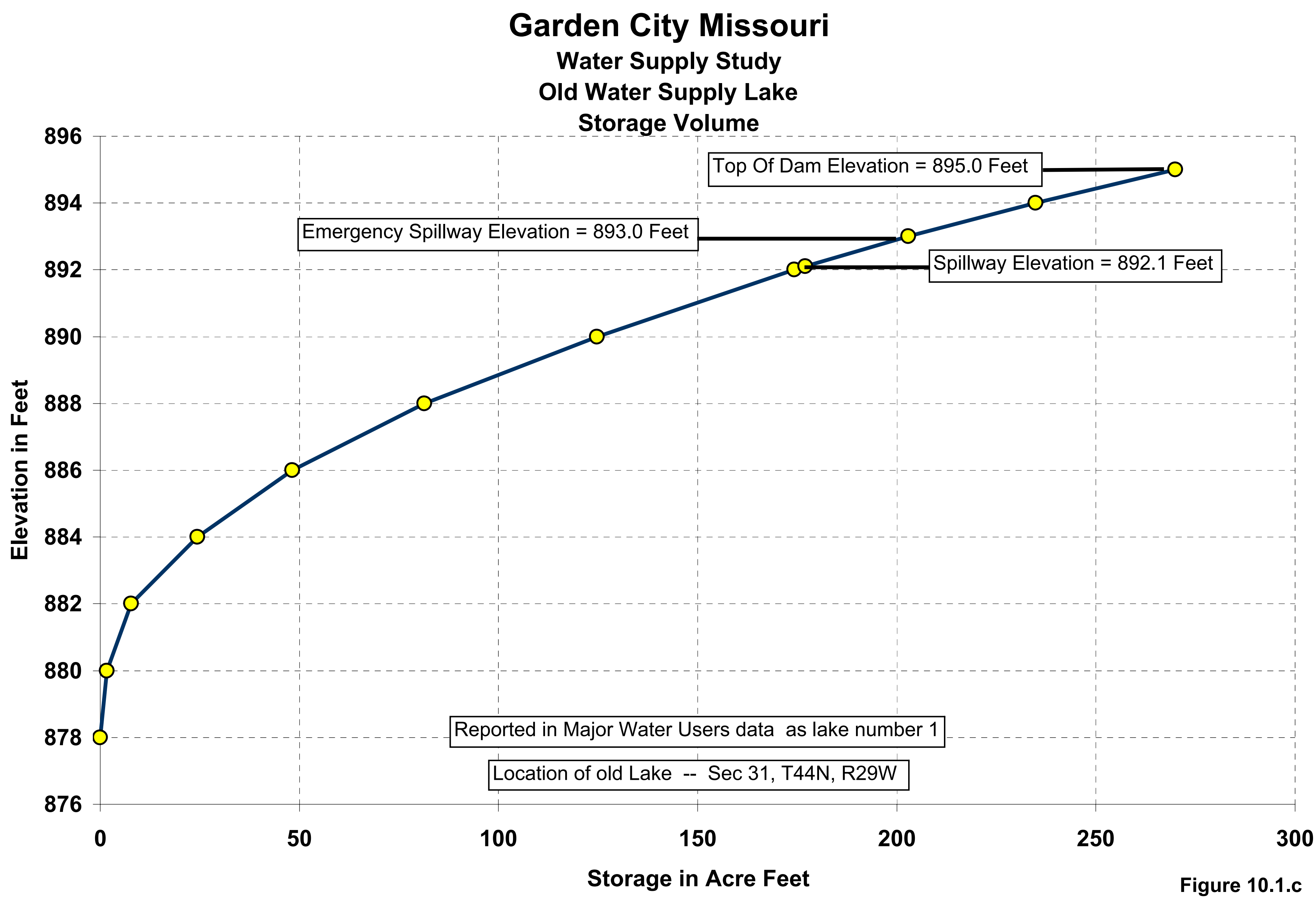
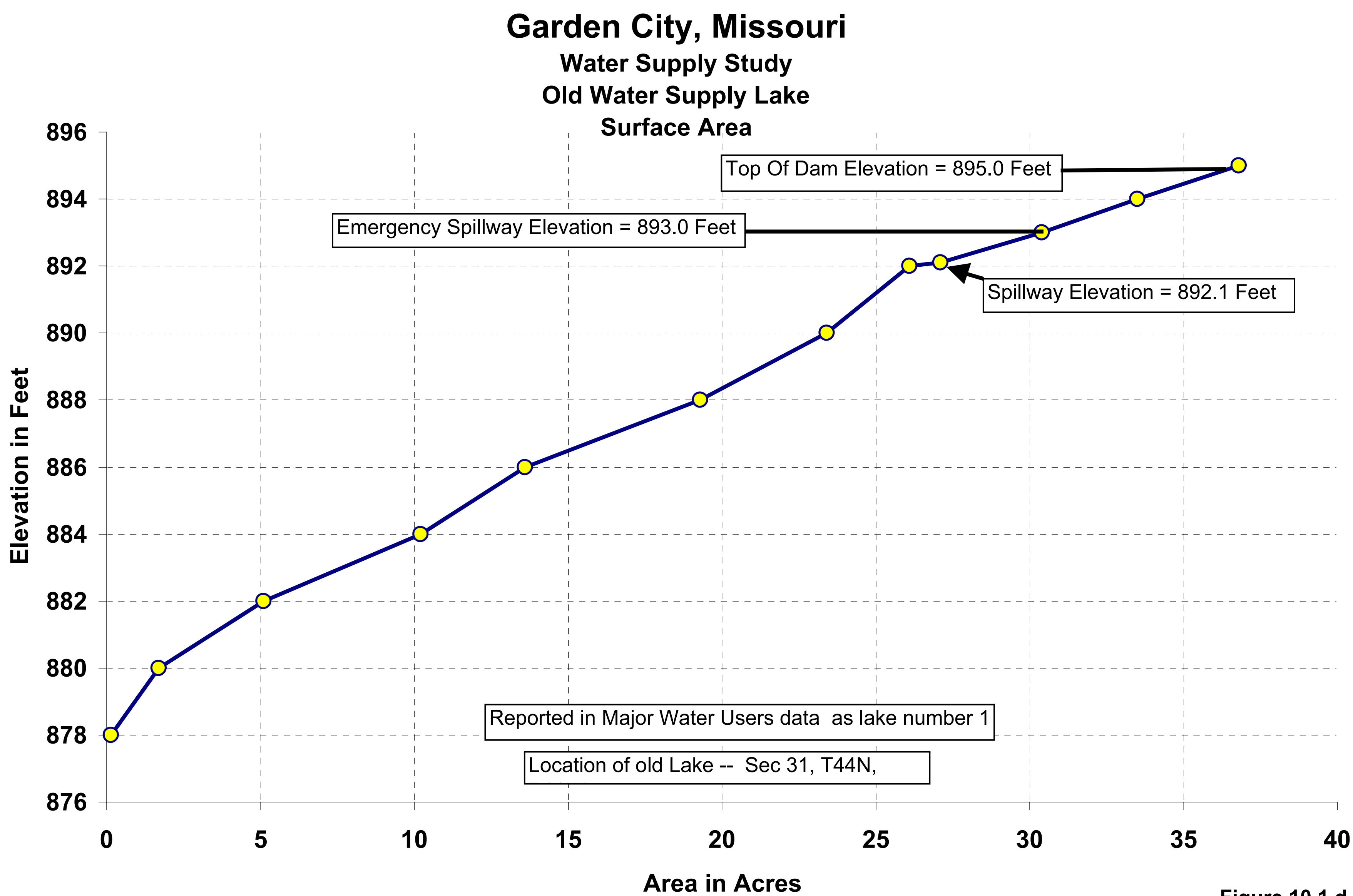

Garden City Missouri
Water Supply Study
Old Water Supply Lake
Storage Volume
Top Of Dam Elevation = 895.0 Feet
Emergency Spillway Elevation = 893.0 Feet
Spillway Elevation = 892.1 Feet
Reported in Major Water Users data as lake number 1
Location of old Lake -- Sec 31, T44N, R29W
Elevation in Feet
Storage in Acre Feet
896
894
892
890
888
886
884
882
880
878
876
0
50
100
150
200
250
300

Figure 10.1.c



Garden City, Missouri
Water Supply Study
Old Water Supply Lake
Surface Area
Top Of Dam Elevation = 895.0 Feet
Emergency Spillway Elevation = 893.0 Feet
Spillway Elevation = 892.1 Feet
Reported in Major Water Users data as lake number 1
Location of old Lake -- Sec 31, T44N,
Elevation in Feet
896
894
892
890
888
886
884
882
880
878
876
0
5
10
15
20
25
30
35
40
Area in Acres

Figure 10.1.d

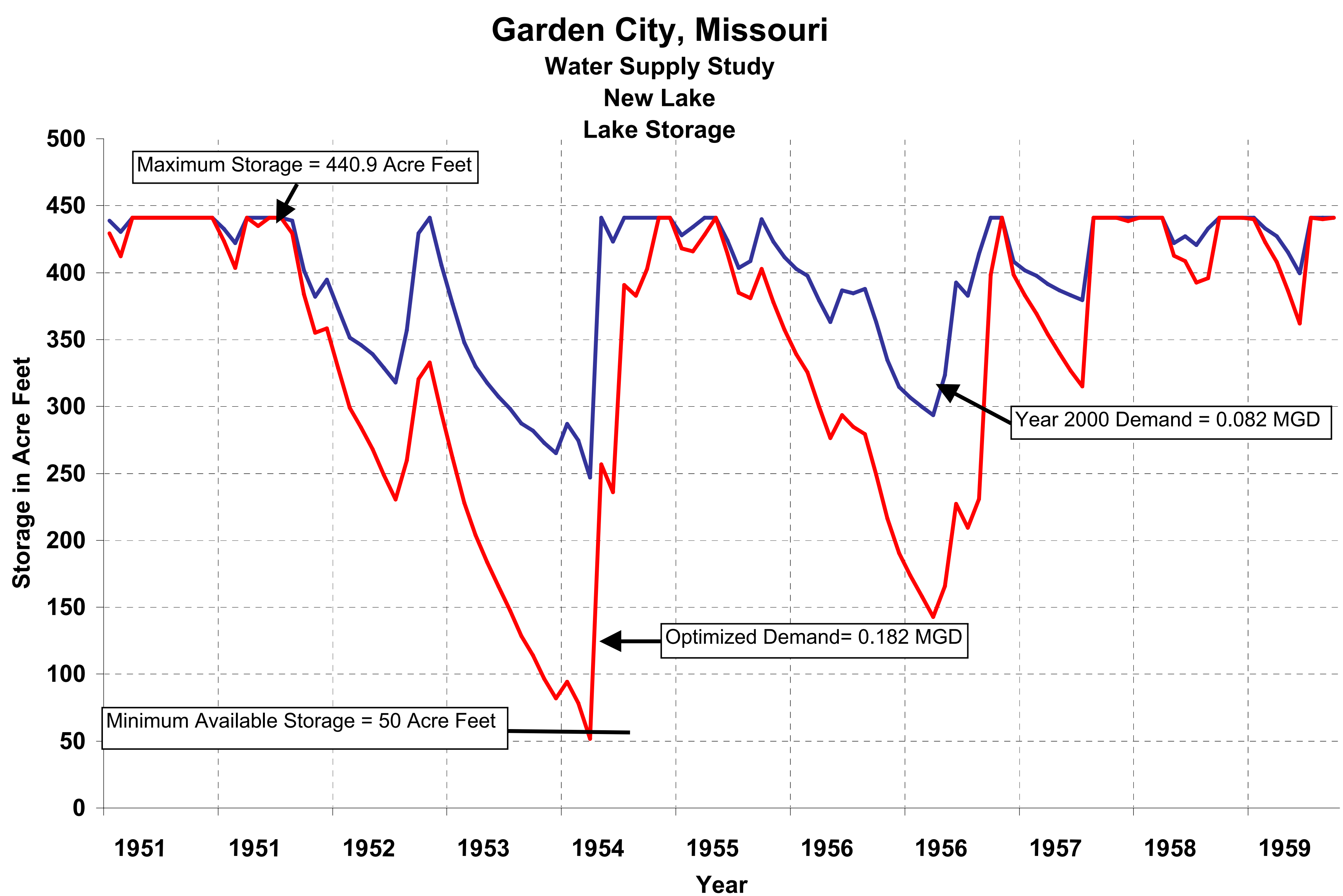
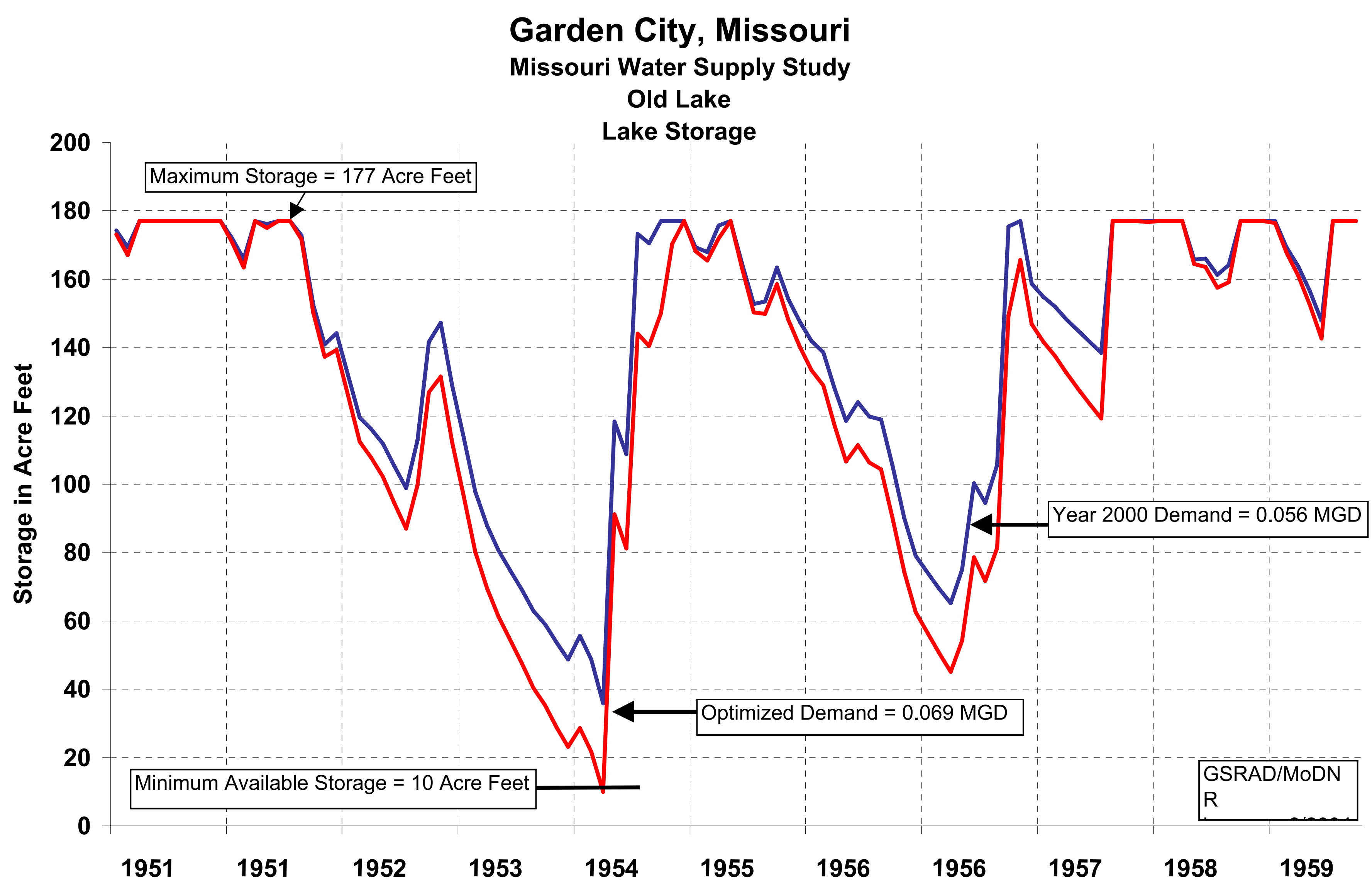
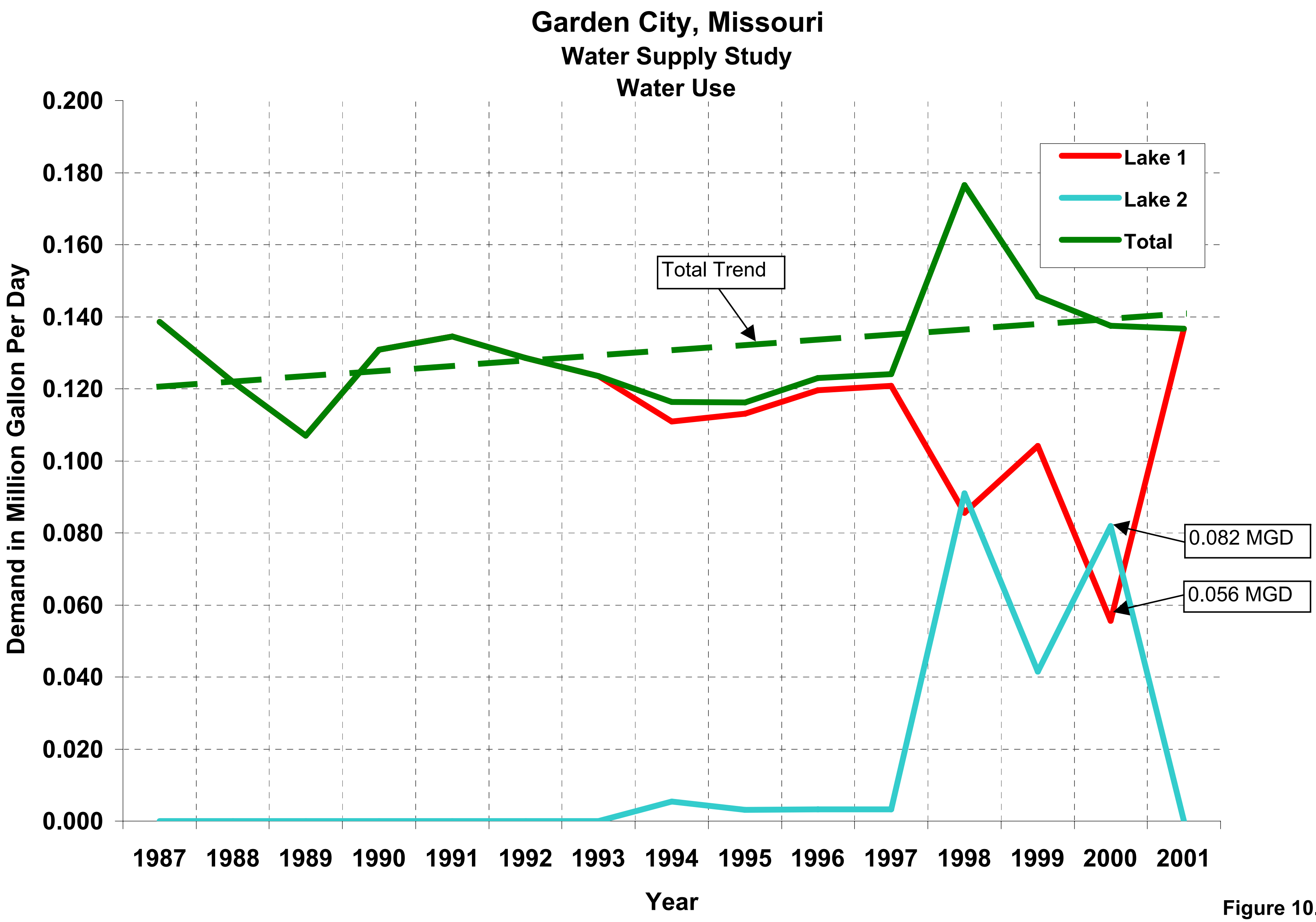

Garden City, Missouri
Water Supply Study
New Lake
Lake Storage
Maximum Storage = 440.9 Acre Feet
Year 2000 Demand = 0.082 MGD
Optimized Demand= 0.182 MGD
Minimum Available Storage = 50 Acre Feet
Storage in Acre Feet
500
450
400
350
300
250
200
150
100
50
0
1951
1951
1952
1953
1954
1955
1956
1956
1957
1958
1959
Year

Figure 10.2.a



Garden City, Missouri
Missouri Water Supply Study
Old Lake
Lake Storage
Storage in Acre Feet
200
180
160
140
120
100
80
60
40
20
0
Maximum Storage = 177 Acre Feet
Minimum Available Storage = 10 Acre Feet
Optimized Demand = 0.069 MGD
Year 2000 Demand = 0.056 MGD
GSRAD/MoDN
R
1951
1951
1952
1953
1954
1955
1956
1956
1957
1958
1959
Year

Figure 10.2.b



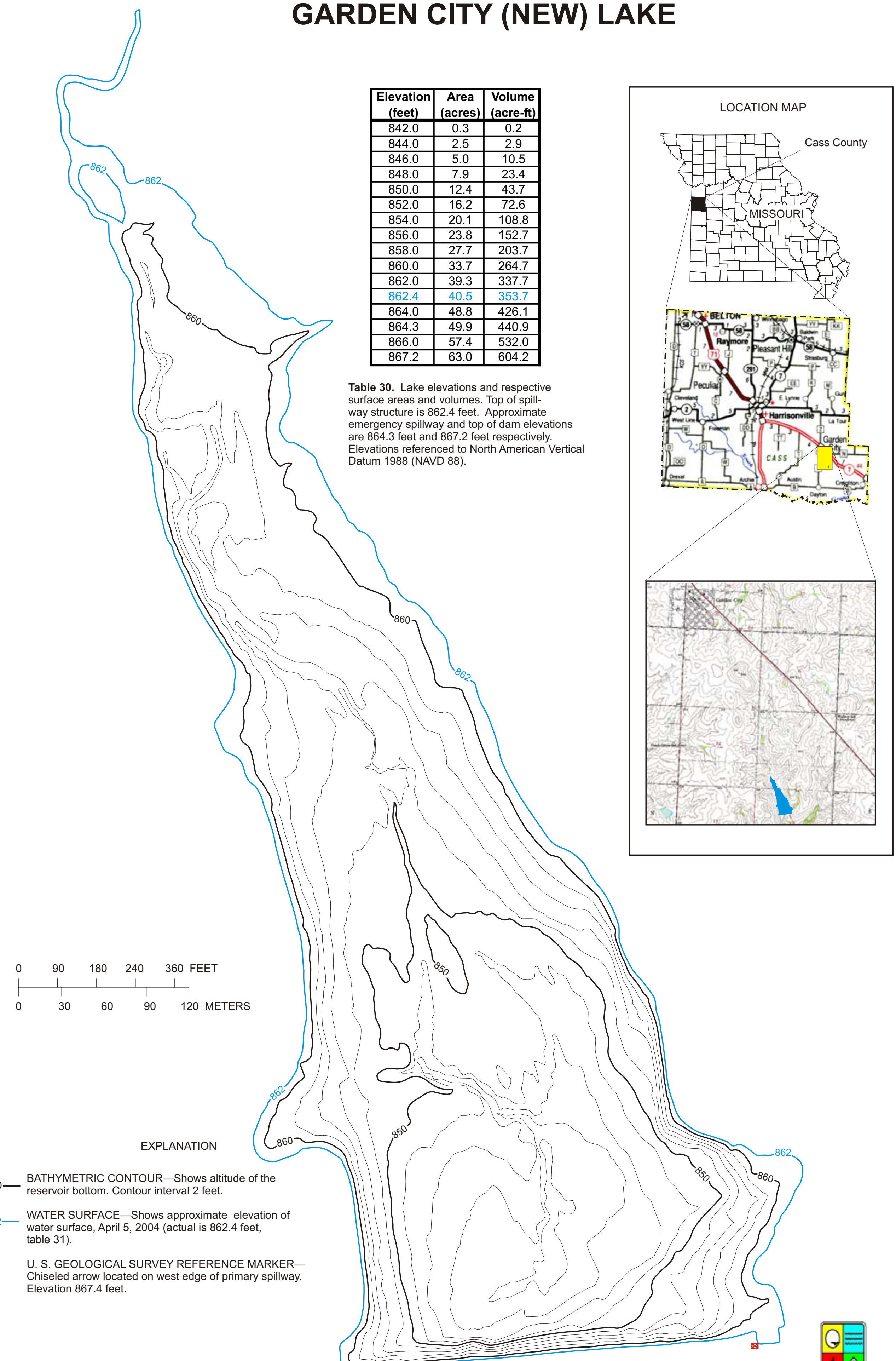
Garden City, Missouri
Water Supply Study
Water Use
Demand in Million Gallon Per Day
0.200
0.180
0.160
0.140
0.120
0.100
0.080
0.060
0.040
0.020
0.000
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
Year
Lake 1
Lake 2
Total
Total Trend
0.082 MGD
0.056 MGD

Figure 10.3

GARDEN CITY (NEW) LAKE

Elevation (feet)	Area (acres)	Volume (acre-ft)
842.0	0.3	0.2
844.0	2.5	2.9
846.0	5.0	10.5
848.0	7.9	23.4
850.0	12.4	43.7
852.0	16.2	72.6
854.0	20.1	108.8
856.0	23.8	152.7
858.0	27.7	203.7
860.0	33.7	264.7
862.0	39.3	337.7
862.4	40.5	353.7
864.0	48.8	426.1
864.3	49.9	440.9
866.0	57.4	532.0
867.2	63.0	604.2

Table 30. Lake elevations and respective surface areas and volumes. Top of spillway structure is 862.4 feet. Approximate emergency spillway and top of dam elevations are 864.3 feet and 867.2 feet respectively. Elevations referenced to North American Vertical Datum 1988 (NAVD 88).



EXPLANATION

860 BATHYMETRIC CONTOUR—Shows altitude of the reservoir bottom. Contour interval 2 feet.

862 WATER SURFACE—Shows approximate elevation of water surface, April 5, 2004 (actual is 862.4 feet, table 31).

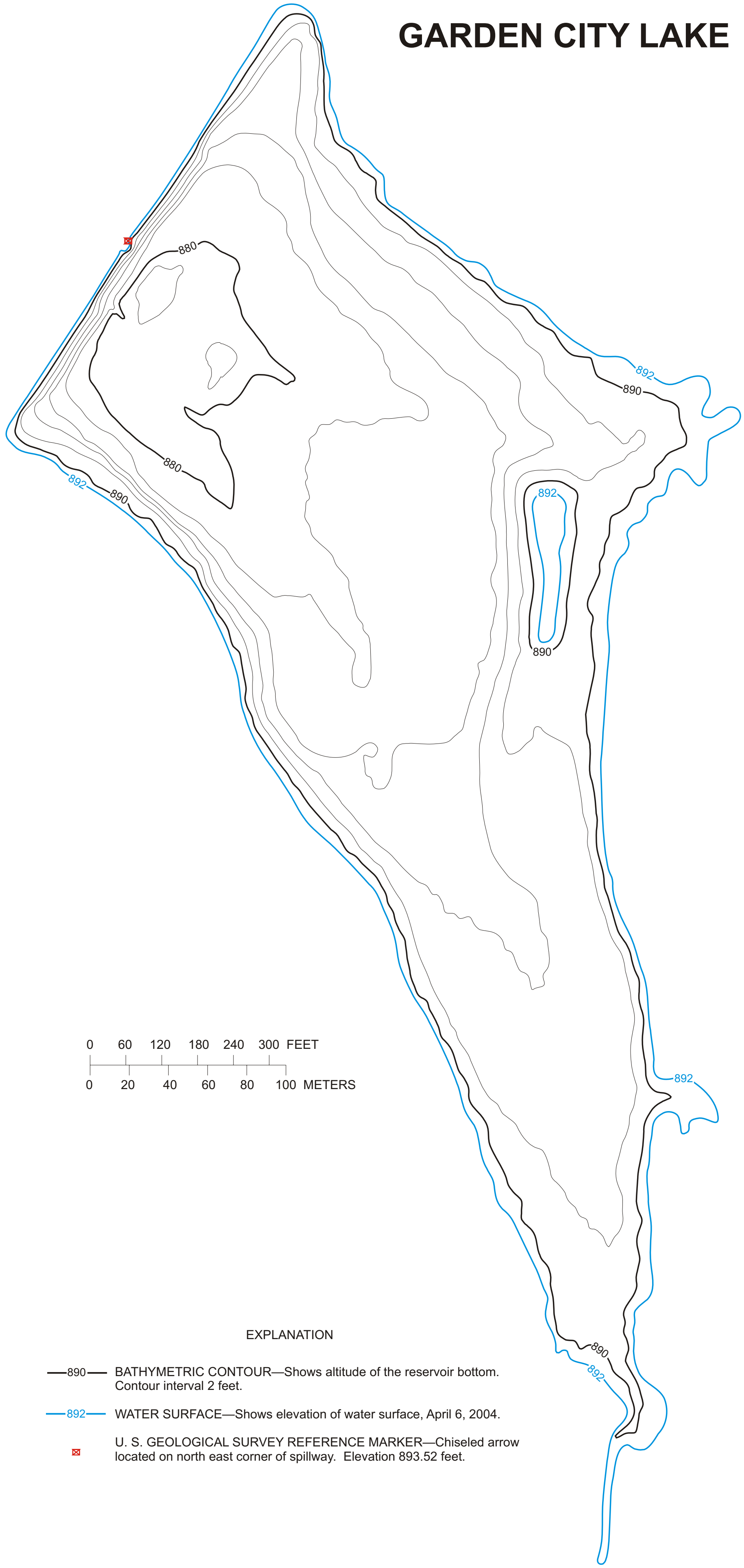
U. S. GEOLOGICAL SURVEY REFERENCE MARKER—Chiseled arrow located on west edge of primary spillway. Elevation 867.4 feet.

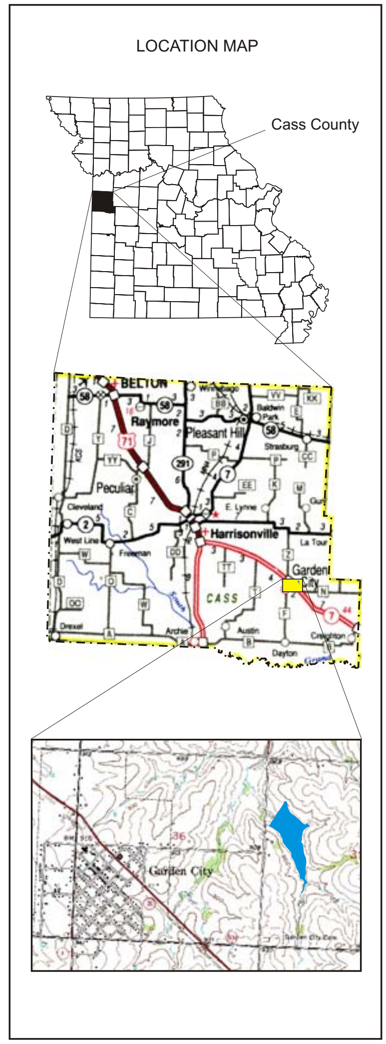
USGS science for a changing world

Figure 30. Bathymetric map and table of areas/volumes of the Garden City (New) Lake near Garden City, Missouri.

In cooperation with Missouri Department of Natural Resources

GARDEN CITY LAKE





Elevation (feet)	Area (acres)	Volume (acre-ft)
878.0	0.15	0.02
880.0	1.7	1.7
882.0	5.1	7.8
884.0	10.2	24.4
886.0	13.6	48.2
888.0	19.3	81.4
890.0	23.4	124.7
892.0	26.1	174.3
892.1	27.1	177.0
893.0	30.4	202.9
894.0	33.5	234.9
895.0	36.8	270.0

Table 29. Lake elevations and respective surface areas and volumes. Top of spillway structure is 892.1 feet. Approximate emergency spillway and top of dam elevations are 893.0 and 895.0 feet respectively. Elevations referenced to North American Vertical Datum 1988 (NAVD 88).

USGS
science for a changing world

Figure 29. Bathymetric map and table of areas/volumes of the Garden City Lake near Garden City, Missouri.

In cooperation with
Missouri Department
of Natural Resources

Green City, Missouri
Water Supply Study
City Lake

Green City is located in the Green Hills Region of Northeast Missouri in Sullivan County. Green City is a rural community serving the agricultural necessities of the surrounding rural community. Green City Reservoir is a source of water supply for Green City, Greencastle and Sullivan Country rural water district. The existing Green City Reservoir was built in 1974, had a drainage area of approximately 871 acres. There are two large private ponds located in this watershed with the total drainage area with 72 acres. The two ponds result in a reduction of the watershed area of the Green City Reservoir of 8.2%. The effective drainage area for reservoir is about 800 acres. A storage capacity was estimated 186 million gallons at normal pool. The nearest weather station is at Milan in Sullivan County, Missouri. The monthly-recorded precipitation from 1952 to 1961 was used for this analysis.

Since there are no pan evaporation data for Green City Reservoir, the closest station with evaporation is at the Spickard, Missouri. However, There are no observed data during winter seasons for Spickard station, the Lakeside station was used for winter pan evaporation values. Pan evaporation data were retrieved for the stations Spickard and Lakeside from National Climatic Data Center. The free water evaporation for the Green City Reservoir was calculated from the pan evaporation and pan to lake coefficients.

There are two spillways for the Green City Reservoir. The drop inlet spillway crest is at elevation 1000 feet. The emergency spillway crest is at 1004 feet. The top of the dam is at 1011 feet. The dam height is about 30 feet. Based upon the model run requirement, the elevation of the drop inlet spillway was set as the upper limit of water elevation in the reservoir.

The NRCS's computer program called "RESOP" was used for the analysis. Following are the data and procedures for input to the program.

For this study, three scenarios were evaluated.

1) Normal demand: Water demand information was obtained from Drinking Water Program, Northeast Regional Office, DNR. The long term averaged water demand of 182,500 gallons per day was used. The reservoir storage lower limit for this run is set to 6.52 acre-feet which is at water intake level:
2) The same as Scenario 1 except the low limit was set to 50 ac-ft at elevation 989 ft.
3) The starting storage was 438 ac-ft at elevation 1000 ft in Jan. 52. The lower limit was 50 acre feet at elevation 989 ft. The demand was 182,500 gallons per day for the period January 1952 to December 1954. The demand was decreased to 90,000 gallons per day for the period January 1955 to December 1960.
4) The starting storage was 98.7 ac-ft at elevation 991 ft, September 1954. The demand was 200,000 gallons per day for the period September 1954 to December 1954. The demand was decreased to 90,000 from January 1955. The lower limit was 14.3 ac-ft at elevation 985 feet.

Following is the data and procedures for input to the "RESOP" program.

STO-AREA Elevation-Storage and Elevation-Area data were determined from July 6, 2000 surveys of both lakes made by USGS.

Elevation (feet)	Area (acres)	Volume (acre-ft)
982.0	1.5	0.6
984.0	4.2	6.5
986.0	8.3	18.8
988.0	13.2	40.3
990.0	19.9	73.2

992.0	27.2	120.5	
994.0	32.0	179.6	
995.0	35.3	213.2	Water Surface on 7/6/2000
996.0	38.7	250.1	
998.0	46.3	334.8	
1,000.0	57.7	437.9	
1,002.0	66.2	561.9	
1,004.0	76.0	704.1	Spillway Elevation

LIMITS For Starting storage see above elevation discussion..
Minimum Pool storage 14.3 Ac.Ft. .
Drainage Area 1.36 Sq.Mi.

Starting storage was considered at full pool elevation.

GENERAL The adjustment to convert from pan evaporation to lake evaporation was made for the control word EVAP. The factors were monthly values. As a result a factor of 100.0 was used here.

The record period of drought is in the 1950's.
Analysis began in January 1951 and ended December 1959.

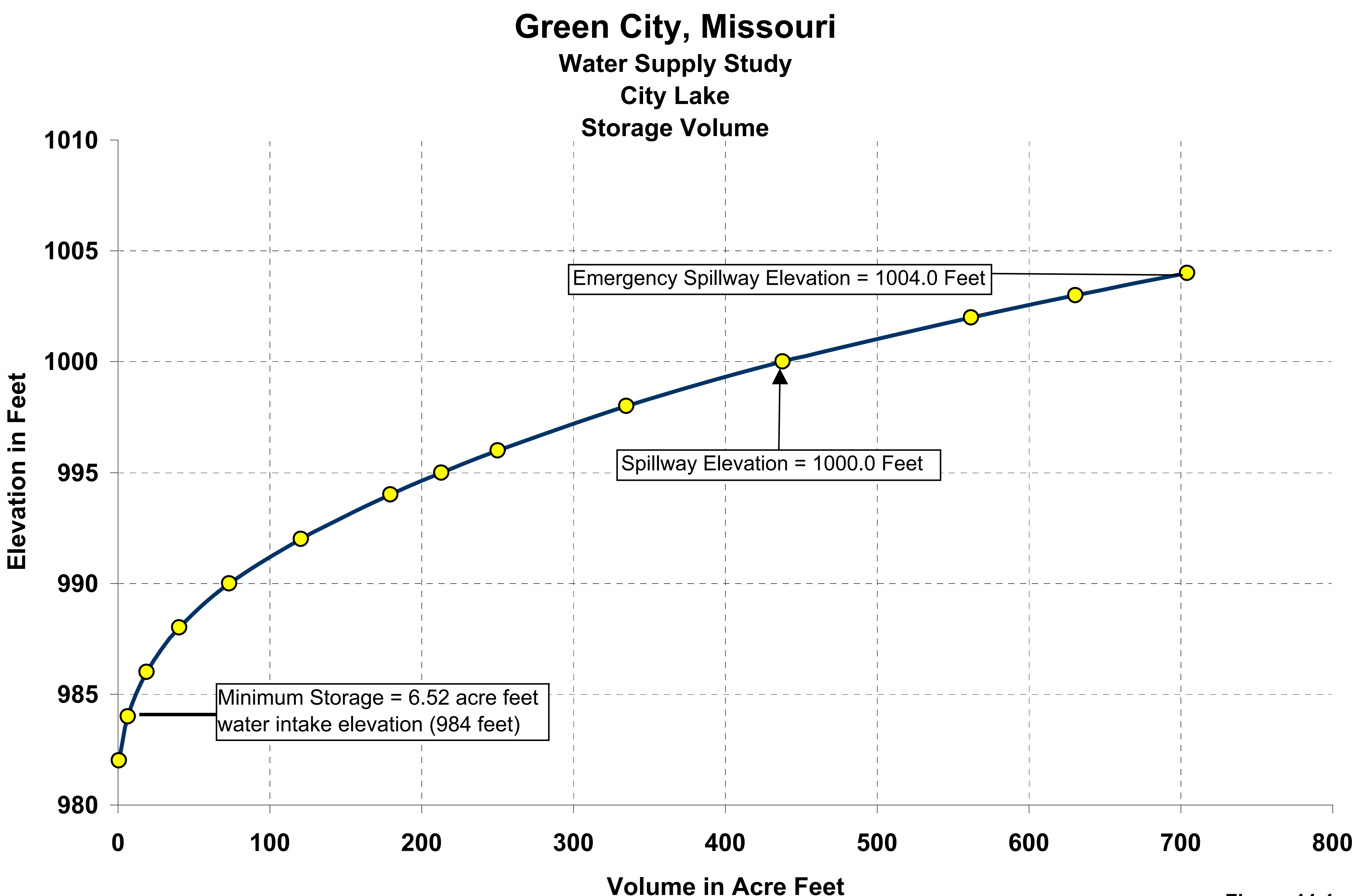
SEEPAGE The reservoir seepage varied from 0 seepage near empty to a maximum of 1 inch per month when at full pool. The material in the dam is compacted earth of clayey soils. The lake is shallow so that static pressure is low. As a result seepage is small.

RAINFALL Rain gage at Milan for the period 1952 through 1960 is used.

RUNOFF This is the runoff into the lake from its drainage area. Monthly runoff volumes in watershed inches were determined at the Locust Creek stream gage at Linneus in Linn County, Missouri. The drainage area is 550.0 square miles.

EVAP. Pan evaporation at the Lakeside gaging station were used as a base because it has data for year around evaporation. This data was updated with gage data from stations at Spickard. The long-term average data were used when there are no data available from both stations. The monthly adjustment factors to convert from Pan to Lake evaporation was applied at this step.

DEMAND Determined from city records. Green City has a daily use of 182,500 Gallon per Day. Four scenarios mentioned above are examined in this study.



Green City, Missouri
Water Supply Study
City Lake
Storage Volume
Emergency Spillway Elevation = 1004.0 Feet
Spillway Elevation = 1000.0 Feet
Minimum Storage = 6.52 acre feet
water intake elevation (984 feet)
Elevation in Feet
Volume in Acre Feet
1010
1005
1000
995
990
985
980
0
100
200
300
400
500
600
700
800

Figure 11.1.a

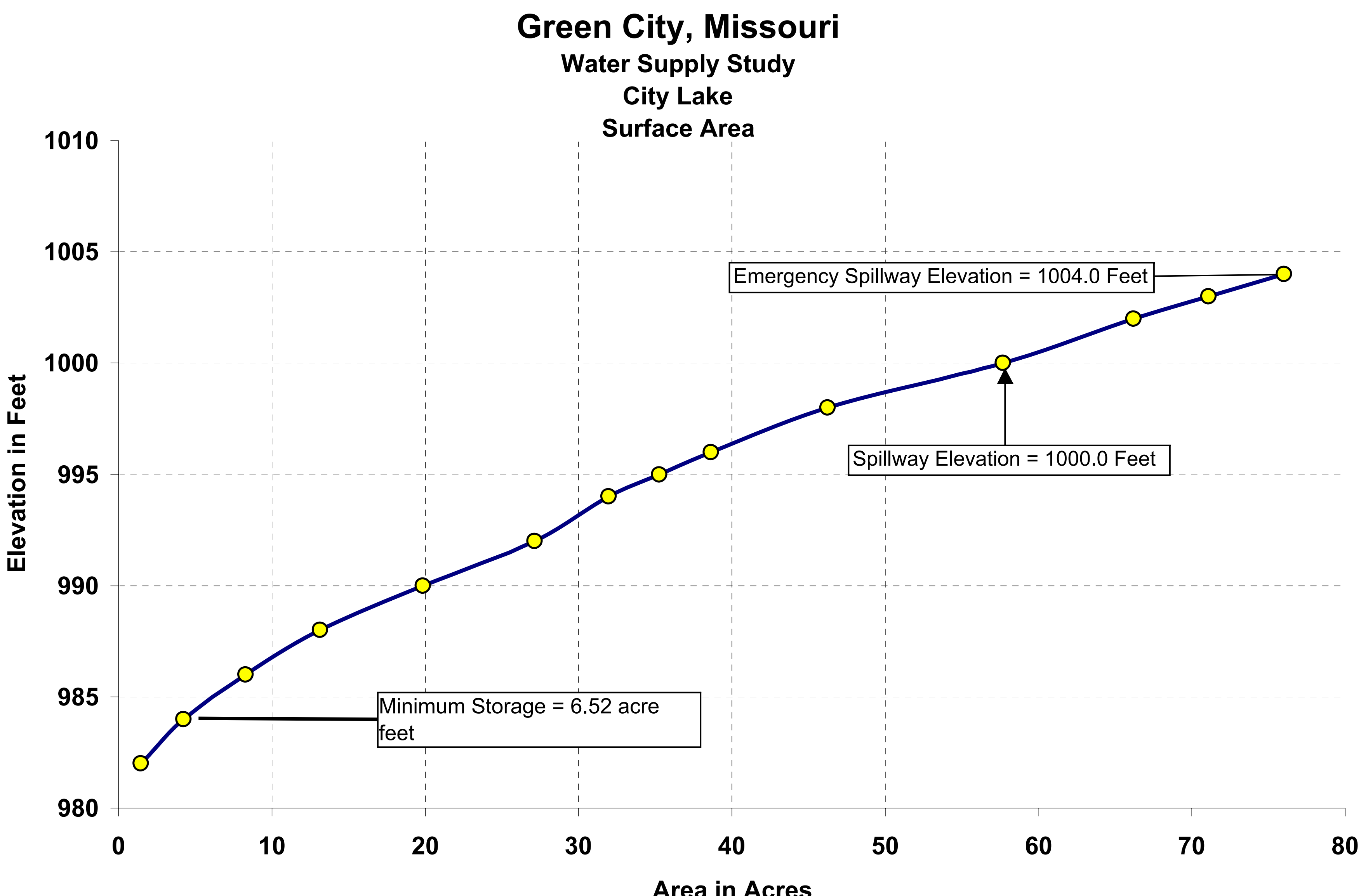

Green City, Missouri
Water Supply Study
City Lake
Surface Area
Elevation in Feet
1010
1005
1000
995
990
985
980
0
10
20
30
40
50
60
70
80
Area in Acres
Emergency Spillway Elevation = 1004.0 Feet
Spillway Elevation = 1000.0 Feet
Minimum Storage = 6.52 acre feet

Figure 11.1.b

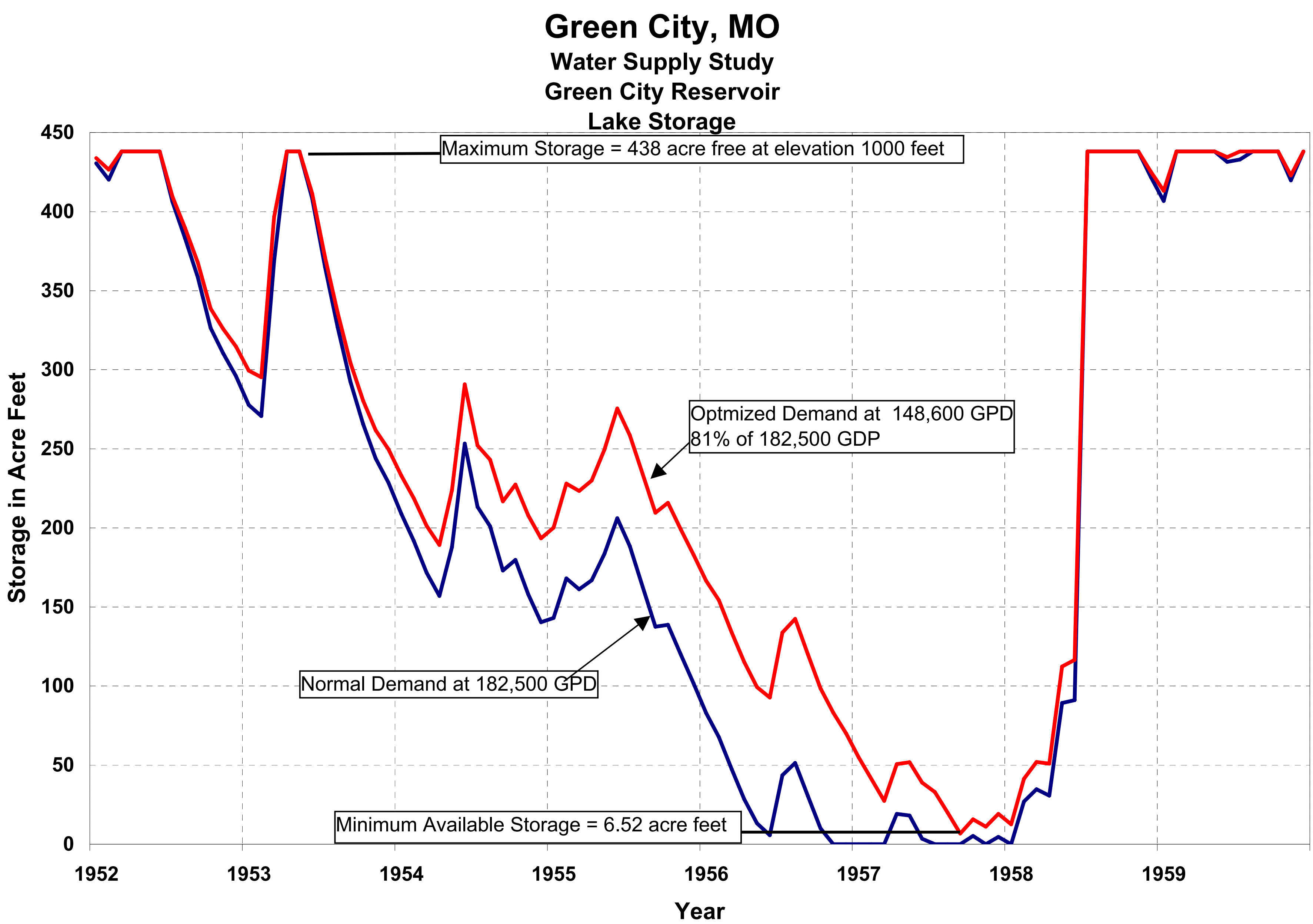

Green City, MO
Water Supply Study
Green City Reservoir
Lake Storage
Maximum Storage = 438 acre free at elevation 1000 feet
Optmized Demand at 148,600 GPD
81% of 182,500 GDP
Normal Demand at 182,500 GPD
Minimum Available Storage = 6.52 acre feet
Storage in Acre Feet
450
400
350
300
250
200
150
100
50
0
1952
1953
1954
1955
1956
1957
1958
1959
Year

Figure 11.2.a

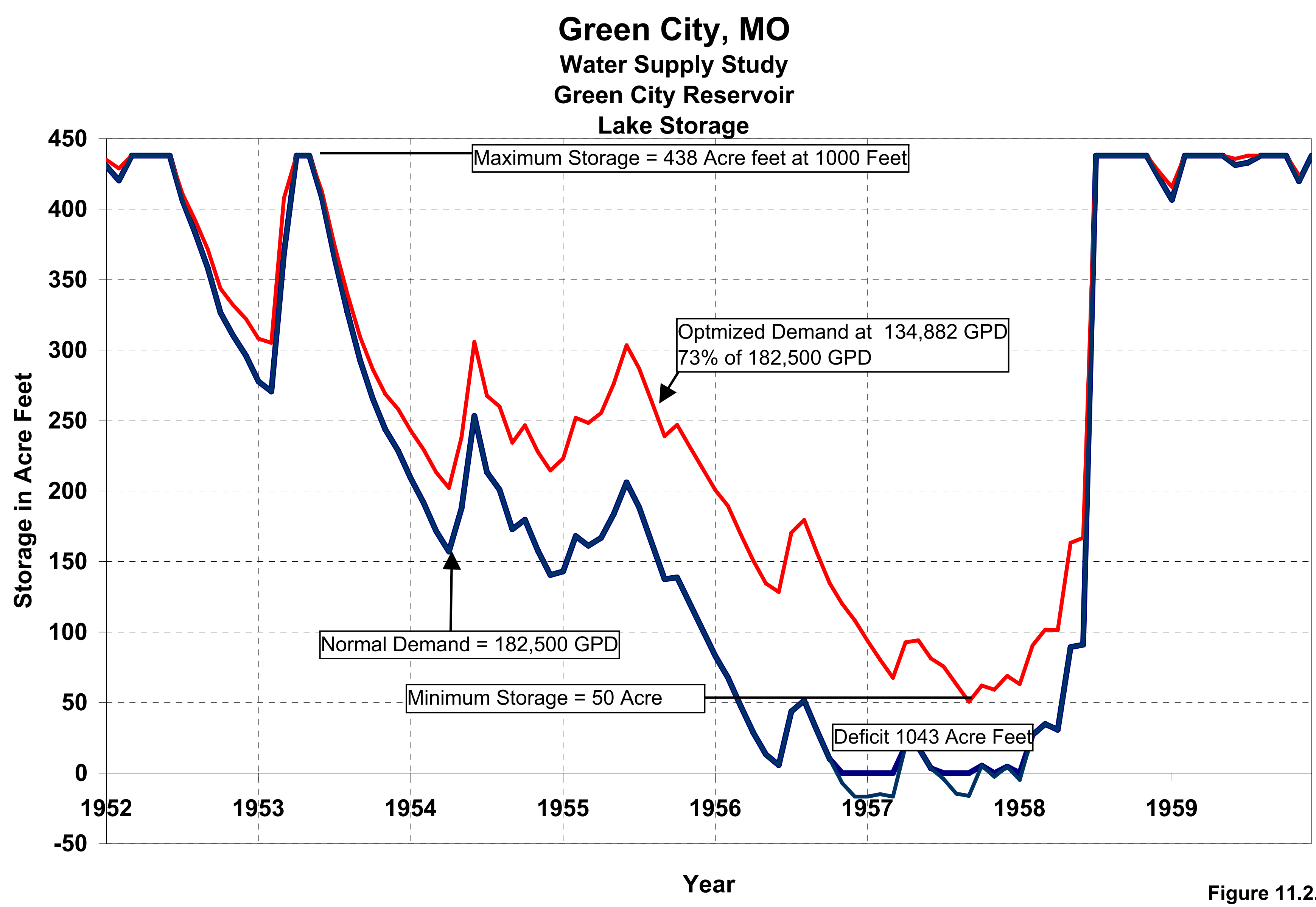

Green City, MO
Water Supply Study
Green City Reservoir
Lake Storage
Storage in Acre Feet
450
400
350
300
250
200
150
100
50
0
-50
1952
1953
1954
1955
1956
1957
1958
1959
Year
Maximum Storage = 438 Acre feet at 1000 Feet
Optmized Demand at 134,882 GPD
73% of 182,500 GPD
Normal Demand = 182,500 GPD
Minimum Storage = 50 Acre
Deficit 1043 Acre Feet

Figure 11.2.b

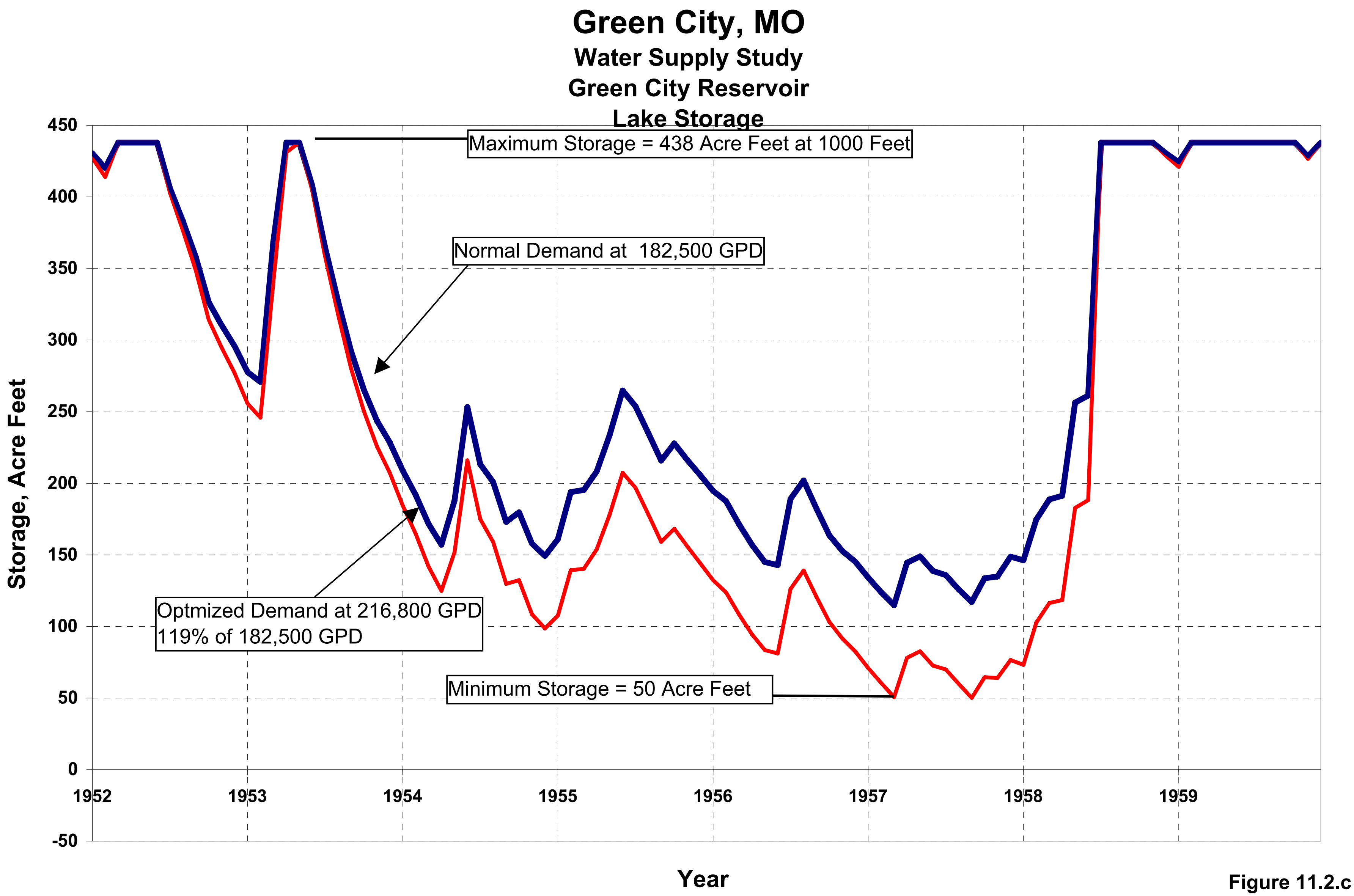
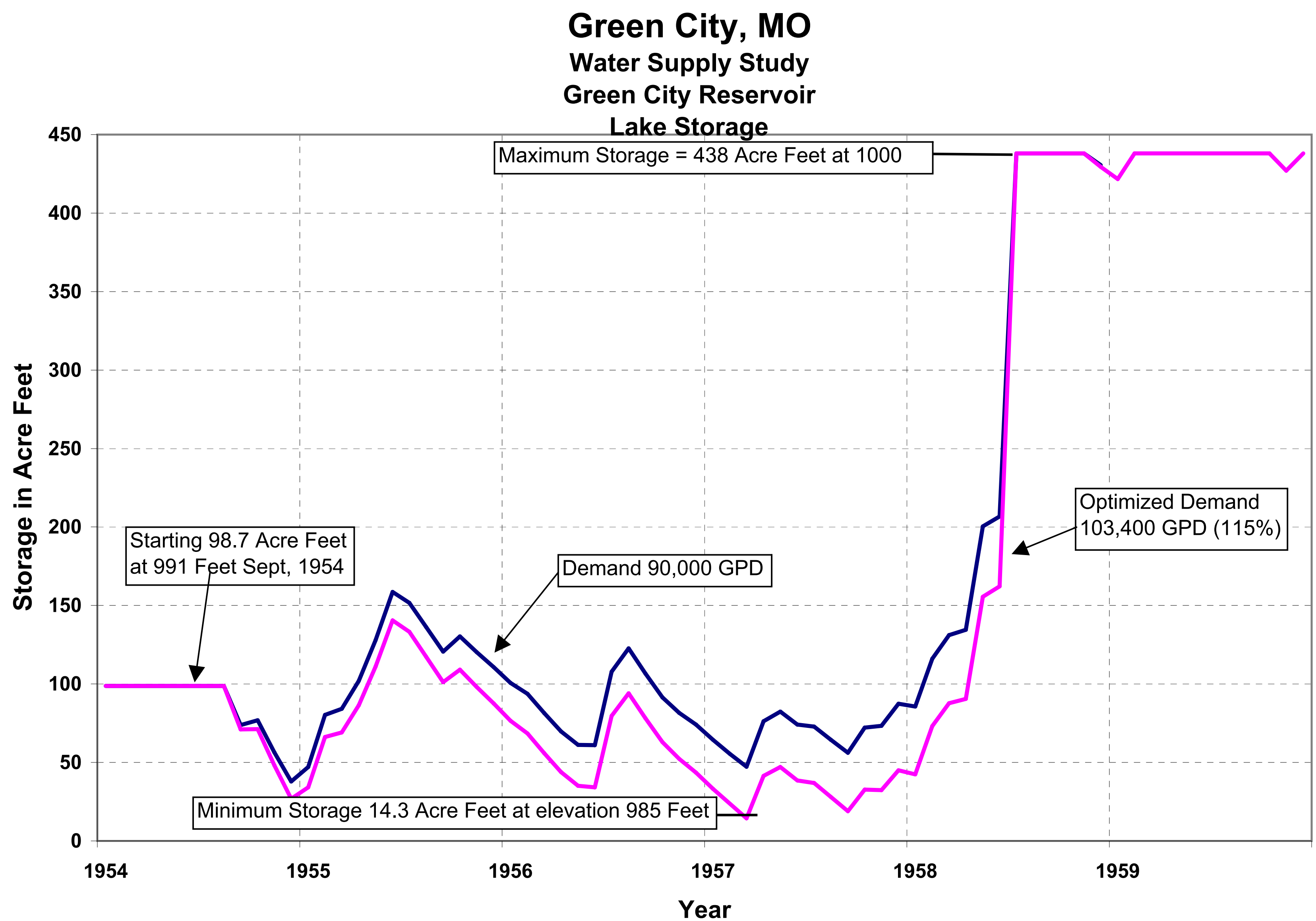

Green City, MO
Water Supply Study
Green City Reservoir
Lake Storage
Maximum Storage = 438 Acre Feet at 1000 Feet
Normal Demand at 182,500 GPD
Optmized Demand at 216,800 GPD
119% of 182,500 GPD
Minimum Storage = 50 Acre Feet
Storage, Acre Feet
450
400
350
300
250
200
150
100
50
0
-50
1952
1953
1954
1955
1956
1957
1958
1959
Year

Figure 11.2.c



Green City, MO
Water Supply Study
Green City Reservoir
Lake Storage
Storage in Acre Feet
450
400
350
300
250
200
150
100
50
0
1954
1955
1956
1957
1958
1959
Year
Maximum Storage = 438 Acre Feet at 1000
Starting 98.7 Acre Feet
at 991 Feet Sept, 1954
Demand 90,000 GPD
Optimized Demand
103,400 GPD (115%)
Minimum Storage 14.3 Acre Feet at elevation 985 Feet

Figure 11.2.d

Green City, Missouri

Water Supply Study

Water Use

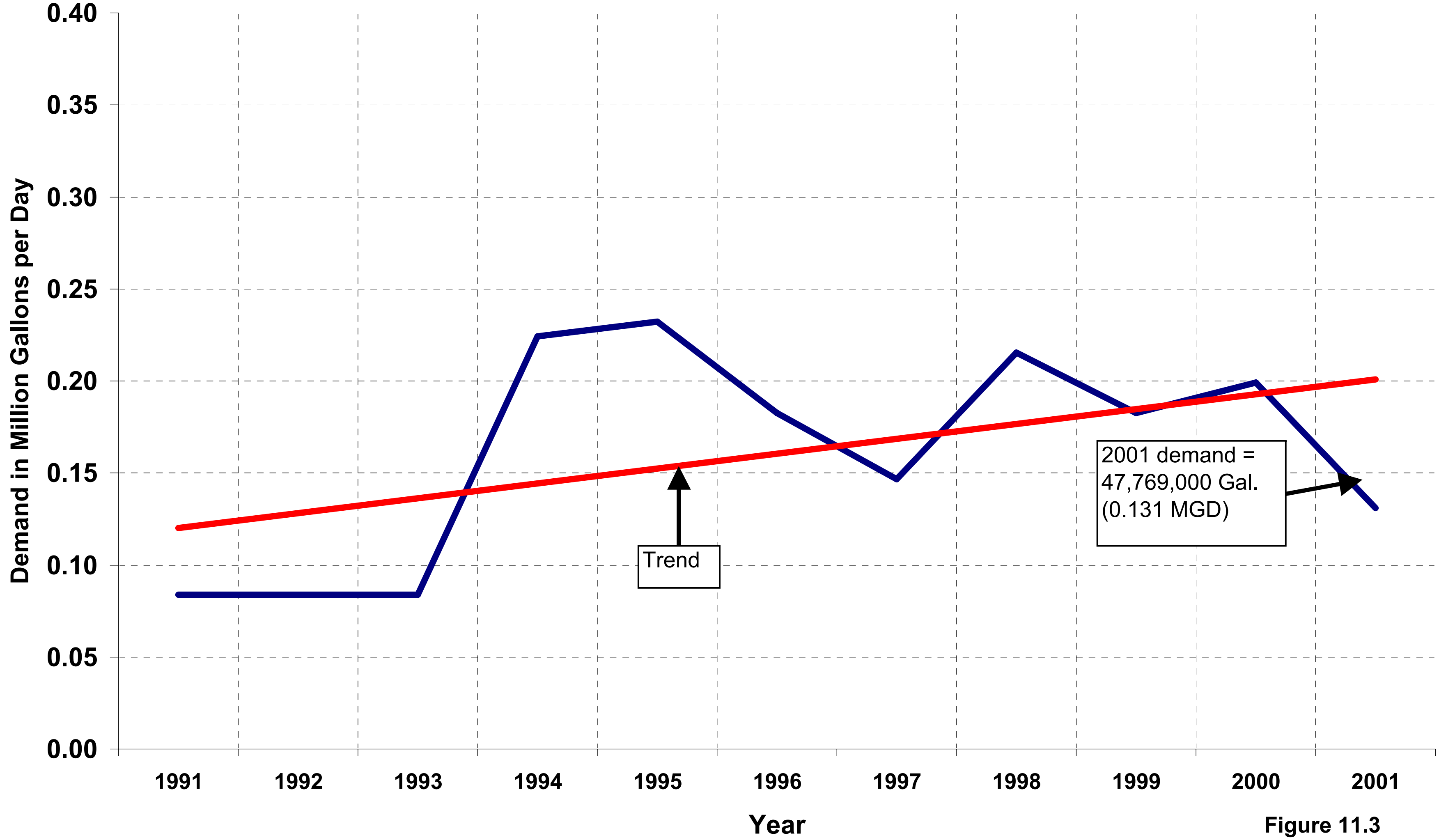
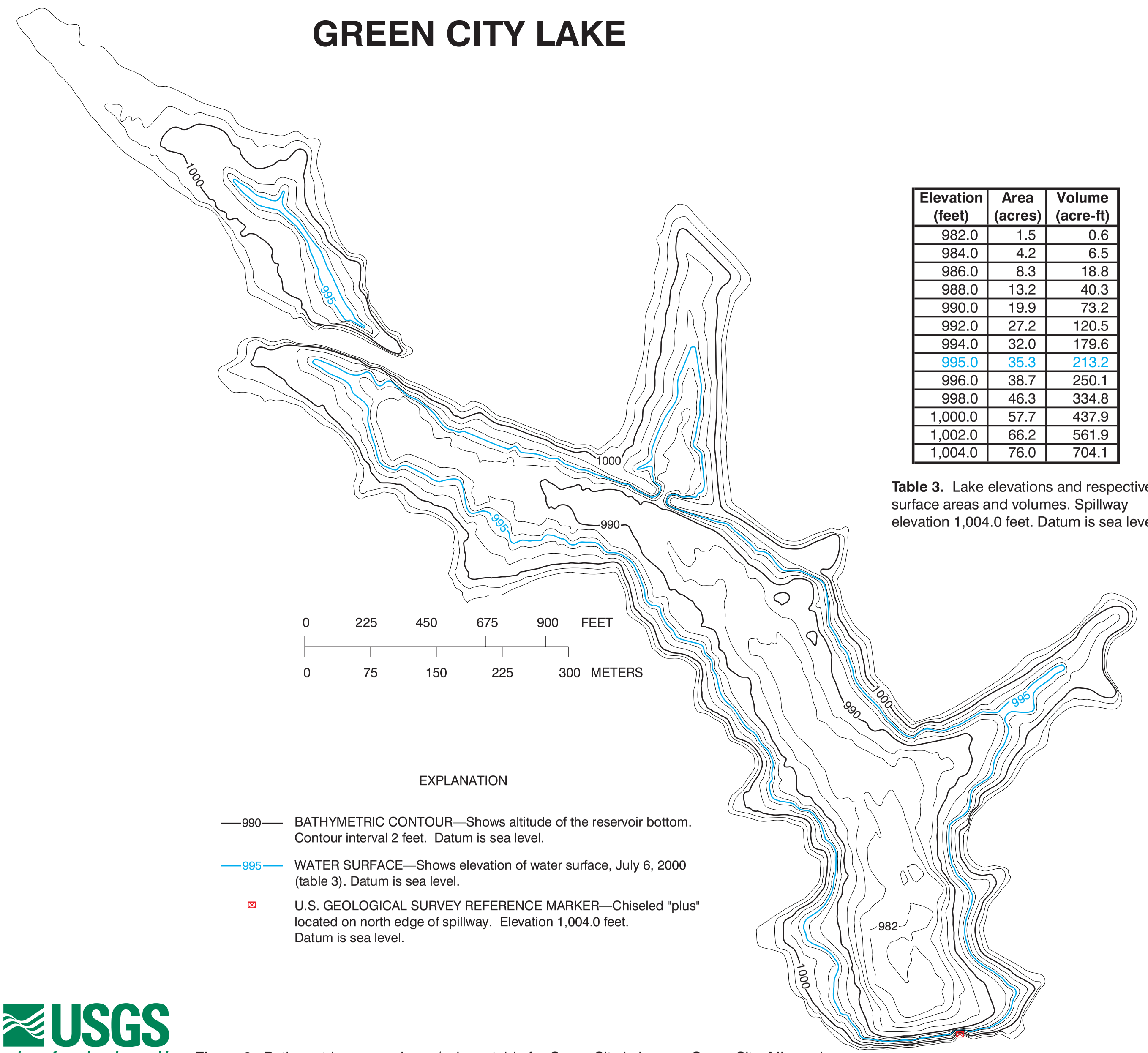


Figure 11.3

GREEN CITY LAKE



Elevation (feet)	Area (acres)	Volume (acre-ft)
982.0	1.5	0.6
984.0	4.2	6.5
986.0	8.3	18.8
988.0	13.2	40.3
990.0	19.9	73.2
992.0	27.2	120.5
994.0	32.0	179.6
995.0	35.3	213.2
996.0	38.7	250.1
998.0	46.3	334.8
1,000.0	57.7	437.9
1,002.0	66.2	561.9
1,004.0	76.0	704.1

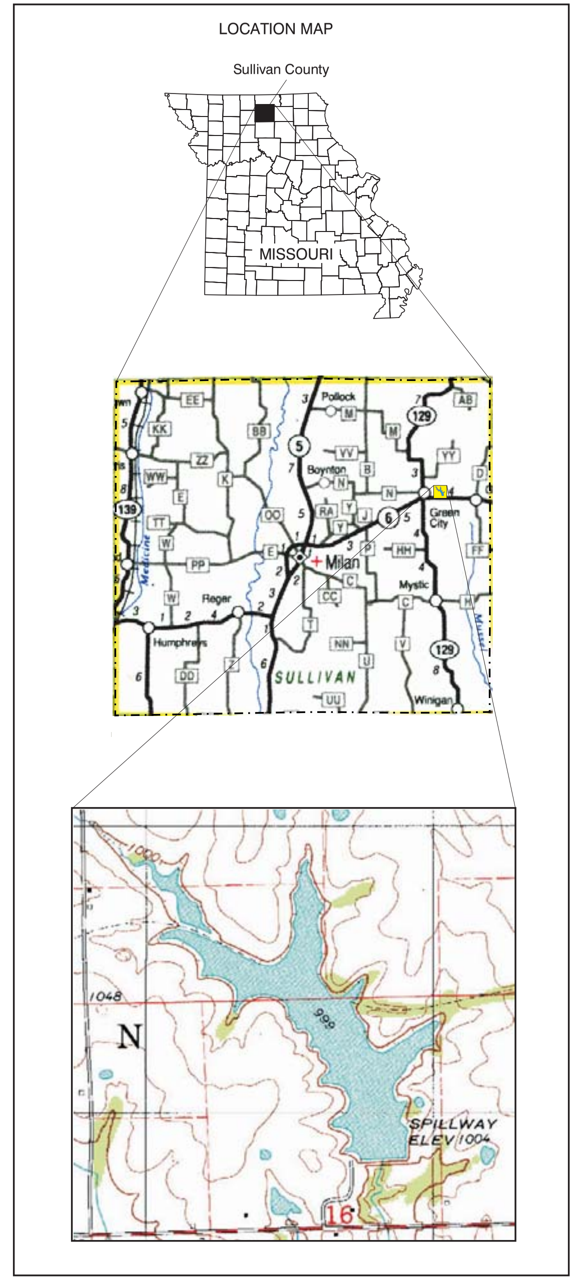
Table 3. Lake elevations and respective surface areas and volumes. Spillway elevation 1,004.0 feet. Datum is sea level.

EXPLANATION

—990— BATHYMETRIC CONTOUR—Shows altitude of the reservoir bottom. Contour interval 2 feet. Datum is sea level.

—995— WATER SURFACE—Shows elevation of water surface, July 6, 2000 (table 3). Datum is sea level.

⊠ U.S. GEOLOGICAL SURVEY REFERENCE MARKER—Chiseled "plus" located on north edge of spillway. Elevation 1,004.0 feet. Datum is sea level.



USGS
science for a changing world

Figure 3. Bathymetric map and area/volume table for Green City Lake near Green City, Missouri.

Hamilton, Missouri
Water Supply Study
City Lake

Hamilton is located in North Central Caldwell County. Their water supply comes from a city owned lake located approximately 2 miles West of Hamilton. The lake is not large enough, both in drainage area and capacity, to meet the demand during extended periods of dry weather. The drainage area of the lake is 1142 acres (1.78 Sq. Mi.). The city has installed a pump to pump water from Marrowbone Creek to the lake. The drainage area at point of intake is 38.2 square miles. The pump is rated at 1000 gallon per minute and can only pump when flow in the creek is sufficient to allow pumping.

Hamilton currently uses 260,000 gallon of water per day. At the time of this study rural water district #1 was planning obtain their water from Hamilton.

The optimized demand for this lake without pumping from Marrowbone Creek is 190,240 gallon per day.

Hamilton Lake analysis consisted of using the NRCS's computer program called "RESOP". Following is the data and procedures for input to the program.

STO-AREA Elevation-Storage and Elevation-Area data were determined from July 11, 2000 survey made by USGS.

Hamilton Lake

Elevation (feet)	Area (acres)	Storage (ac-ft)	
901	0.42	0.14	
903	4.37	4.47	
905	10.98	19.35	
907	17.18	46.95	
909	23.41	86.83	
911	29.35	139.49	
913	39.17	207.91	
915	48.36	295.03	
917	61.39	404.06	
919	73.65	539.65	
921	82.09	695.49	
921.6	84.77	745.49	Water Surface on 7/11/2000
923	90.50	868.80	
923.3	91.48	896.09	Spillway Elev.

Spillway Elev. = 923.3 Feet mean sea level - Plans show assumed elev. 113.
Intake Elev. = 917.3 Feet mean sea level - Plans show assumed elev. 107.

LIMITS Max. Pool storage 896 Ac.Ft.
Minimum Pool storage 405 Ac.Ft.

This was later changed by a letter from Breck Summerford on 8/9/2000. Lowered to elevation 905.0 feet. This seemed low so it was raised 2 feet to 47 Ac.Ft. storage.

Starting storage was considered at maximum pool.

The elevation difference between the spillway and intake is only 6 feet. The intake is at elevation of 917.3. The lower limit for the analysis was set at elevation 907.

GENERAL The adjustment to convert from pan evaporation to lake evaporation was made for the control word EVAP. The factor was 0.76. As a result a factor of 100.0 was used here.

The record period of drought is in the 1950's.
Analysis began in January 1951 and ended December 1959.

SEEPAGE The reservoir seepage varied from 0 seepage near empty to a maximum of 1 inch per month when at full pool. The material in the dam is compacted earth of clayey soils. The lake is shallow so that static pressure is low. As a result seepage is small.

RAINFALL Rainfall data came from the Gallatin, Mo. rain gage for the period 1951 through May 1954. Then records were kept for Hamilton and were used for the period June 1954 through 1959. Gallatin is located 14 miles north of Hamilton.

RUNOFF This is the runoff into the lake from its drainage area. Monthly runoff volumes in watershed inches were determined at the Jenkins Branch stream gage, a tributary to Platte River. The drainage area is 2.72 square miles. Jenkins Br. gage is located approximately 30 miles WSW from Hamilton. This monthly runoff was compared to the rainfall and if the results did not appear reasonable, adjustments were made for that month by looking at individual rains and estimating antecedent moisture, then adjusting runoff based on NRCS's runoff curve numbers.

EVAP. Pan evaporation at the Lakeside gaging station was used as a base because it has data for year around evaporation. This data was updated with gage data from stations at Spickard, New Franklin, and Columbia. Depending on the latest data for the station nearest to Hamilton. The adjustment factor of 0.76 to convert from Pan to Lake evaporation was applied at this step.

DEMAND This was determined by city records. Hamilton has a daily use of 180,000 Gallon per Day. Also Water district #1 plans to purchase 80,000 GPD of water from Hamilton. The total use will be 260,000 gallon per day.

OTHER This refers to the volume of water pumped from Marrowbone Creek into Hamilton Reservoir.

Determination of the volume of water available for pumping was made using daily discharges at the Crooked River stream gage near Richmond. The Crooked River gage is about 26 miles South of Hamilton. The drainage area is 159 Square Miles and the drainage area at the point of pumping on Marrowbone Creek is 24,455 acres (38.2 square miles).

Daily discharge rates for Crooked River were reduced by a ratio of 38/159 to determine potential pumping rates. Pumping was only planned for flows above 2 cubic feet per second. This was determined from agreements on Locust Creek. Pumping on Locust Creek began at 10 cubic feet per second for 225 square miles drainage area. This is 10/225=0.044 cubic feet per second per square miles drainage area. 38.2 square miles times 0.044 = 1.7 cubic feet per second rounded up to 2 cfs.

The maximum rate of pumping was 1000 gallon per minute or 2.23 cfs.

Some months had pumping reduced from the maximum available because the reservoir filled and there was flow through the spillway.

Hamilton, Missouri

Water Supply Study

City Lake

Storage Volume

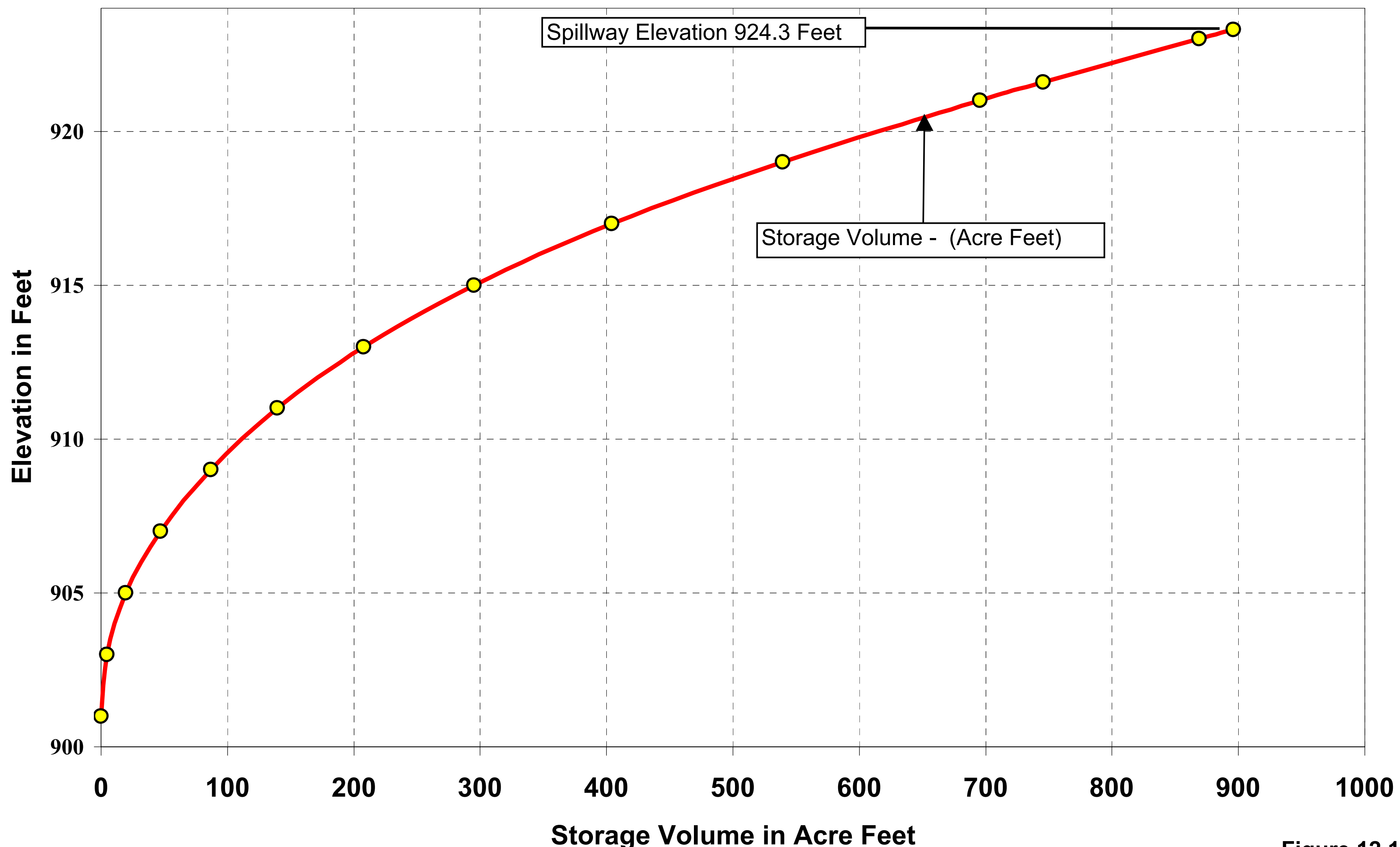


Figure 12.1.a

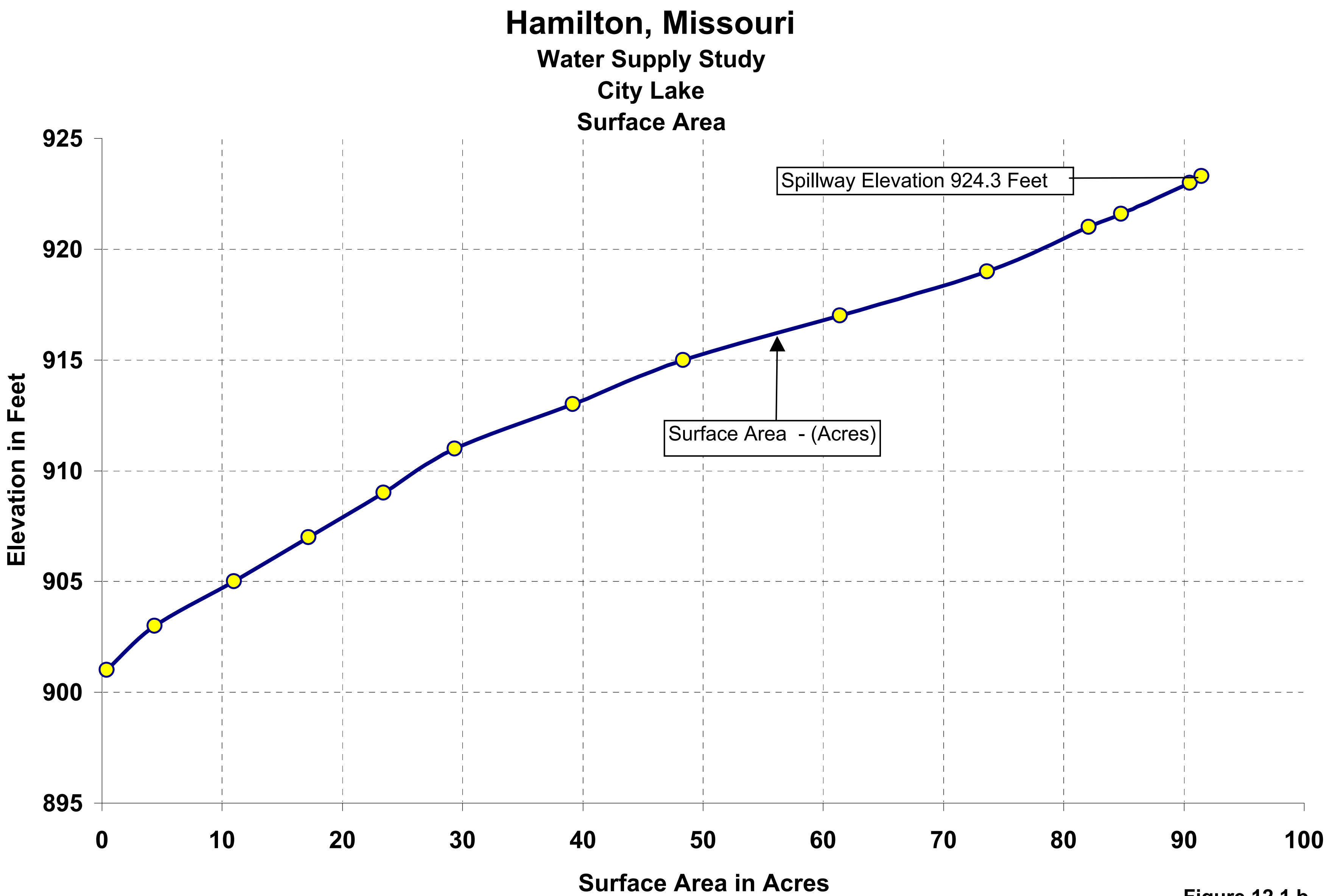

Hamilton, Missouri
Water Supply Study
City Lake
Surface Area
925
920
915
910
905
900
895
Elevation in Feet
0
10
20
30
40
50
60
70
80
90
100
Surface Area in Acres
Spillway Elevation 924.3 Feet
Surface Area - (Acres)

Figure 12.1.b

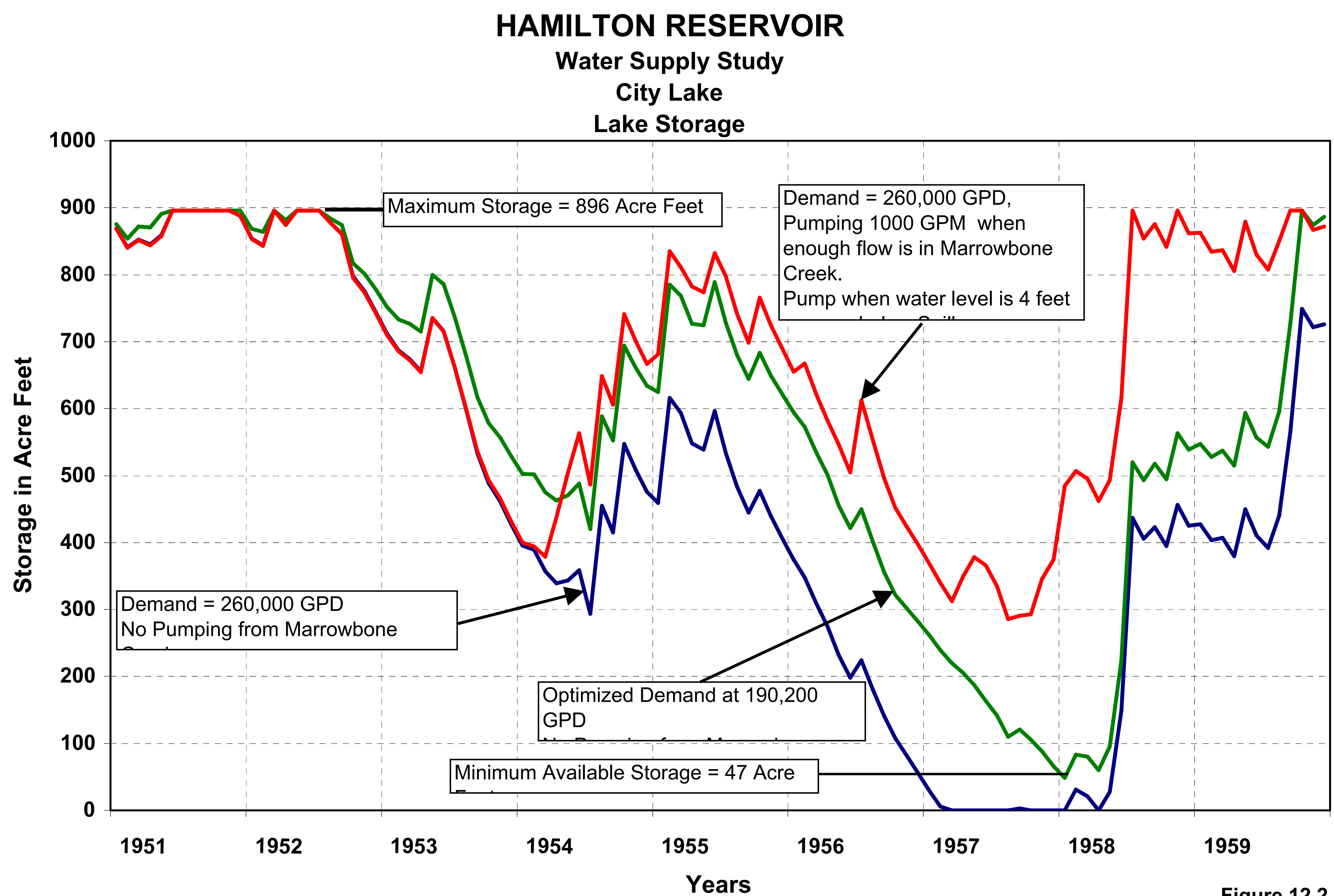
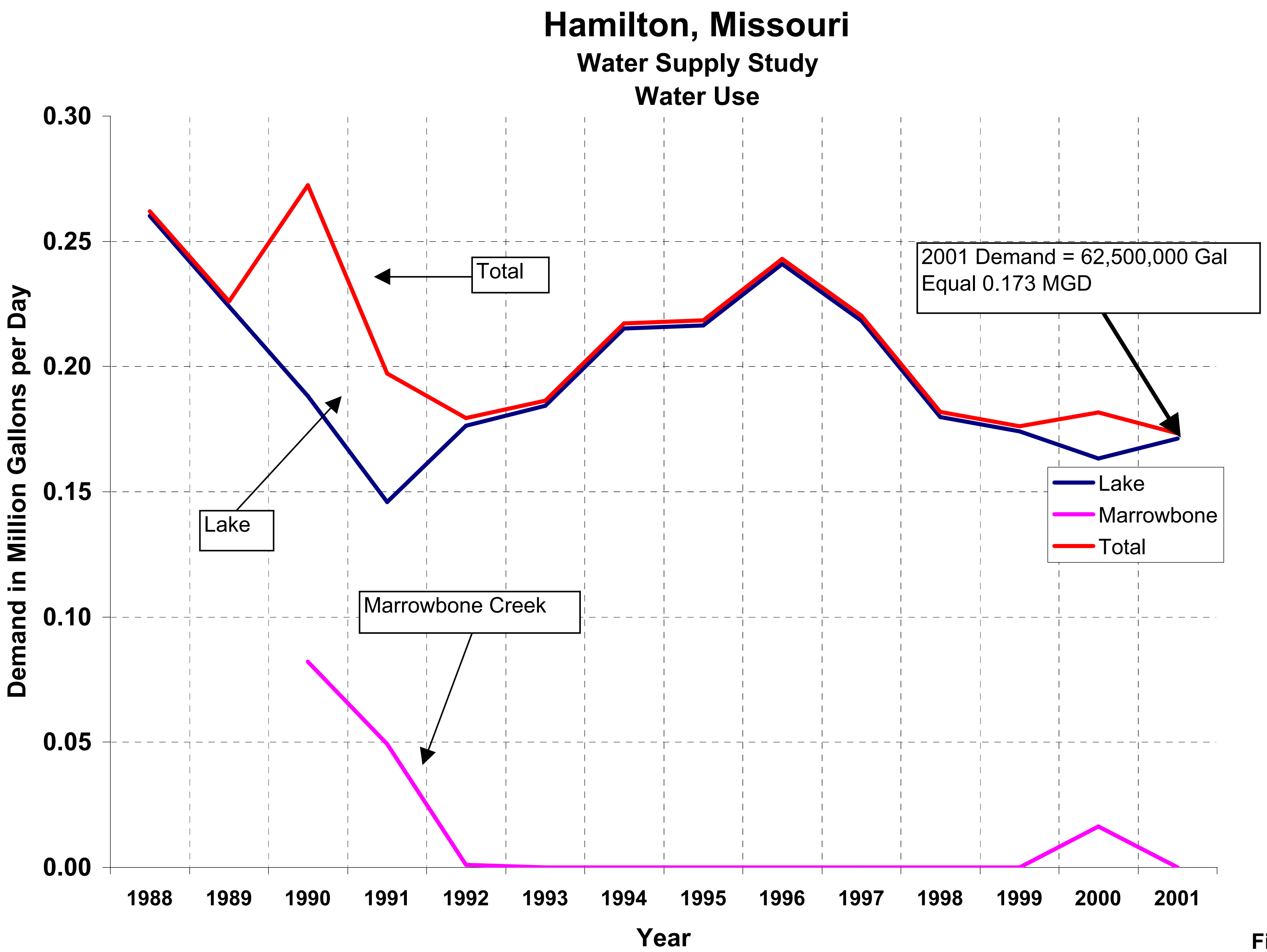

HAMILTON RESERVOIR
Water Supply Study
City Lake
Lake Storage
Storage in Acre Feet
1000
900
800
700
600
500
400
300
200
100
0
1951
1952
1953
1954
1955
1956
1957
1958
1959
Years
Maximum Storage = 896 Acre Feet
Demand = 260,000 GPD, Pumping 1000 GPM when enough flow is in Marrowbone Creek. Pump when water level is 4 feet
Demand = 260,000 GPD No Pumping from Marrowbone
Optimized Demand at 190,200 GPD
Minimum Available Storage = 47 Acre

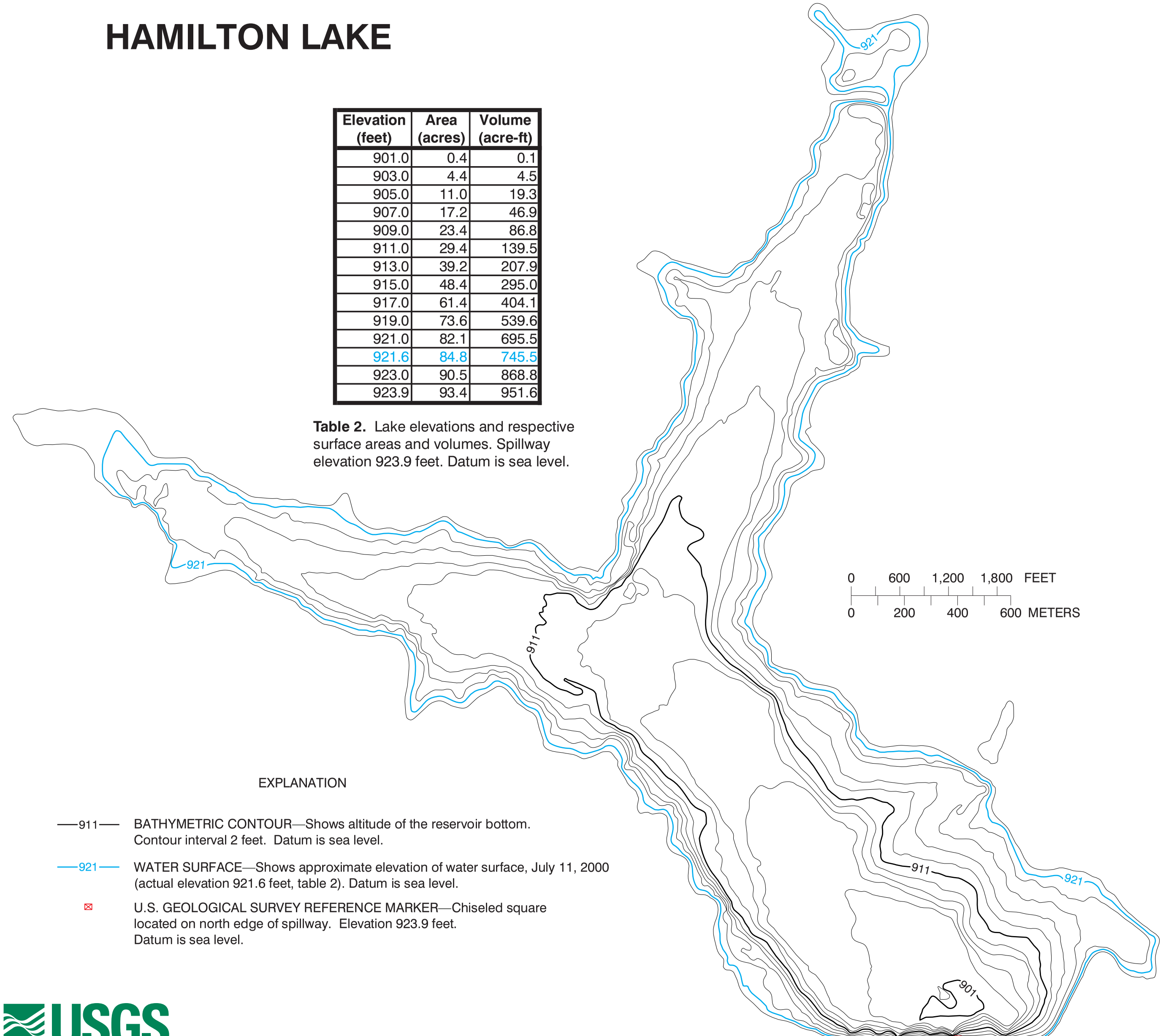
Figure 12.2



Hamilton, Missouri
Water Supply Study
Water Use
Demand in Million Gallons per Day
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Total
Lake
Marrowbone Creek
2001 Demand = 62,500,000 Gal
Equal 0.173 MGD
Lake
Marrowbone
Total
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
Year

Figure 12.3

HAMILTON LAKE



Elevation (feet)	Area (acres)	Volume (acre-ft)
901.0	0.4	0.1
903.0	4.4	4.5
905.0	11.0	19.3
907.0	17.2	46.9
909.0	23.4	86.8
911.0	29.4	139.5
913.0	39.2	207.9
915.0	48.4	295.0
917.0	61.4	404.1
919.0	73.6	539.6
921.0	82.1	695.5
921.6	84.8	745.5
923.0	90.5	868.8
923.9	93.4	951.6

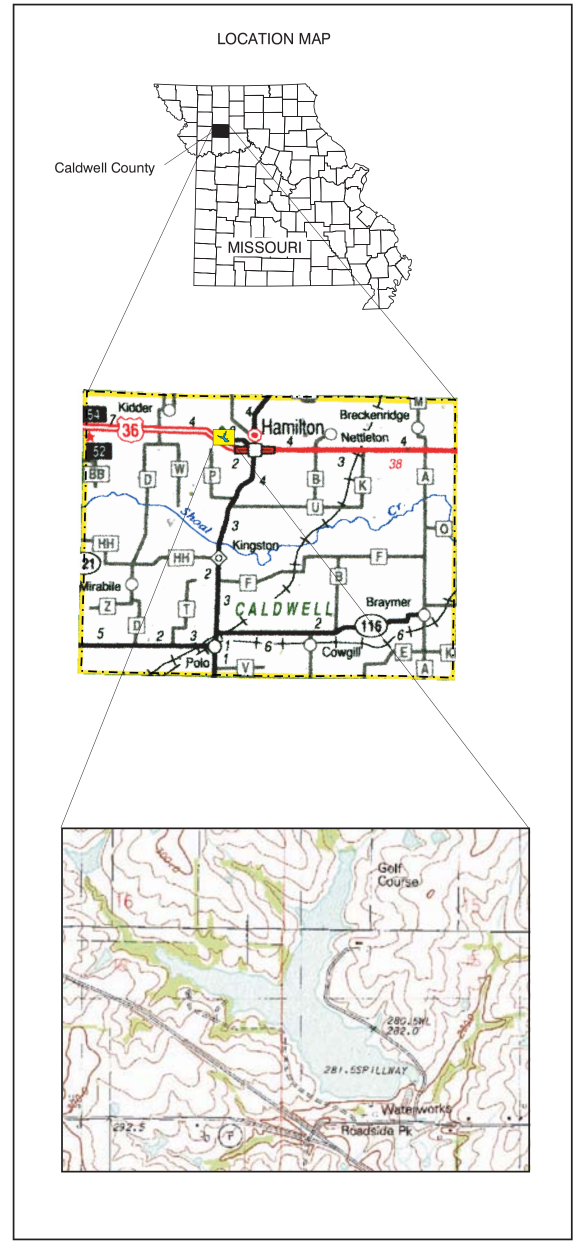
Table 2. Lake elevations and respective surface areas and volumes. Spillway elevation 923.9 feet. Datum is sea level.

EXPLANATION

—911— BATHYMETRIC CONTOUR—Shows altitude of the reservoir bottom. Contour interval 2 feet. Datum is sea level.

—921— WATER SURFACE—Shows approximate elevation of water surface, July 11, 2000 (actual elevation 921.6 feet, table 2). Datum is sea level.

⊠ U.S. GEOLOGICAL SURVEY REFERENCE MARKER—Chiseled square located on north edge of spillway. Elevation 923.9 feet. Datum is sea level.

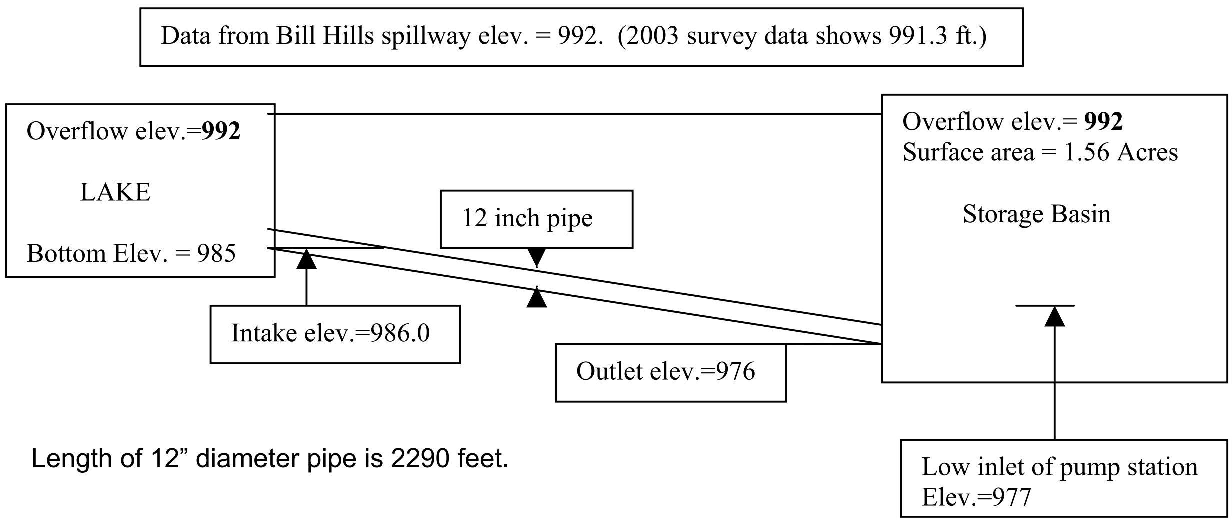


USGS science for a changing world

Figure 2. Bathymetric map and area/volume table for Hamilton Lake near Hamilton, Missouri.

Eagleville, Missouri
Harrison County PWSD #1
Water Supply Study

Eagleville Lake supplies water for Harrison County PWSD #1. This lake was built as part of the East Fork Big Creek PL-566 watershed project. It does not have planned water supply as part of the design of the lake. Water is drawn from the sediment pool. At the time of construction the city elected not to include municipal water supply but requested use of the water in the sediment pool. As a result the lake is very shallow. Because the lake is shallow, evaporation can be a problem. A holding basin for additional storage has been constructed just downstream of the lake. There is a 12-inch diameter pipe connecting the lake and the basin. The overflow elevation for the basin is the same elevation as the spillway of the lake. As a result the pipe connecting the two water bodies serves as an equalization medium so that the water level is the same for each reservoir. The following shows the elevations and configuration of the water supply system.



Length of 12" diameter pipe is 2290 feet.

The existing demand in year 2000 was 86,000 gallon per day.
Optimized demand from the lake without the downstream storage basin is 43,615 gallon per day and the optimized demand from the lake in combination with the downstream storage basin is 87,000 gallon per day.

Lake analysis consisted of using the NRCS's computer program called "RESOP". Following is the data and procedures for input to the program.

STO-AREA Elevation-Storage and Elevation-Area data for the lake were determined from July 11, 2003 survey made by USGS. The storage in the basin was estimated based on a surface area of 1.56 acres and a depth of 16 feet. The values for the basin were determined by

adding the lake and basin together. Following is the results of the lake survey.

Harrison County PWSD #1
Eagleville Lake

Elevation (feet)	Area (acres)	Storage (ac-ft)
985.0	3.4	1.0
986.0	7.9	6.8

987.0	11.4	16.4
988.0	15.3	29.8
989.0	20.7	47.4 Water Surface on 5/28/2003
990.0	25.7	70.7
991.0	27.7	97.6
991.3	28.2	111.6 Spillway Elevation

To treat the lake and basin as one reservoir the following table was used.

	Lake plus Basin	
Elevation (feet)	Area (acres)	Storage (ac-ft)
973	0.0	0.0
974	1.56	0.8
976	1.56	3.9
978	1.56	7.1
980	1.56	10.2
982	1.56	13.3
984	1.56	16.5
985	5.0	19.1
986	9.5	26.4
987	13.0	37.6
988	16.9	52.6
989	22.3	71.7
990	27.3	96.6
991	29.3	125.1
991.3	29.8	139.5

Spillway Elev. = 991.3 Feet msl.
Minimum Elev. = 987.3 Feet msl.

The holding basin has a surface area of 1.56 acres and is approximately 16 feet deep. There is no drainage area to the holding pond.

LIMITS Maximum Pool storage 139.5 Ac.Ft.
Minimum Pool storage 5.5 Ac.Ft.

Starting storage was considered at maximum pool.

The Drainage area of the lake is 3009 acres (4.70 Sq.Mi.).
The holding pond has no drainage area of its own.

GENERAL The adjustment to convert from pan evaporation to lake evaporation was made for the control word EVAP. The factor was 0.76. As a result, a factor of 100 was used here.

The record period of drought is in the 1950's, analysis began in January 1951 and ended December 1959.

SEEPAGE The reservoir seepage varied from 0 seepage near empty to a maximum of 1.0 inch per month when at full pool. The material in the dam is compacted earth of clayey soils. The lake is shallow so that static pressure is low. As a result seepage is small.

RAINFALL Rainfall data came from the Bethany, Mo. rain gage.

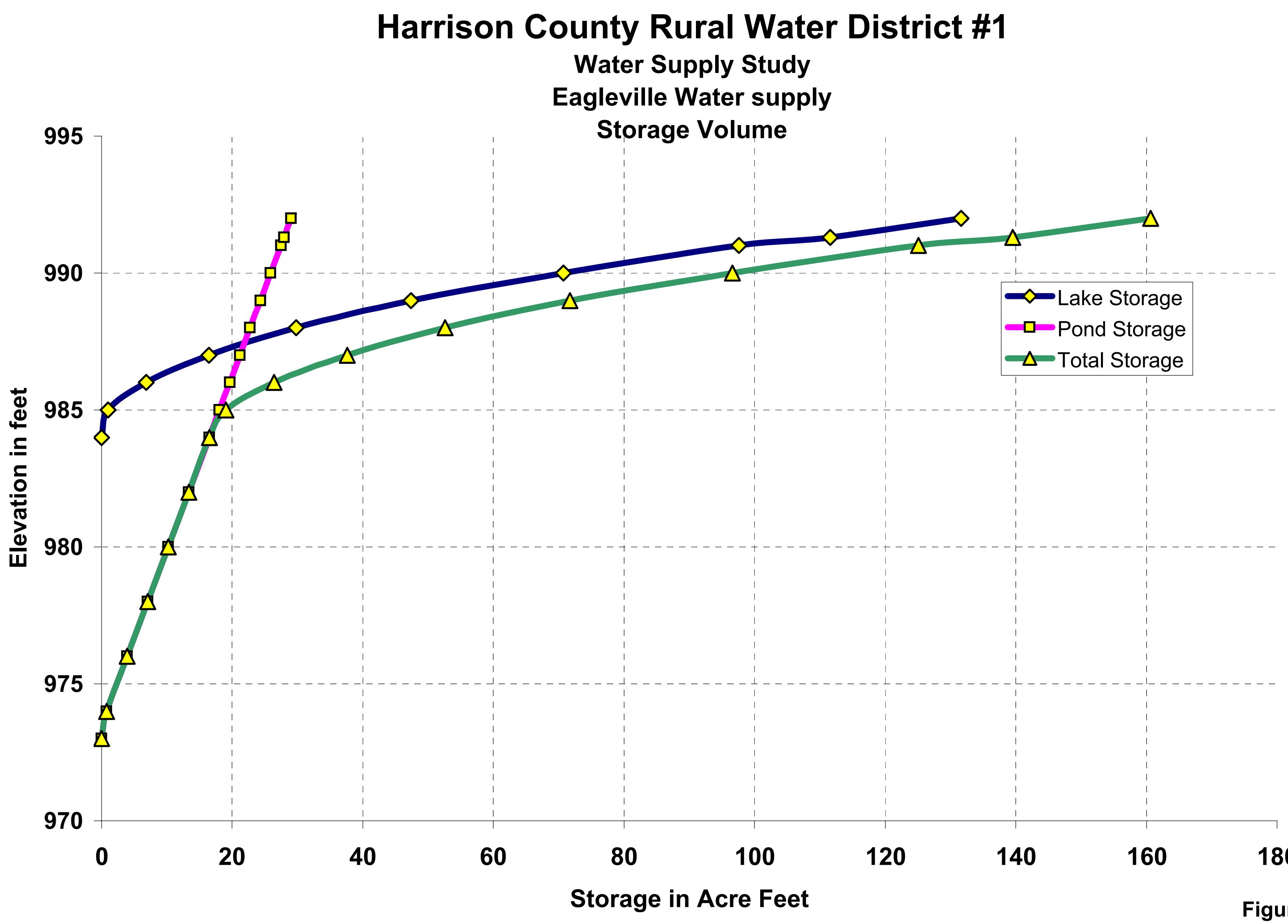
RUNOFF This is the runoff into the lake from its drainage area. Monthly runoff volumes in watershed inches. To determine runoff, East Fork Big Creek stream gage at Bethany having was used. The drainage area at the gage is 95 square miles. Eagleville is in the East Fork Big Creek watershed. Monthly runoff was compared to the rainfall and if the results did not appear reasonable, adjustments were made for that month by looking at individual rains and estimating antecedent moisture then adjusting runoff based on NRCS's runoff curve numbers.

EVAP. Pan evaporation at the Lakeside gaging station was used as a base because it has data for year around evaporation. This data was updated with gage data from stations at Spickard, New Franklin, and Columbia. Depending on the latest data for the station nearest to Eagleville. The adjustment factor of 0.76 to convert from pan to lake evaporation was applied at this step.

DEMAND Harrison County PWSD #1 used 0.086 MGD in year 2000. The lake, by itself, would supply only supply 44,000 gallon per day during the 1950's when the drought of record occurred.

The lake plus the basin meets the demand of 0.086 MGD with no extra volume of storage in reserve.

OTHER Other is other gains or losses from other sources but is not applicable for this water supply.



Harrison County Rural Water District #1
Water Supply Study
Eagleville Water supply
Storage Volume
Elevation in feet
995
990
985
980
975
970
0
20
40
60
80
100
120
140
160
180
Storage in Acre Feet
Lake Storage
Pond Storage
Total Storage

Figure 13.1.a

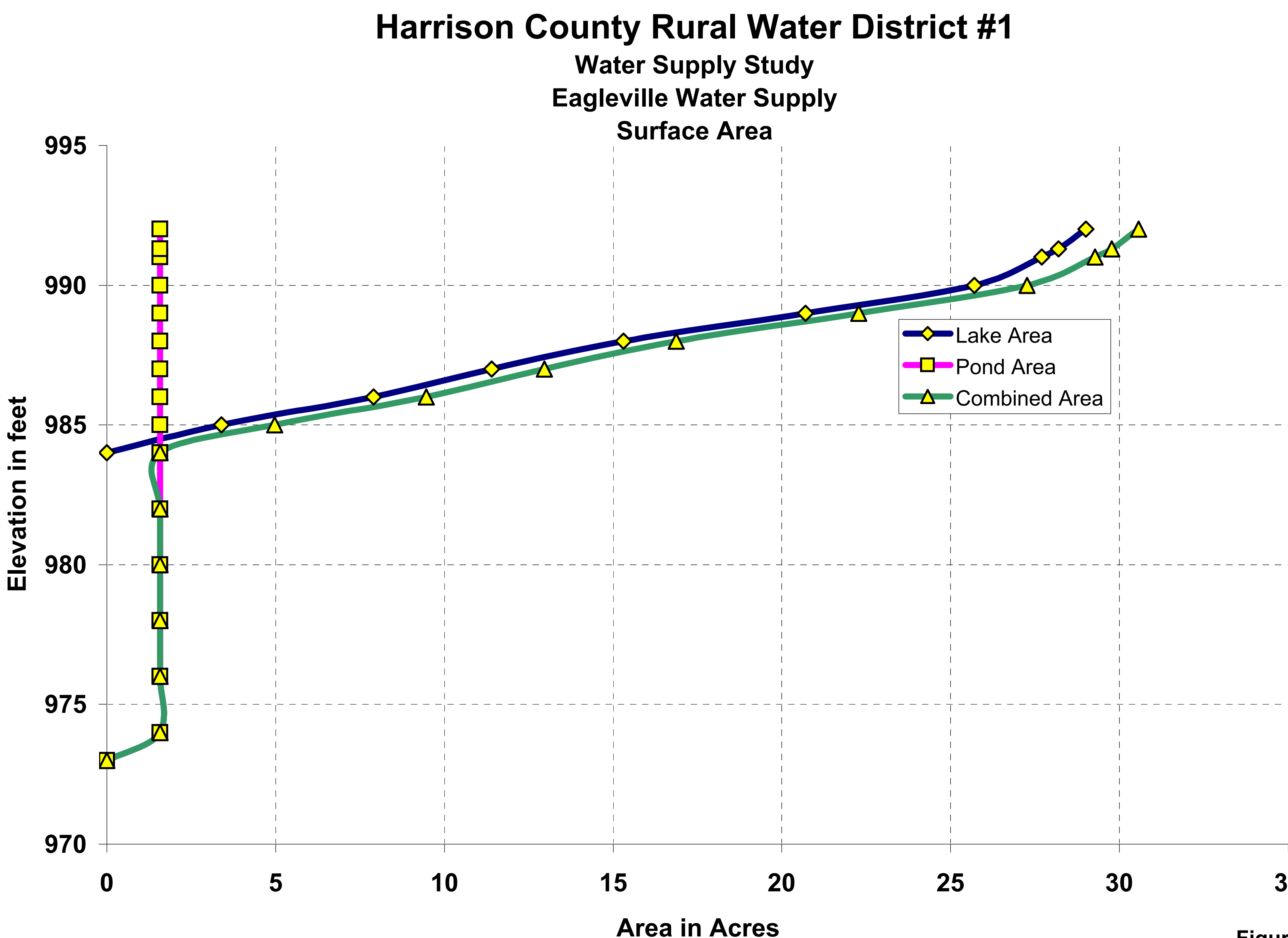
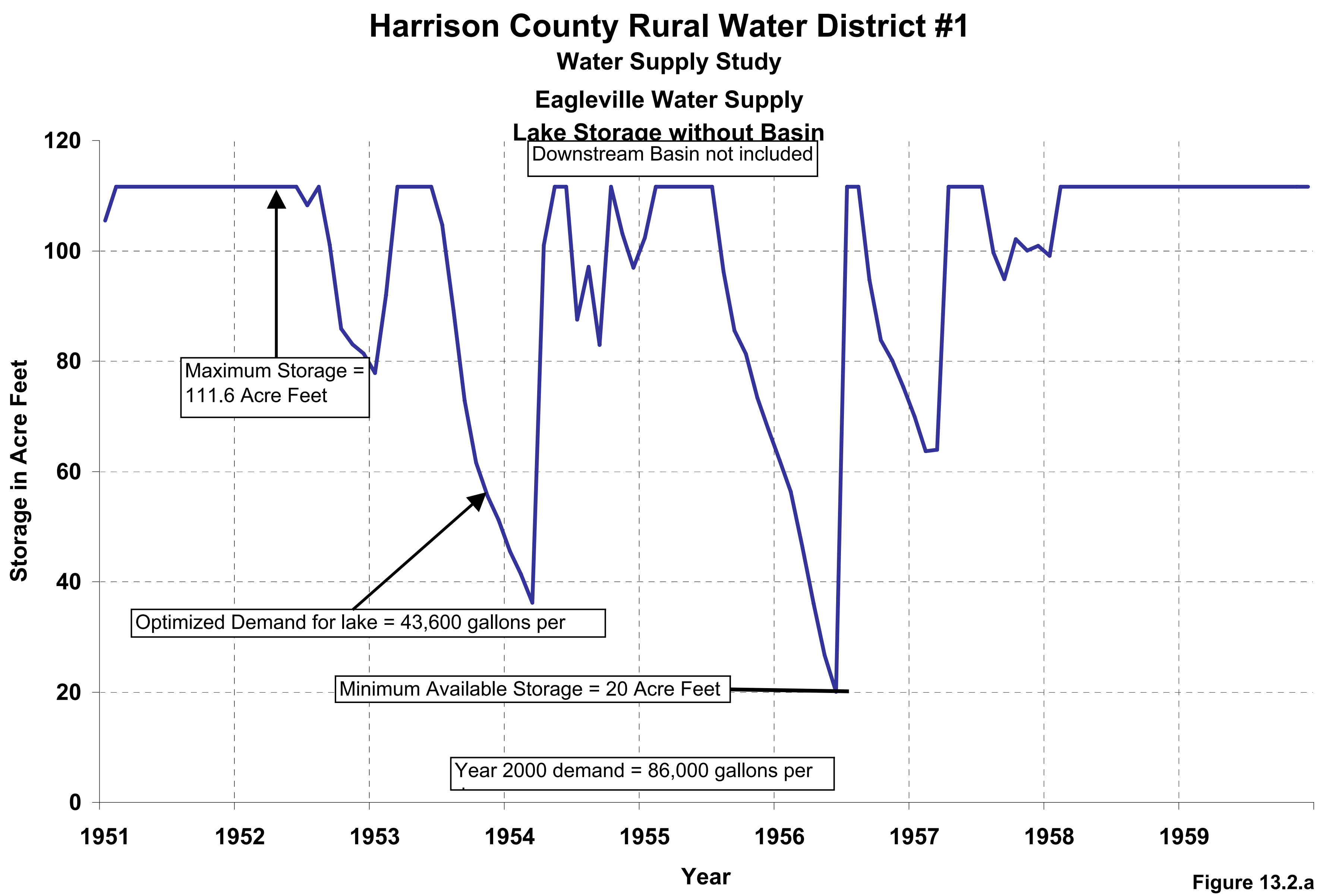

Harrison County Rural Water District #1
Water Supply Study
Eagleville Water Supply
Surface Area
Elevation in feet
995
990
985
980
975
970
0
5
10
15
20
25
30
35
Area in Acres
Lake Area
Pond Area
Combined Area

Figure 13.1.b



Harrison County Rural Water District #1
Water Supply Study
Eagleville Water Supply
Lake Storage without Basin
Downstream Basin not included
Maximum Storage =
111.6 Acre Feet
Optimized Demand for lake = 43,600 gallons per
Minimum Available Storage = 20 Acre Feet
Year 2000 demand = 86,000 gallons per
Storage in Acre Feet
120
100
80
60
40
20
0
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year

Figure 13.2.a

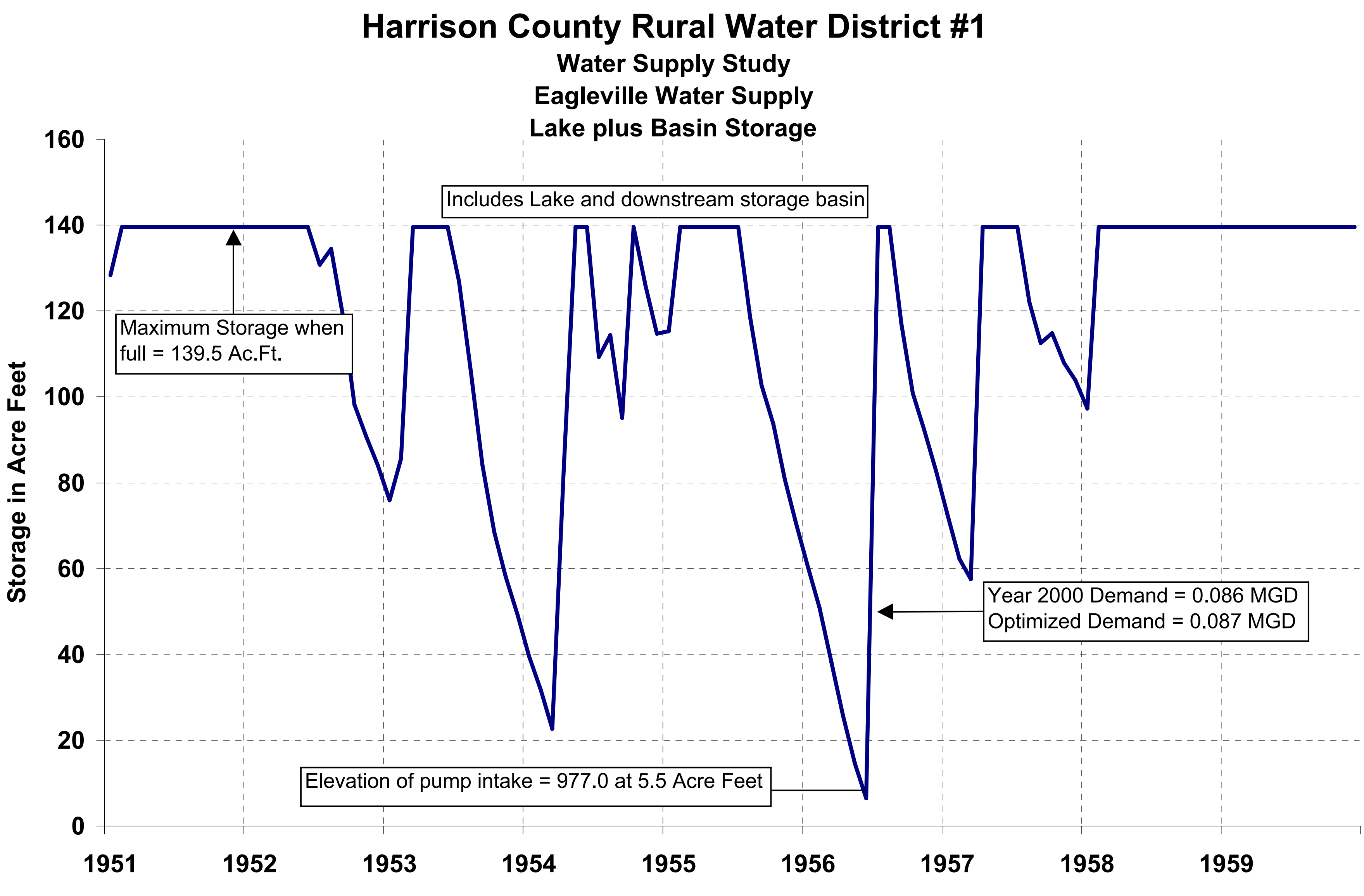

Harrison County Rural Water District #1
Water Supply Study
Eagleville Water Supply
Lake plus Basin Storage
Includes Lake and downstream storage basin
Maximum Storage when
full = 139.5 Ac.Ft.
Year 2000 Demand = 0.086 MGD
Optimized Demand = 0.087 MGD
Elevation of pump intake = 977.0 at 5.5 Acre Feet
Storage in Acre Feet
0
20
40
60
80
100
120
140
160
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year

Figure 13.2.b

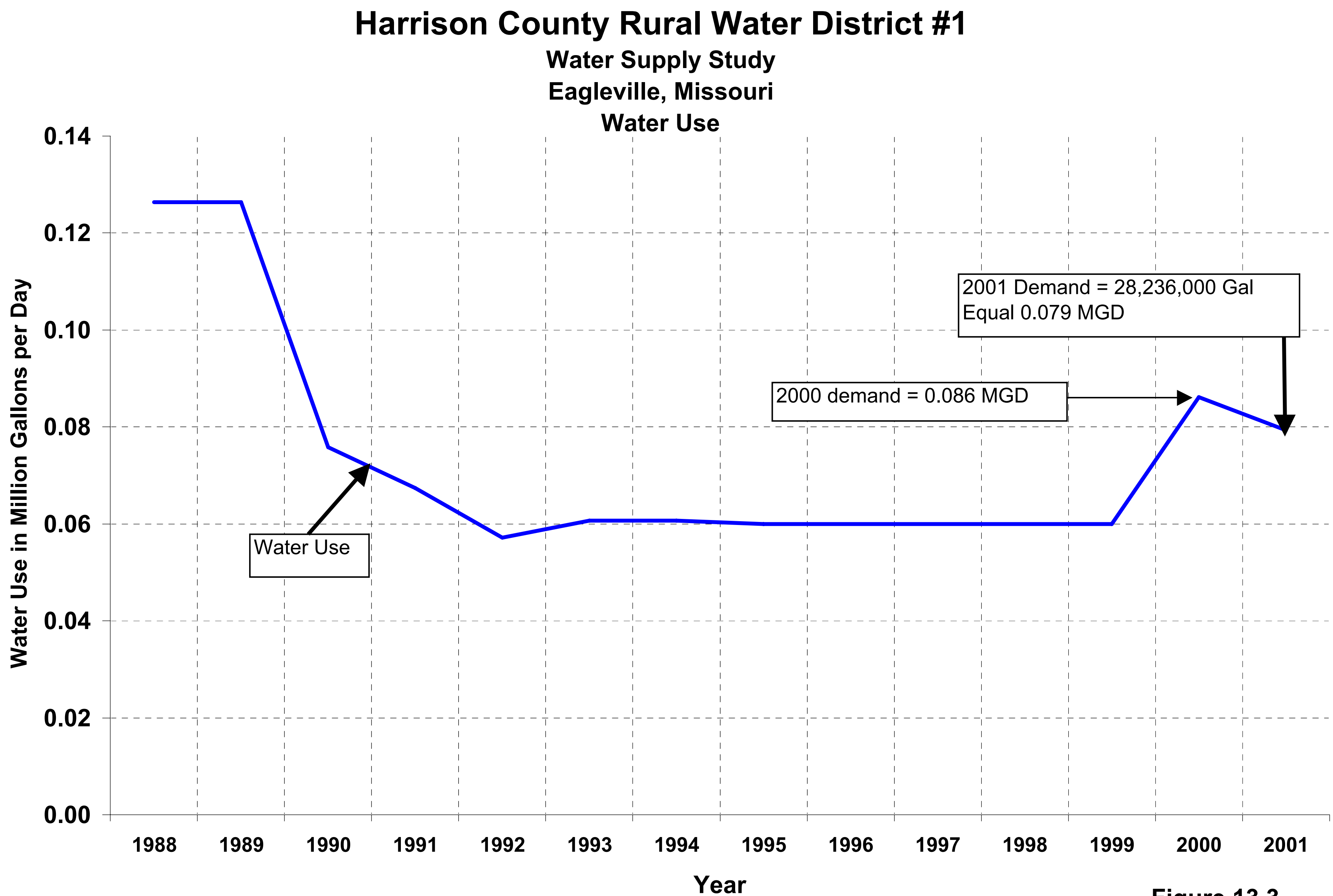
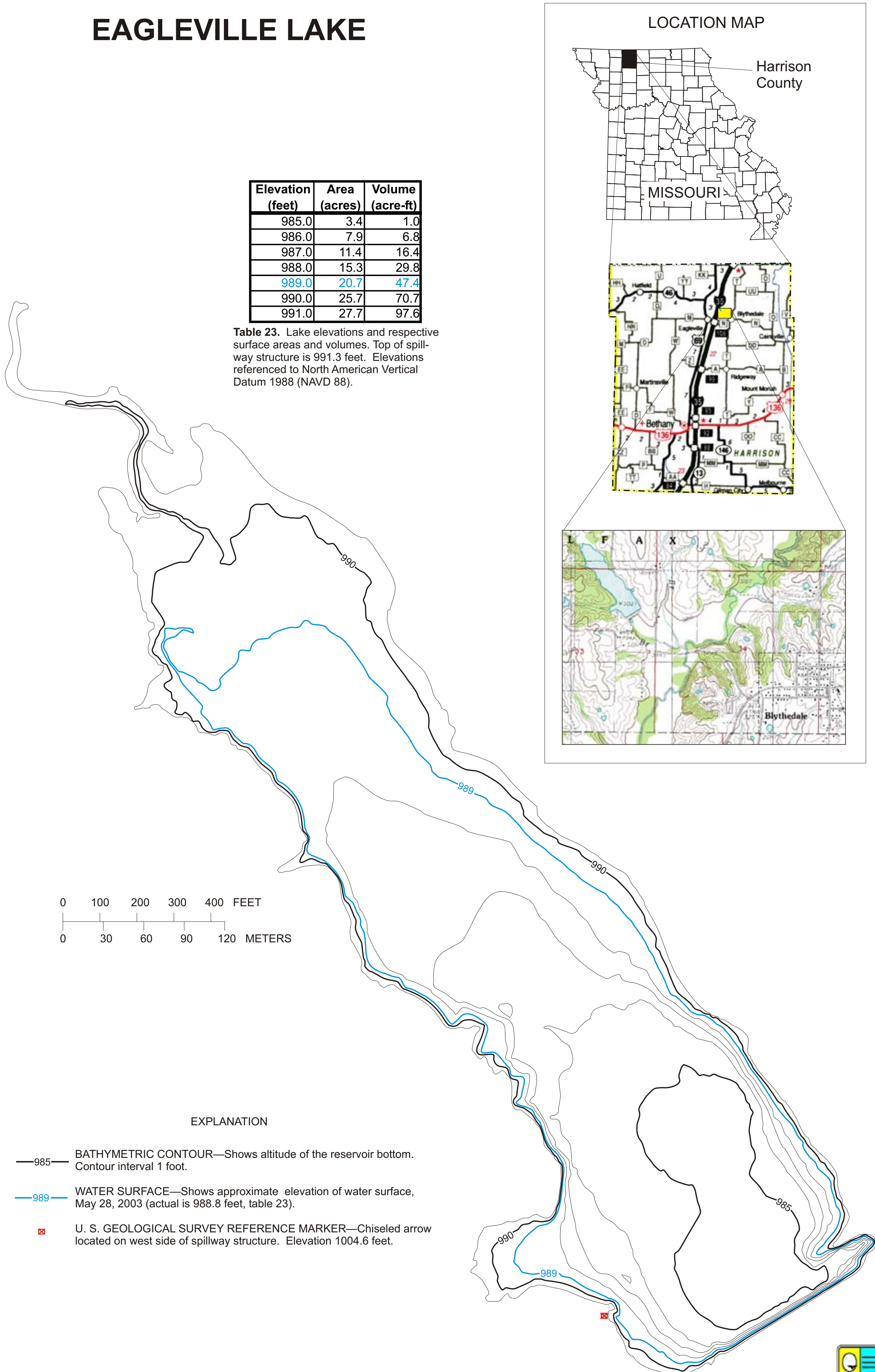

Harrison County Rural Water District #1
Water Supply Study
Eagleville, Missouri
Water Use
Water Use in Million Gallons per Day
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
Year
Water Use
2000 demand = 0.086 MGD
2001 Demand = 28,236,000 Gal
Equal 0.079 MGD

Figure 13.3

EAGLEVILLE LAKE



Elevation (feet)	Area (acres)	Volume (acre-ft)
985.0	3.4	1.0
986.0	7.9	6.8
987.0	11.4	16.4
988.0	15.3	29.8
989.0	20.7	47.4
990.0	25.7	70.7
991.0	27.7	97.6

Table 23. Lake elevations and respective surface areas and volumes. Top of spillway structure is 991.3 feet. Elevations referenced to North American Vertical Datum 1988 (NAVD 88).

EXPLANATION

985 BATHYMETRIC CONTOUR—Shows altitude of the reservoir bottom. Contour interval 1 foot.

989 WATER SURFACE—Shows approximate elevation of water surface, May 28, 2003 (actual is 988.8 feet, table 23).

U. S. GEOLOGICAL SURVEY REFERENCE MARKER—Chiseled arrow located on west side of spillway structure. Elevation 1004.6 feet.

Figure 23. Bathymetric map and table of areas/volumes of Eagleville Lake near Blythedale, Missouri.

USGS science for a changing world

In cooperation with Missouri Department of Natural Resources

Higginsville, Missouri
Water Supply Study
City Lake

Higginsville Lake is in Lafayette County Missouri.

Higginsville water supply comes from a city owned lake located about 2 miles east of Higginsville on a tributary to Davis Creek.

When lake levels reach three feet below the spillway, water is pumped from the Missouri River into the lake. When the water level in the lake reaches about 10 inches below the spillway, they cease pumping.

Average annual rainfall is 37.2 inches. Annual rainfall for 1953 through 1957 is 24.1, 33.6, 39.4, 25.59, and 47.1 inches.

Higginsville Lake analysis consisted of using the NRCS's computer program "RESOP". This program analyses remaining stored water at the end of each month by summing gains and losses.

Four analysis were made:

1. First run was the entire demand was taken from the lake. This resulted in an extended period of water shortage.
2. The lake was analyzed for the optimum daily use without emptying the lake during the evaluation period.
3. The existing plan of operation to maintain an adequate level of water in the lake.
4. A Plan was determined that shared distributing the supply in the lake and pumping from the Missouri River, not allowing the lake to completely dry up.

There are two lakes, a small one immediately upstream of the larger water supply lake. It is very shallow and is used for sediment detention. The main effect of the small lake is water lost to evaporation. Spillage from the upper lake flows into the large lake.

The drainage area of the upper lake is 2.70 square miles.
The drainage area of the lower lake is 2.66 square miles.
Total drainage area of the two lakes is 5.36 square miles.

In 2001 Higginsville used an average use of 0.956 million gallon of water per day. The lake would only Supply an average of 0.456 million gallon per day.

Following are considerations for data input to the "RESOP" program.

STO-AREA Elevation-Storage and Elevation-Area data were determined from June 25, 2002 survey made by USGS. There are two lakes in series. The upper lake is small and overflow spills into the lower lake.

Higginsville water supply lake

Elevation (feet)	Area (acres)	Storage (ac-ft)
736	3.3	1.8
738	14.0	18.4
740	30.4	62.3
742	47.2	139.8
744	67.8	254.8
746	83.9	407.5
748	98.6	589.9

Upper Lake

Elevation (feet)	Area (acres)	Storage (ac-ft)
758	9.1	4.3
760	22.4	37.7
762	32.2	94.1
* 762.8	34.5	120.8
** 763	34.9	127.7

* Water Surface on 6/24/2002
** Spillway Elevation (Full Pool)

750	114.8	803.1	
752	129.3	1048.1	
754	140.8	1318.1	
754.7	145.2	1418.1	Water Surface on 6/25/2002
755	147.1	1462.0	Spillway Elevation (Full Pool)

LIMITS Full Pool storage 1462 Ac.Ft.
Minimum Pool storage 50 Ac.Ft.

Starting storage was considered at full pool.

GENERAL The adjustment factor of 0.76 to convert from pan evaporation to lake evaporation was applied prior to entering the data for the control word EVAP. As a result a factor of 100 is used.

The record period of drought is in the 1950's. Analysis began in Jan. 1951 and ended December 1959.

SEEPAGE The reservoir seepage varied from 0 seepage near empty to a maximum of 2.0 inches per month at full pool. The seepage rate is a best estimate based on history of the reservoir, soil type, material of the core of the dam and compaction of the earth fill. The material in the dam is compacted earth of clayey soils.

RAINFALL Rainfall data is used to determine the amount of rainfall on the lake. The long-term gage at Lexington, Missouri was used.

RUNOFF This is the runoff into the lake from its drainage area. Monthly runoff volumes in Watershed inches were determined and comparisons were made for the Blackwater River Gage at Blue Lick, South Fork Blackwater River near Elm and Shiloh Creek gage near Marshall. The three gages yielded similar monthly runoff volumes with Shiloh Creek being the highest. However The Shiloh creek drainage has a higher percentage of cropland than the other gages and also Higginsville lake. The Blackwater River Gage was used for 1951 to June 1954, when data from South Fork Blackwater River near Elm became available which was used to complete the study. The drainage area at the South Fork gage is 16.6 square miles.

The South Fork Blackwater River gage is located Northwest of Warrensburg. The soils and land use in the drainage area of the gage and the lake are similar.

In cases where rainfall to runoff values did not appear reasonable, adjustments were made for that month by looking at individual rains and estimating antecedent moisture and then, adjusting runoff based on NRCS's runoff curve numbers.

EVAP. Pan evaporation at the Lakeside gaging station was used as a base because it has data for year around evaporation. All other stations only measure data between April through November. Lakeside data was updated during these months with gage data from stations at New Franklin, and Columbia. Depending on the latest data for the station nearest to Higginsville.

DEMAND This was determined by city records. In Year 2001 Higginsville used 348,980,000 gallons. The average daily use is 956,110 gallons per day.

OTHER Other refers to water gained or lost from other sources, in this case it is the amount of water pumped to the reservoir from the Missouri River.

Higginsville, Missouri
Water Supply Study
City Lake
Storage Volume

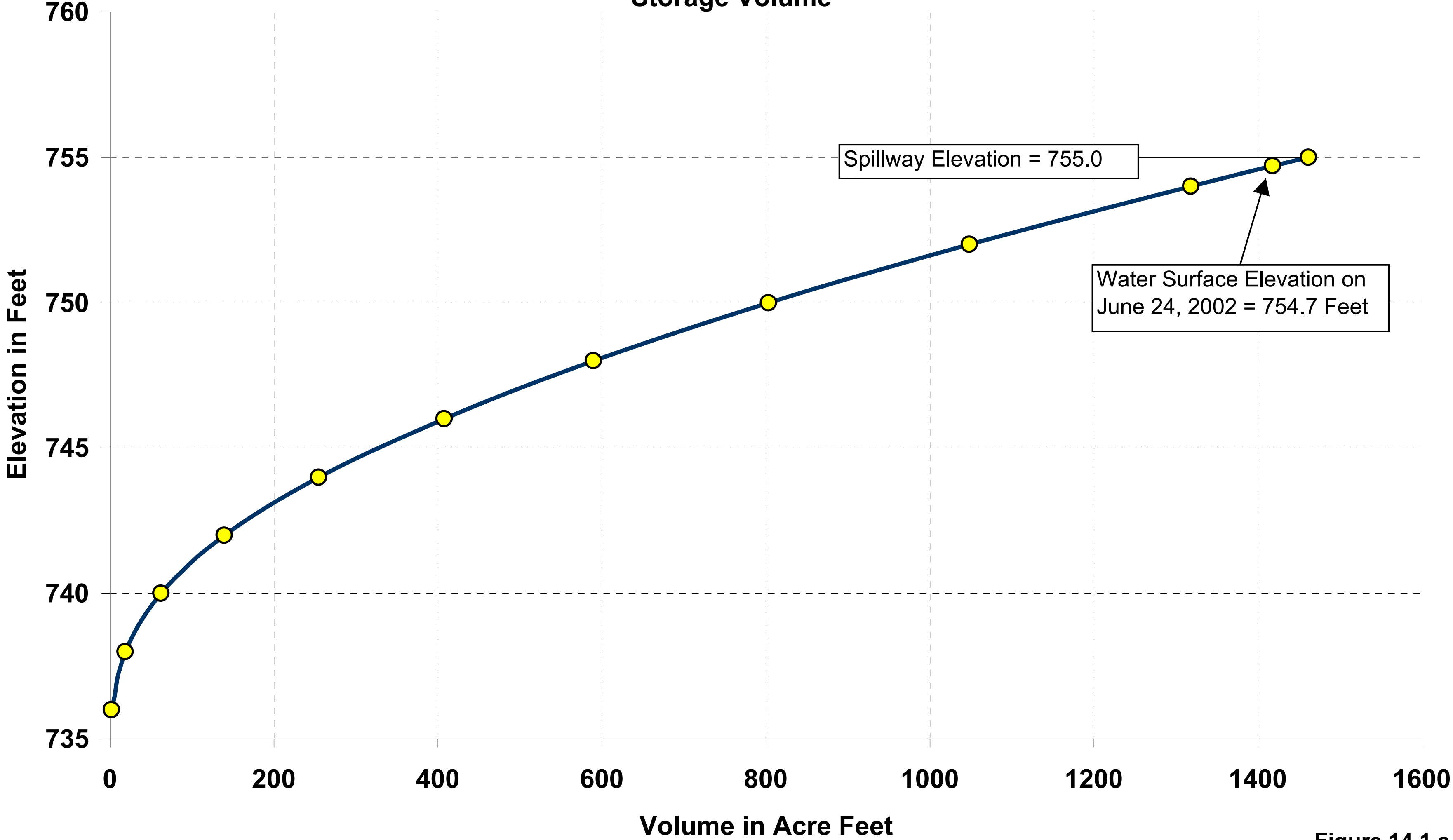


Figure 14.1.a

Higginsville, Missouri
Water Supply Study
City Lake
Surface Area

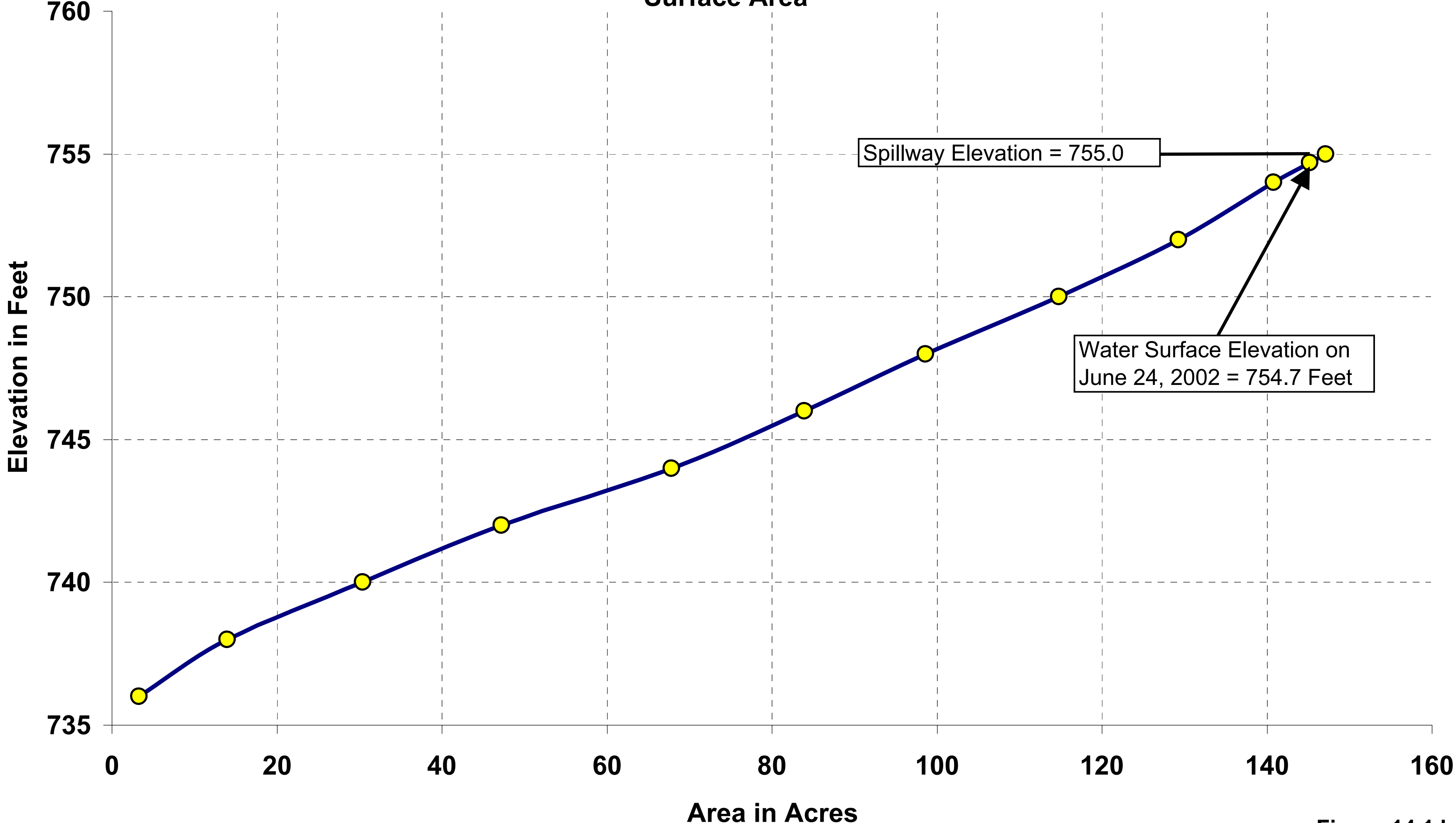


Figure 14.1.b

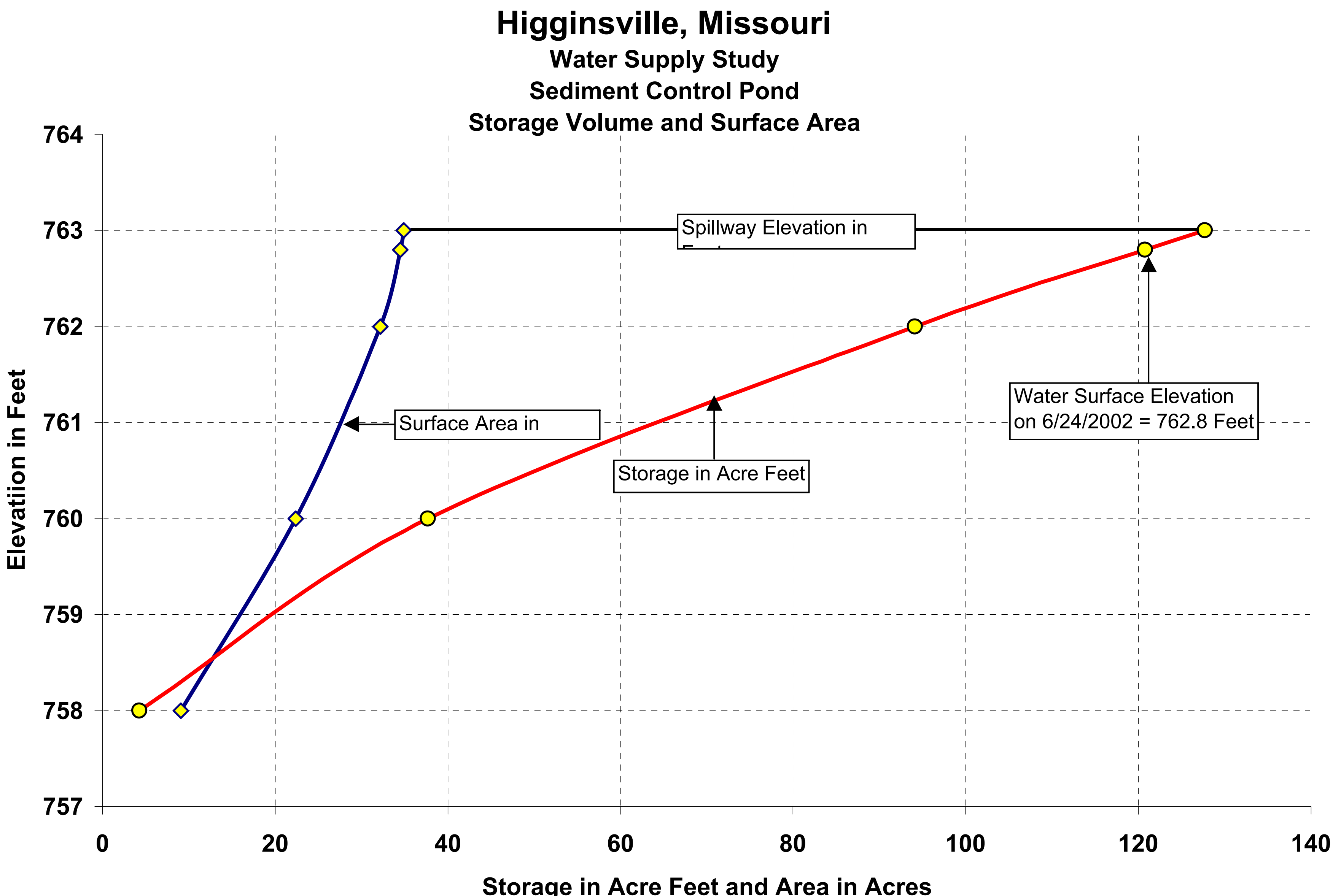

Higginsville, Missouri
Water Supply Study
Sediment Control Pond
Storage Volume and Surface Area
764
763
762
761
760
759
758
757
Elevatiion in Feet
0
20
40
60
80
100
120
140
Storage in Acre Feet and Area in Acres
Spillway Elevation in
Surface Area in
Storage in Acre Feet
Water Surface Elevation
on 6/24/2002 = 762.8 Feet

Figure 14.1.c

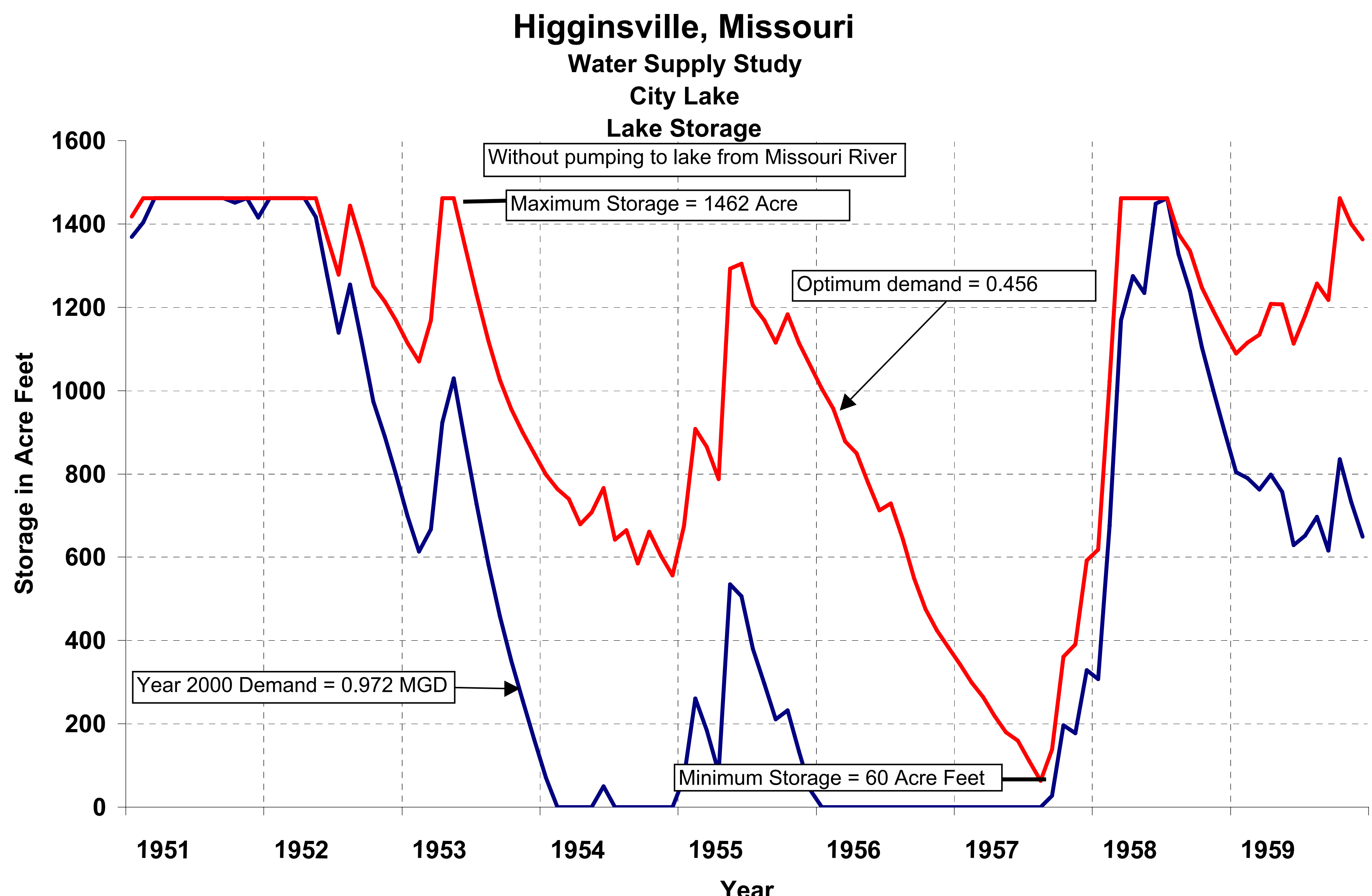
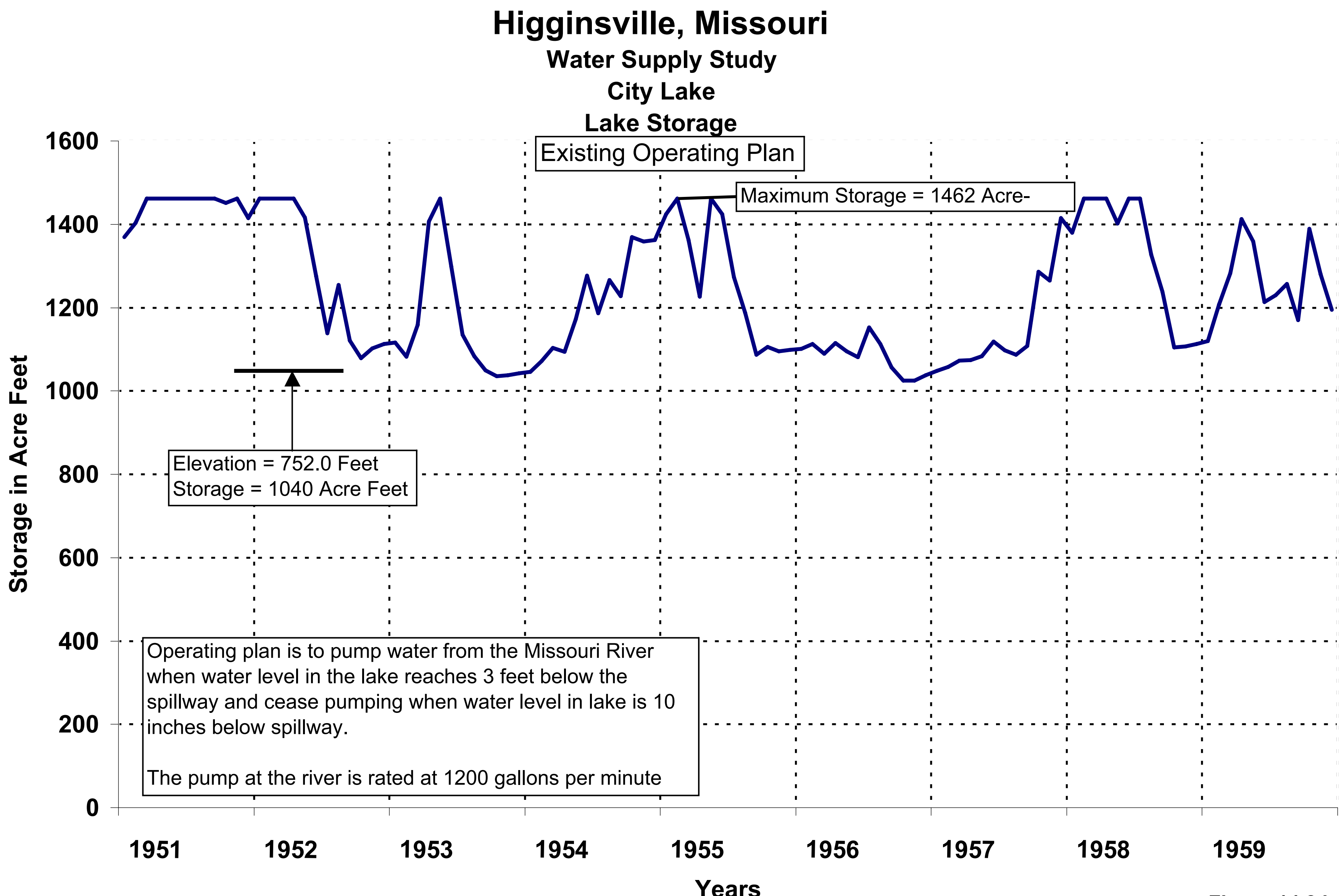

Higginsville, Missouri
Water Supply Study
City Lake
Lake Storage
Without pumping to lake from Missouri River
Maximum Storage = 1462 Acre
Optimum demand = 0.456
Year 2000 Demand = 0.972 MGD
Minimum Storage = 60 Acre Feet
Storage in Acre Feet
1600
1400
1200
1000
800
600
400
200
0
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year

Figure 14.2.a



Higginsville, Missouri
Water Supply Study
City Lake
Lake Storage
Existing Operating Plan
Maximum Storage = 1462 Acre-
Elevation = 752.0 Feet
Storage = 1040 Acre Feet
Operating plan is to pump water from the Missouri River when water level in the lake reaches 3 feet below the spillway and cease pumping when water level in lake is 10 inches below spillway.
The pump at the river is rated at 1200 gallons per minute
Storage in Acre Feet
1600
1400
1200
1000
800
600
400
200
0
1951
1952
1953
1954
1955
1956
1957
1958
1959
Years

Figure 14.2.b

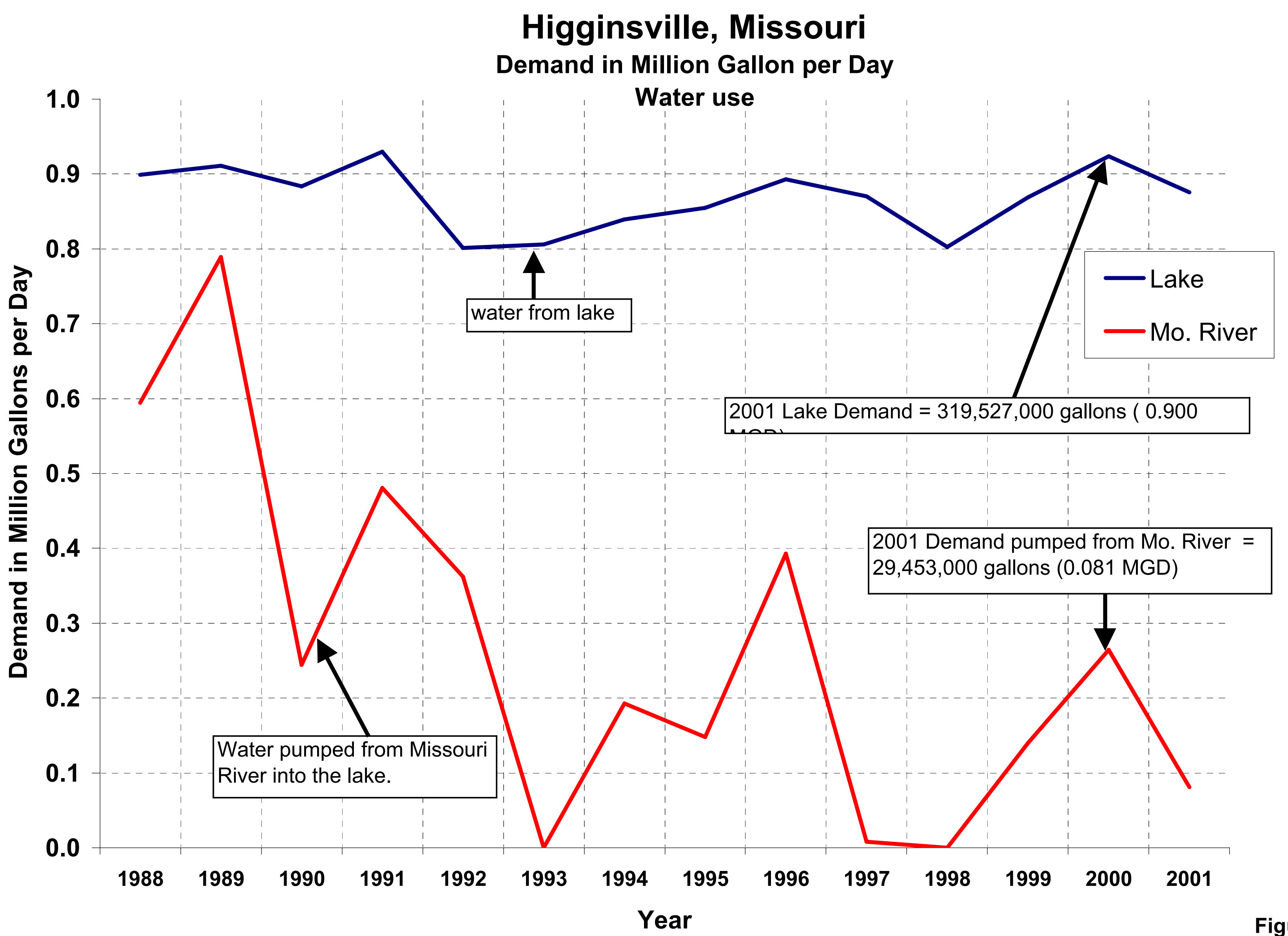
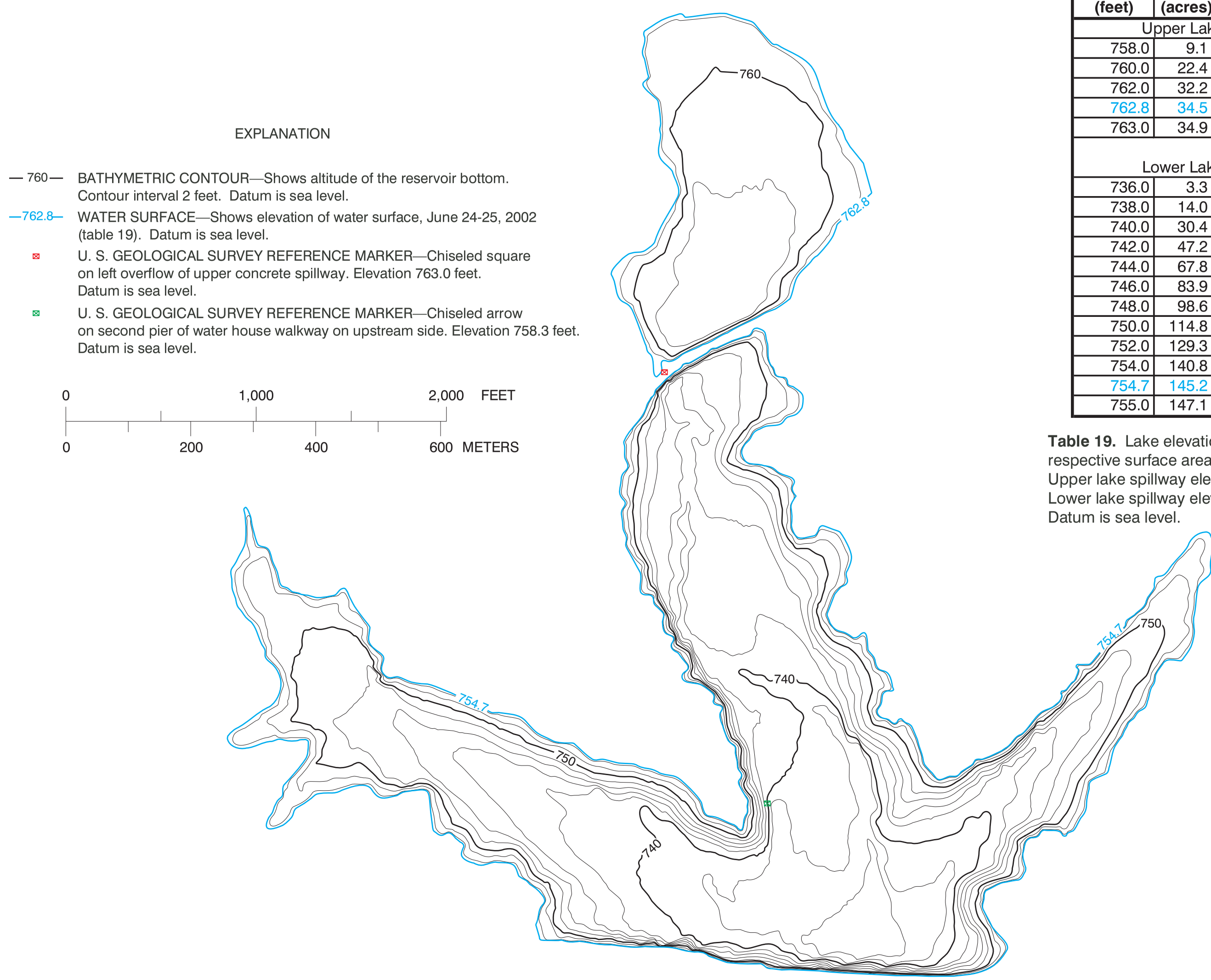

Higginsville, Missouri
Demand in Million Gallon per Day
Water use
Demand in Million Gallons per Day
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
Year
water from lake
Lake
Mo. River
2001 Lake Demand = 319,527,000 gallons (0.900
2001 Demand pumped from Mo. River =
29,453,000 gallons (0.081 MGD)
Water pumped from Missouri
River into the lake.

Figure 14.3

HIGGINSVILLE LAKE



Elevation (feet)	Area (acres)	Volume (acre-ft)
Upper Lake		
758.0	9.1	4.3
760.0	22.4	37.7
762.0	32.2	94.1
762.8	34.5	120.8
763.0	34.9	127.7
Lower Lake		
736.0	3.3	1.8
738.0	14.0	18.4
740.0	30.4	62.3
742.0	47.2	139.8
744.0	67.8	254.8
746.0	83.9	407.5
748.0	98.6	589.9
750.0	114.8	803.1
752.0	129.3	1,048.1
754.0	140.8	1,318.1
754.7	145.2	1,418.1
755.0	147.1	1,462.0

Table 19. Lake elevations and respective surface areas and volumes. Upper lake spillway elevation 763.0 feet. Lower lake spillway elevation 755.0 feet. Datum is sea level.

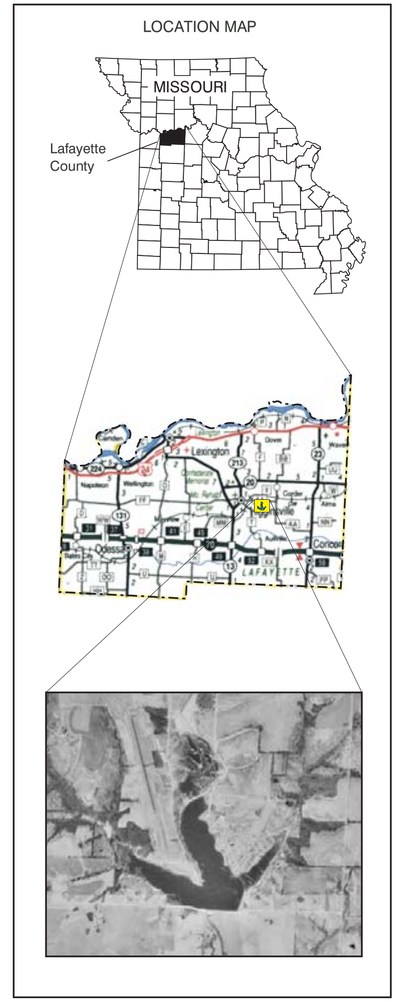


Figure 19. Bathymetric map and area/volume table for Higginsville Lake near Higginsville, Missouri.

USGS science for a changing world

Holden, Missouri
Water Supply Study
City Lake

Holden Lake is located on a tributary to South Fork Blackwater River, about three Miles Northwest of Holden. Holden is located in Johnson County Missouri.

Average annual rainfall for the last 50 years is 40.0 inches at Warrensburg. Annual rainfall for 1953 through 1957 is 25.4, 32.7, 34.7, 21.1, and 40.0 inches.

Holden has not been reporting their water use. They are using enough water to be considered in the category of major water user and will be reporting their usage. The Safe Drinking Water Information System (SDWIS) database indicates they are currently using an average of 250,000 million gallon per day.

Holden's Lake analysis consisted of using the NRCS's computer program "RESOP". This program analyzes remaining stored water at the end of each month by summing gains and losses.

Following is the data and procedures for input to the "RESOP" program.

STO-AREA Elevation-Storage and Elevation-Area data were determined from June 26, 2003 survey made by USGS.

Holden Lake

Elevation (Feet)	Area (Acres)	Storage (Ac-Ft)	
802.0	0.07	0.01	
804.0	1.0	0.8	
806.0	3.2	4.9	
808.0	6.2	14	
810.0	10	31	
812.0	17	58	
814.0	26	101	
816.0	36	162	
818.0	47	245	
820.0	58	350	
822.0	74	480	
824.0	90	650	
826.0	105	840	
828.0	124	1070	
830.0	143	1340	
832.0	162	1640	
834.0	184	1990	
836.0	207	2380	
837.0	222	2590	
838.0	237	2820	
840.0	262	3320	
841.3	277	3670	Water Surface on 6/2/2003
841.8	292	3810	Spillway Elevation

LIMITS Full Pool storage 3810 Ac.Ft.
Minimum Pool storage 200 Ac.Ft.

Starting storage was considered at full pool elevation.

The drainage area of the lake is 4.02 square miles.

GENERAL The adjustment factor of 0.76 to convert from pan evaporation to lake evaporation was applied prior to entering the data for the control word EVAP. As a result a factor of 100 is applied.

The record period of drought is in the 1950's.
Analysis began in January 1951 and ended December 1959.

SEEPAGE The reservoir seepage varied from 0 seepage near empty to a maximum of 3.0 inch per month when at full pool. The material in the dam is compacted earth of clayey soils.

RAINFALL Rainfall data came from the Warrensburg, Mo. rain gage for the period 1951 through 1959.

RUNOFF This is the runoff into the lake from its drainage area. Monthly runoff volumes in watershed inches were determined and comparisons were made for the Blackwater River Gage at Blue Lick, South Fork Blackwater River near Elm and Shiloh Creek near Marshall. The three gages yielded similar monthly runoff volumes with Shiloh Creek being the highest. However The Shiloh Creek drainage has a higher percentage of cropland than the other gages. The Blackwater River Gage was used for 1951 to June 1954, when data from South Fork Blackwater River near Elm became available and was used. The drainage area at the South Fork gage is 16.6 square miles. The gage is located East of Warrensburg. The soils and land use in the drainage area of the gage on South Fork Blackwater River and the lake are similar.

In cases where rainfall to runoff values did not appear reasonable, adjustments were made for that Month by looking at individual rains and estimating antecedent moisture and then, adjusting runoff based on NRCS's runoff curve numbers.

EVAP. Pan evaporation at the Lakeside gaging station was used as a base because it has data for year around evaporation. All other stations only measure data between April through November. Lakeside data was updated during these months with gage data from stations at New Franklin, and Columbia. Depending on the latest data for the station nearest to Holden.

DEMAND Holden has not been reporting their water use because they were not considering themselves to be major water users. This RESOP run was for the daily use recorded in the SDWIS data base. The daily amount recorded is 0.250 MGD. The optimized use would be 0.567 million gallon per day.

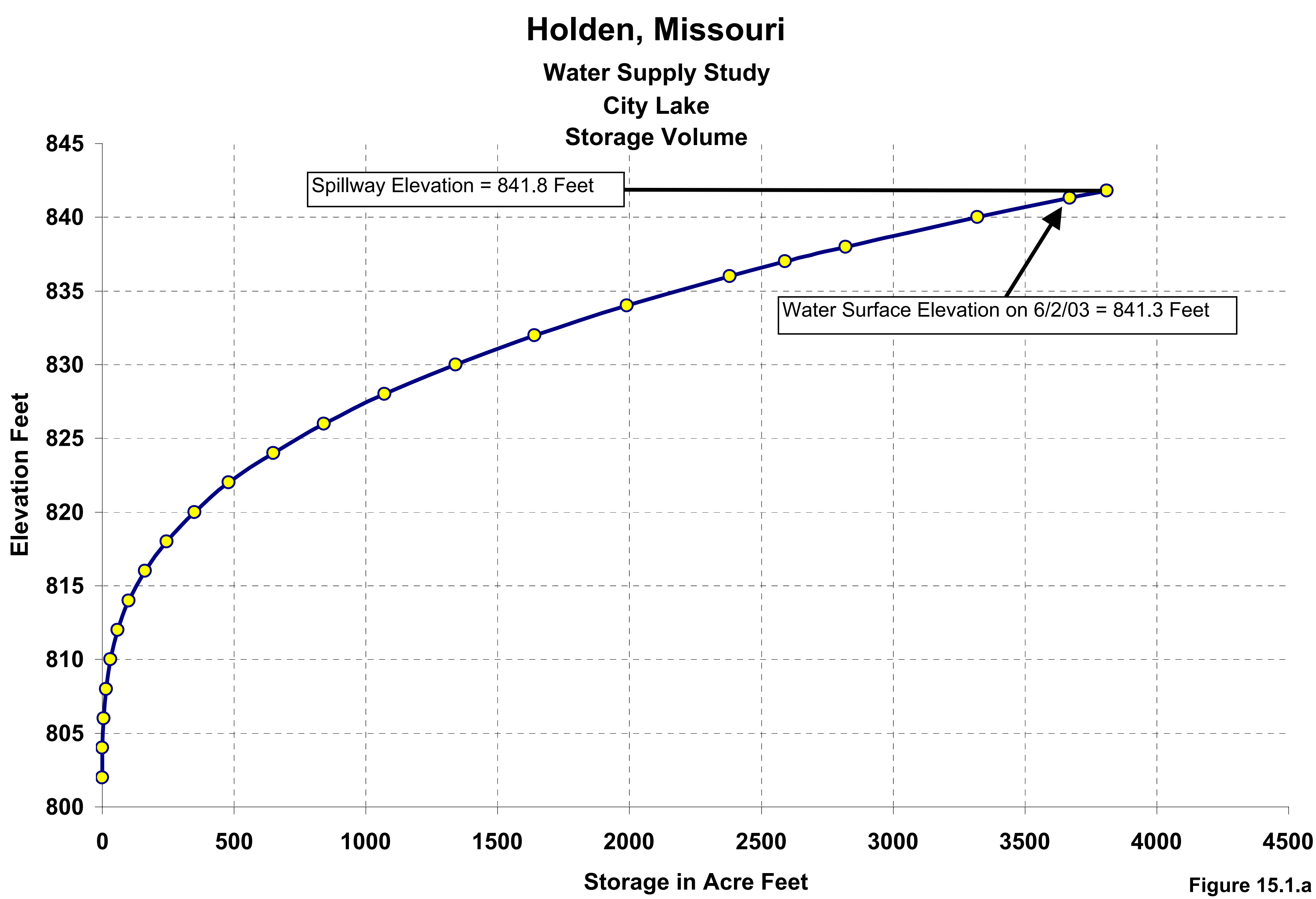
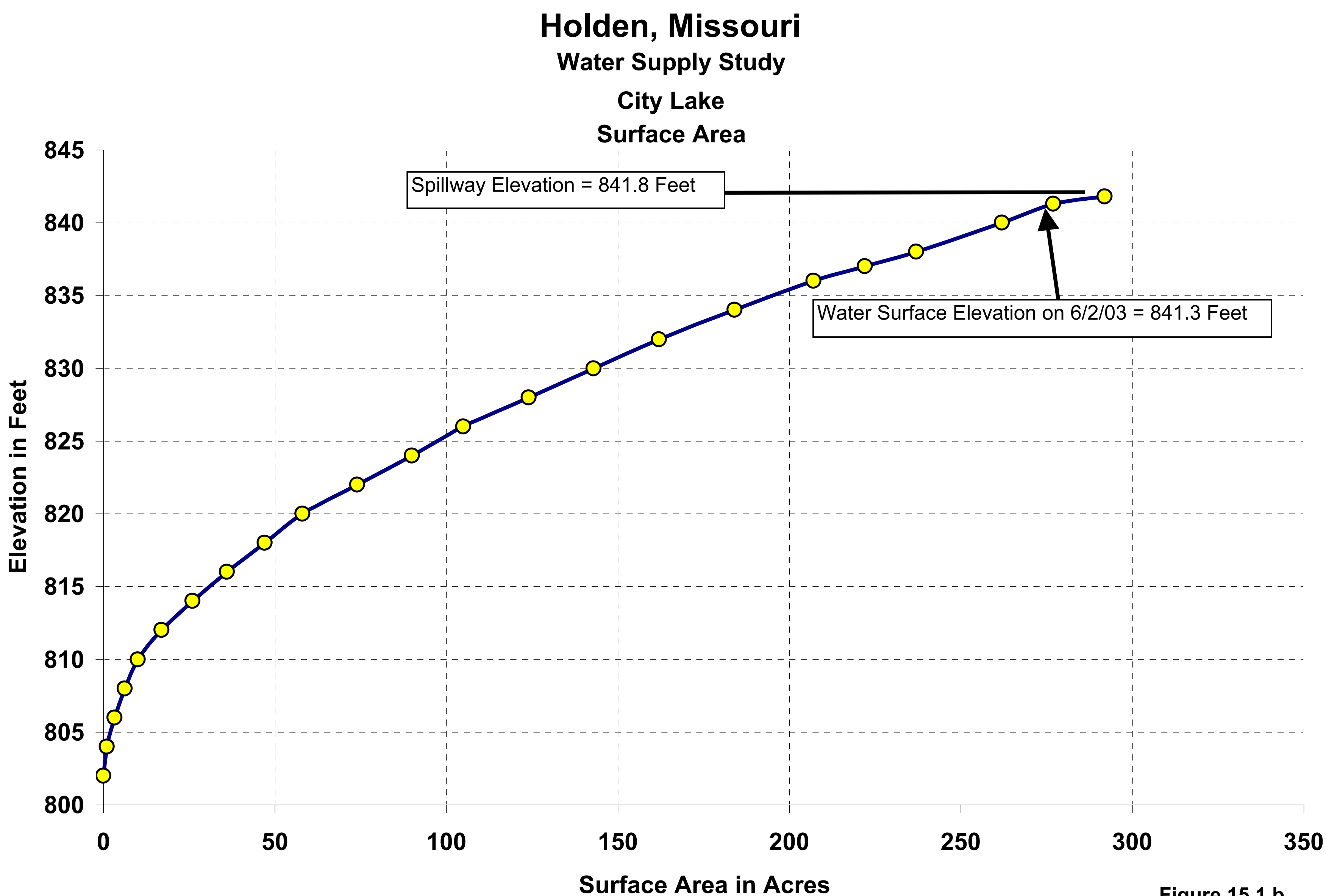

Holden, Missouri
Water Supply Study
City Lake
Storage Volume
Spillway Elevation = 841.8 Feet
Water Surface Elevation on 6/2/03 = 841.3 Feet
Elevation Feet
845
840
835
830
825
820
815
810
805
800
0
500
1000
1500
2000
2500
3000
3500
4000
4500
Storage in Acre Feet

Figure 15.1.a



Holden, Missouri
Water Supply Study
City Lake
Surface Area
Spillway Elevation = 841.8 Feet
Water Surface Elevation on 6/2/03 = 841.3 Feet
Elevation in Feet
845
840
835
830
825
820
815
810
805
800
0
50
100
150
200
250
300
350
Surface Area in Acres

Figure 15.1.b

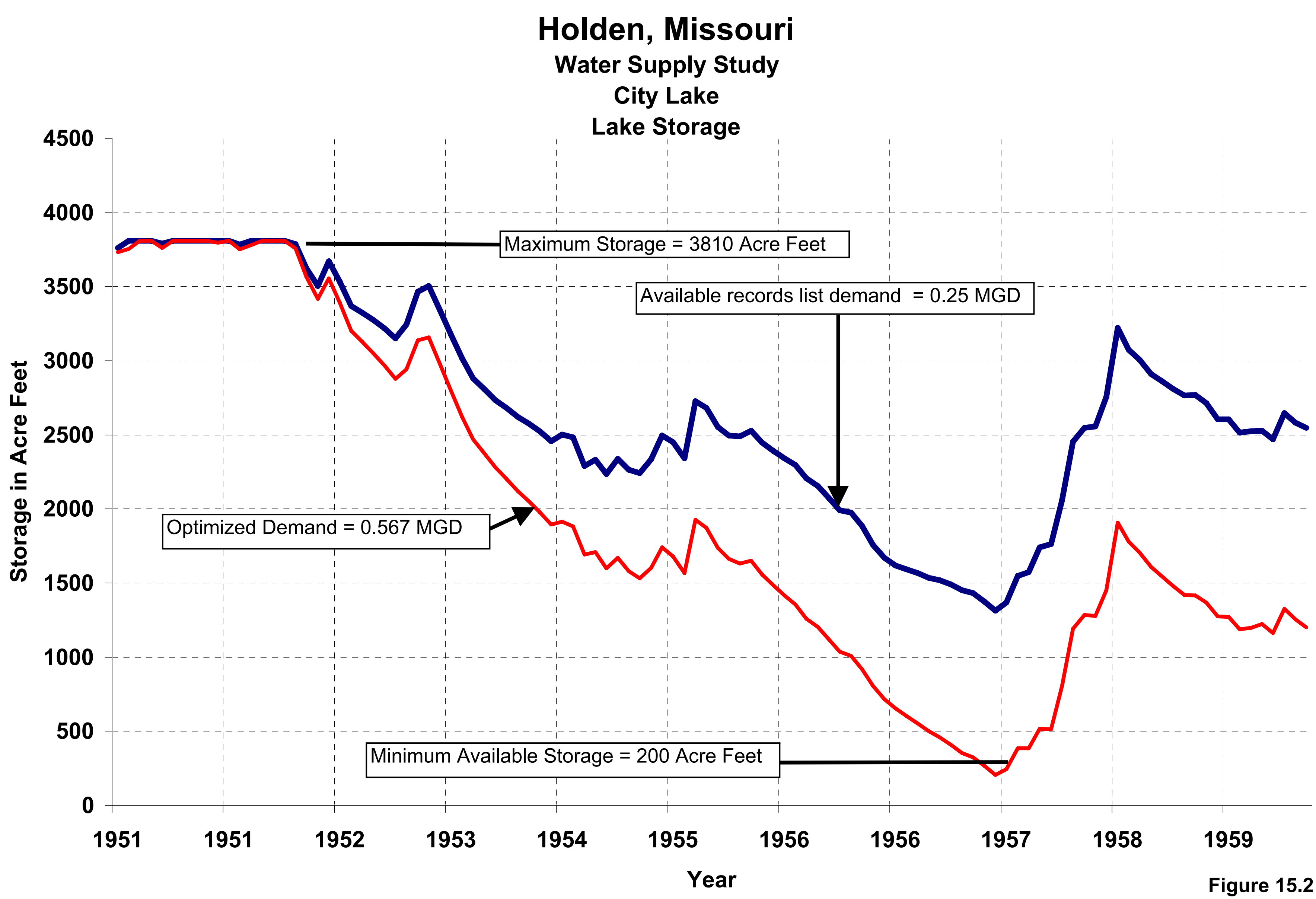
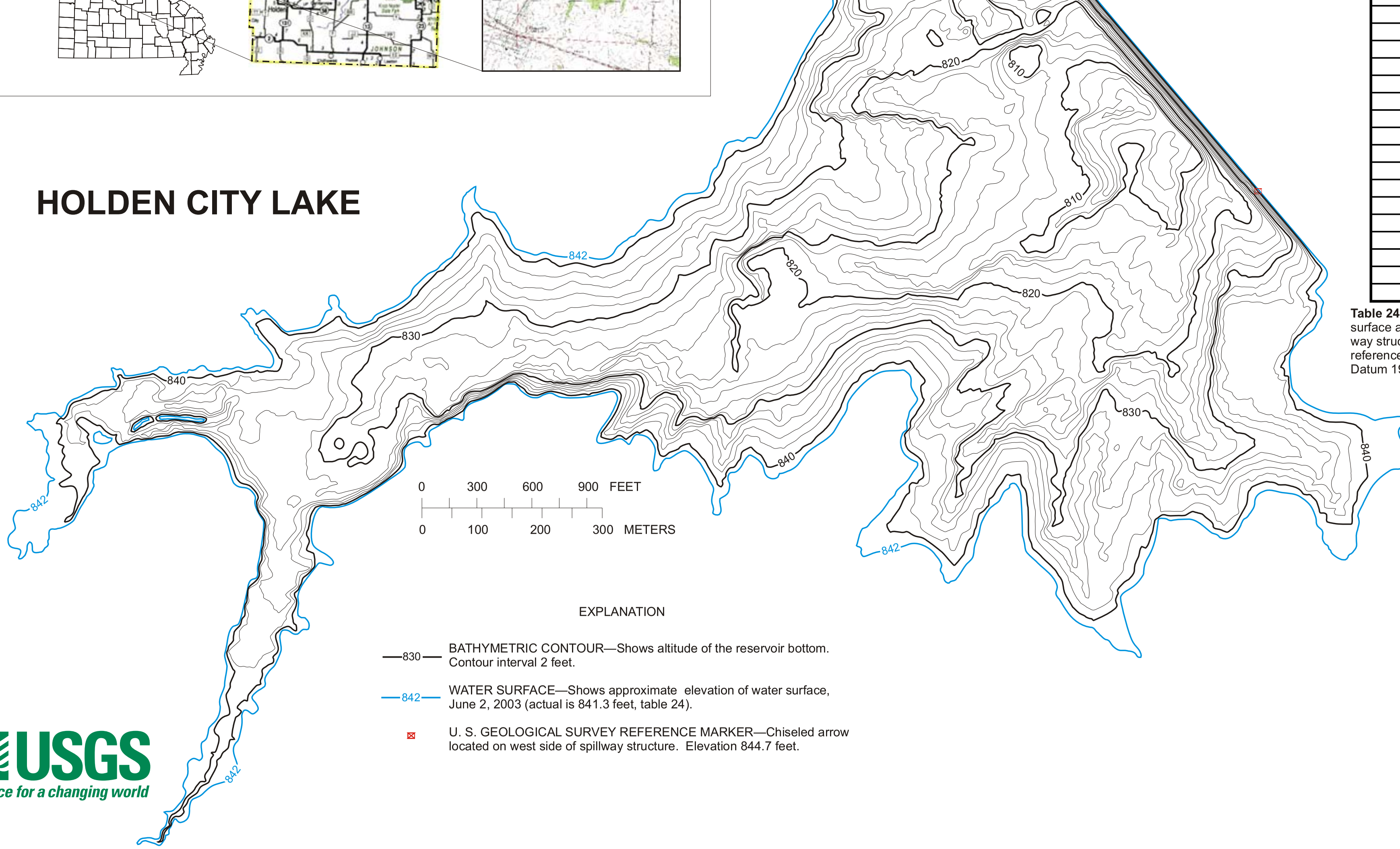

Holden, Missouri
Water Supply Study
City Lake
Lake Storage
Storage in Acre Feet
4500
4000
3500
3000
2500
2000
1500
1000
500
0
1951
1951
1952
1953
1954
1955
1956
1956
1957
1958
1959
Year
Maximum Storage = 3810 Acre Feet
Available records list demand = 0.25 MGD
Optimized Demand = 0.567 MGD
Minimum Available Storage = 200 Acre Feet

Figure 15.2

HOLDEN CITY LAKE



EXPLANATION

—830— BATHYMETRIC CONTOUR—Shows altitude of the reservoir bottom. Contour interval 2 feet.

—842— WATER SURFACE—Shows approximate elevation of water surface, June 2, 2003 (actual is 841.3 feet, table 24).

⊠ U. S. GEOLOGICAL SURVEY REFERENCE MARKER—Chiseled arrow located on west side of spillway structure. Elevation 844.7 feet.

Elevation (feet)	Area (acres)	Volume (acre-ft)
802.0	0.07	0.01
804.0	1.0	0.8
806.0	3.2	4.9
808.0	6.2	14
810.0	10	31
812.0	17	58
814.0	26	101
816.0	36	162
818.0	47	245
820.0	58	350
822.0	74	480
824.0	90	650
826.0	105	840
828.0	124	1,070
830.0	143	1,340
832.0	162	1,640
834.0	184	1,990
836.0	207	2,380
837.0	222	2,590
838.0	237	2,820
840.0	262	3,320
841.3	277	3,670
841.8	292	3,810

Table 24. Lake elevations and respective surface areas and volumes. Top of spillway structure is 841.8 feet. Elevations referenced to North American Vertical Datum 1988 (NAVD 88).

Figure 24. Bathymetric map and table of areas/volumes of the Holden City Lake near Kingsville, Missouri.

USGS science for a changing world

In cooperation with Missouri Department of Natural Resources

James port, Missouri
Water Supply Study
City Lake

Jamesport is located in East Central Daviess County Missouri, on State Highway 190. The Jamesport Lake is located approximately two miles North of town, just North of highway 6.

Jamesport uses about 60,000 gallon of water daily.
Optimized demand is 69,050 gallon per day.
Drainage area of the lake is 900 acres.

JAMESPORT City Lake analysis consisted of using the NRCS's computer program called "RESOP". Following is the data and procedures for input to the program.

Jamesport lake was critically low in 1988 and since then, the lake was enlarged to provide additional storage. Following is storage table for the existing lake.

STO-AREA Elevation-Storage and Elevation-Area data were determined from July 16, 2000 survey made by USGS.

JAMESPORT LAKE

Elevation (feet)	Area (acres)	Volume (acre-ft)	
869.0	0.01	0.001	
871.0	0.43	0.35	
873.0	1.47	2.14	
875.0	2.78	6.39	
877.0	4.39	13.54	
879.0	6.25	24.07	
881.0	9.62	39.38	
883.0	12.44	61.53	
885.0	15.02	89.26	
887.0	17.04	121.15	
889.0	19.49	157.52	Water Surface Elevation on 7/16/00
889.3	20.14	163.46	Spillway Elevation

Starting storage was considered at maximum pool.

GENERAL The adjustment to convert from pan evaporation to lake evaporation was made for the control word EVAP. The factor was 0.76. As a result a factor of 100.0 was used here.

The record period of drought is in the 1950's.
Analysis began in January 1951 and ended December 1959.

LIMITS Max. Pool storage 163 Ac.Ft.
Minimum Pool storage 10 Ac.Ft.

Starting storage was considered at maximum pool.

The drainage area of the lake is 900 acres (1.41 square miles).

SEEPAGE	The reservoir seepage varied from 0 seepage near empty to a maximum of 2 inch per month when at full pool. The material in the dam is compacted earth of loamy clay soils. The lakes are shallow so that static pressure is low. As a result seepage is small.
RAINFALL	Rainfall data came from the Gallatin, Mo. rain gage. For periods of missing data the Trenton gage was used to fill in this missing dates.
RUNOFF	This is the runoff into the lake from its drainage area. Monthly runoff volumes in watershed inches were determined at the Weldon River stream gage at Mill Grove. These values were compared to the runoff at the East Fork Big Creek located at Bethany. Results were very similar. Monthly runoff was compared to the rainfall and if the results did not appear reasonable, adjustments were made for that month by looking at individual rains and estimating antecedent moisture, then adjusting runoff based on NRCS's runoff curve numbers.
EVAP.	Pan evaporation at the Lakeside gaging station was used as a base because it has data for year around evaporation. This data was updated with gage data from stations at Spickard, New Franklin, and Columbia. Depending on the latest data for the station nearest to King City. The adjustment factor of 0.76 to convert from pan to lake evaporation was applied at this step.
DEMAND	This was determined by city records. Jamesport has a total daily use of 60,000 gallons per day.
OTHER	This refers other inflows or outflows. Because there was nothing added or used, this control word was not used.

James Port, Missouri
Water Supply Study
City Lake
Storage Volume

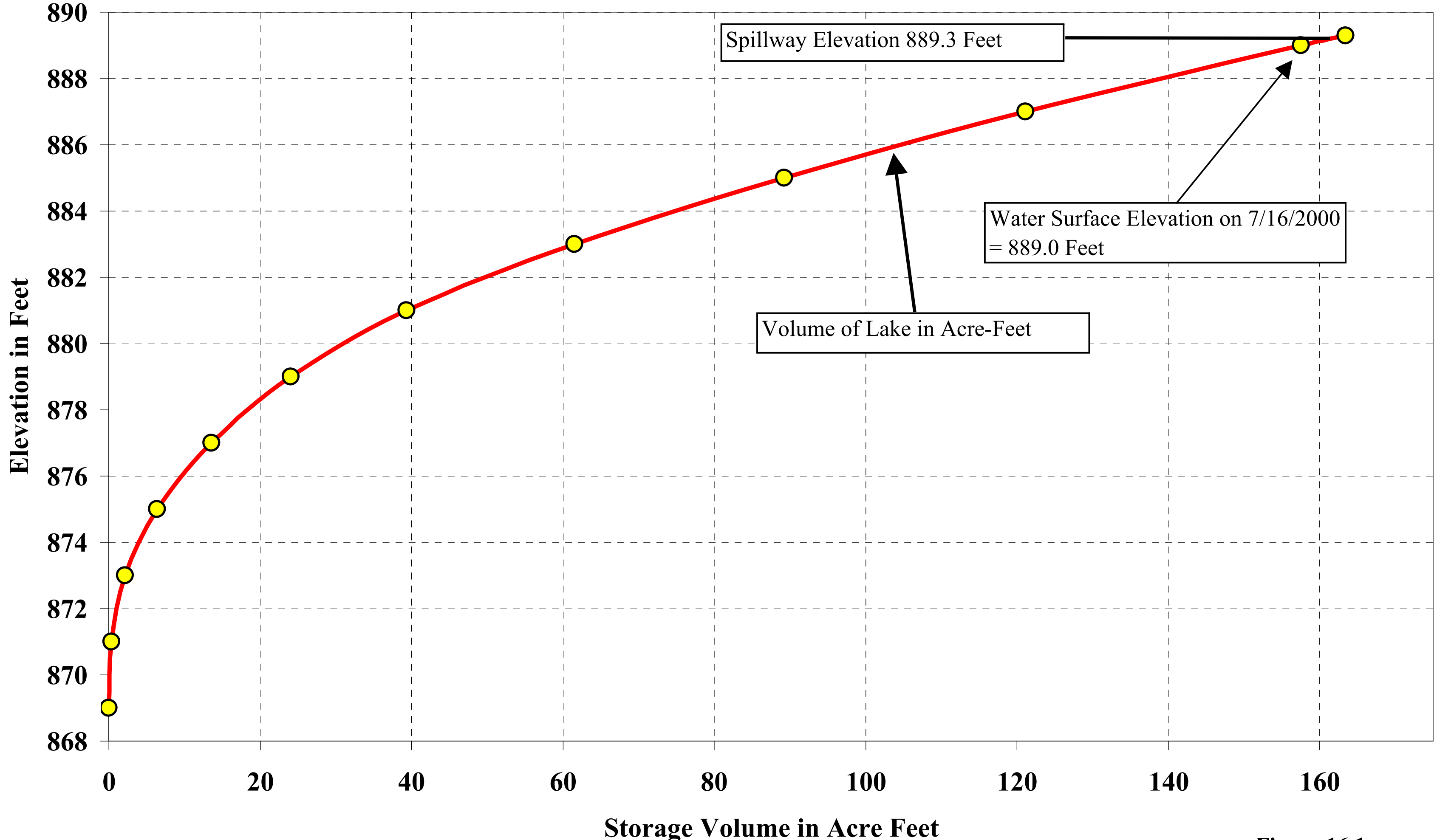


Figure 16.1.a

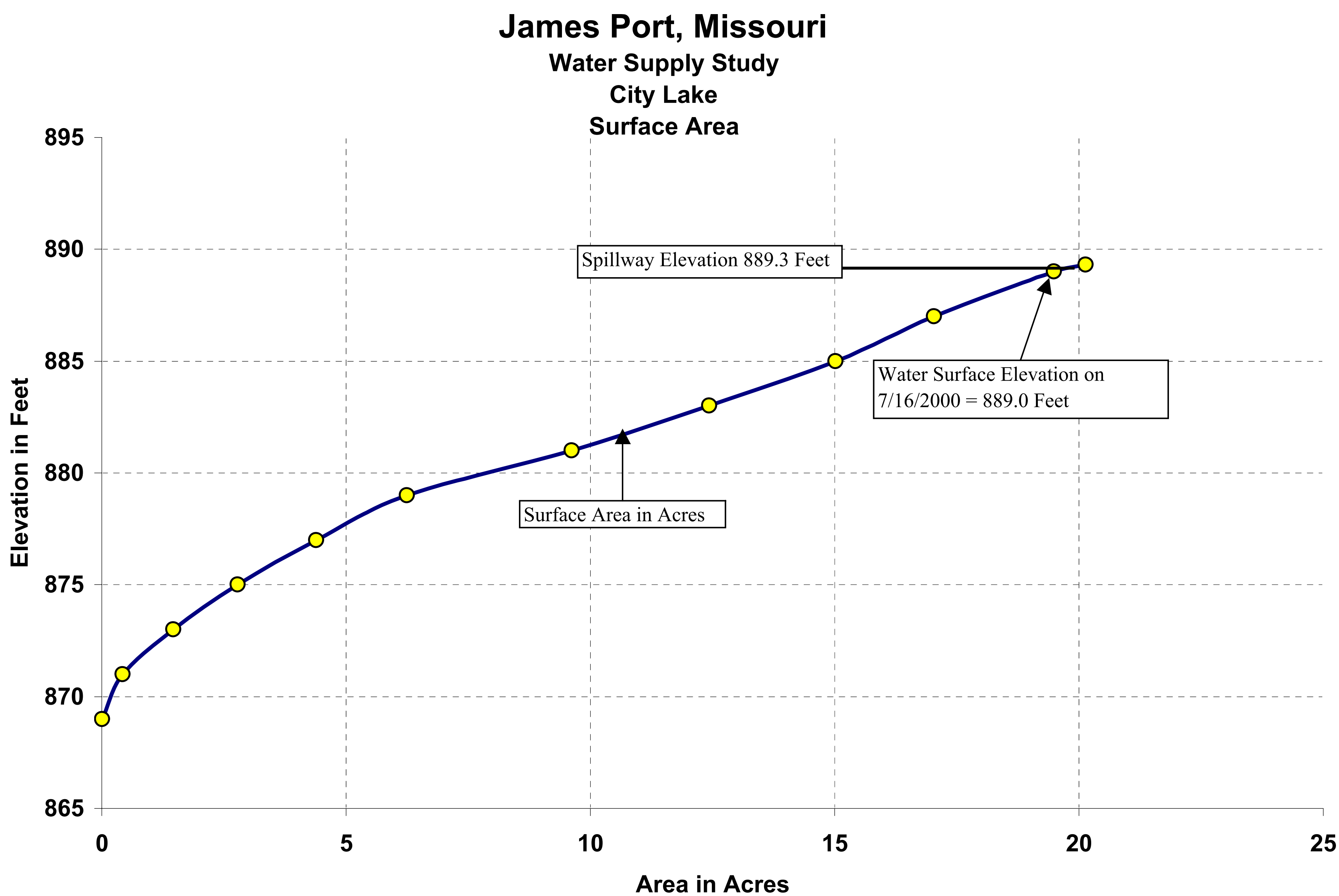
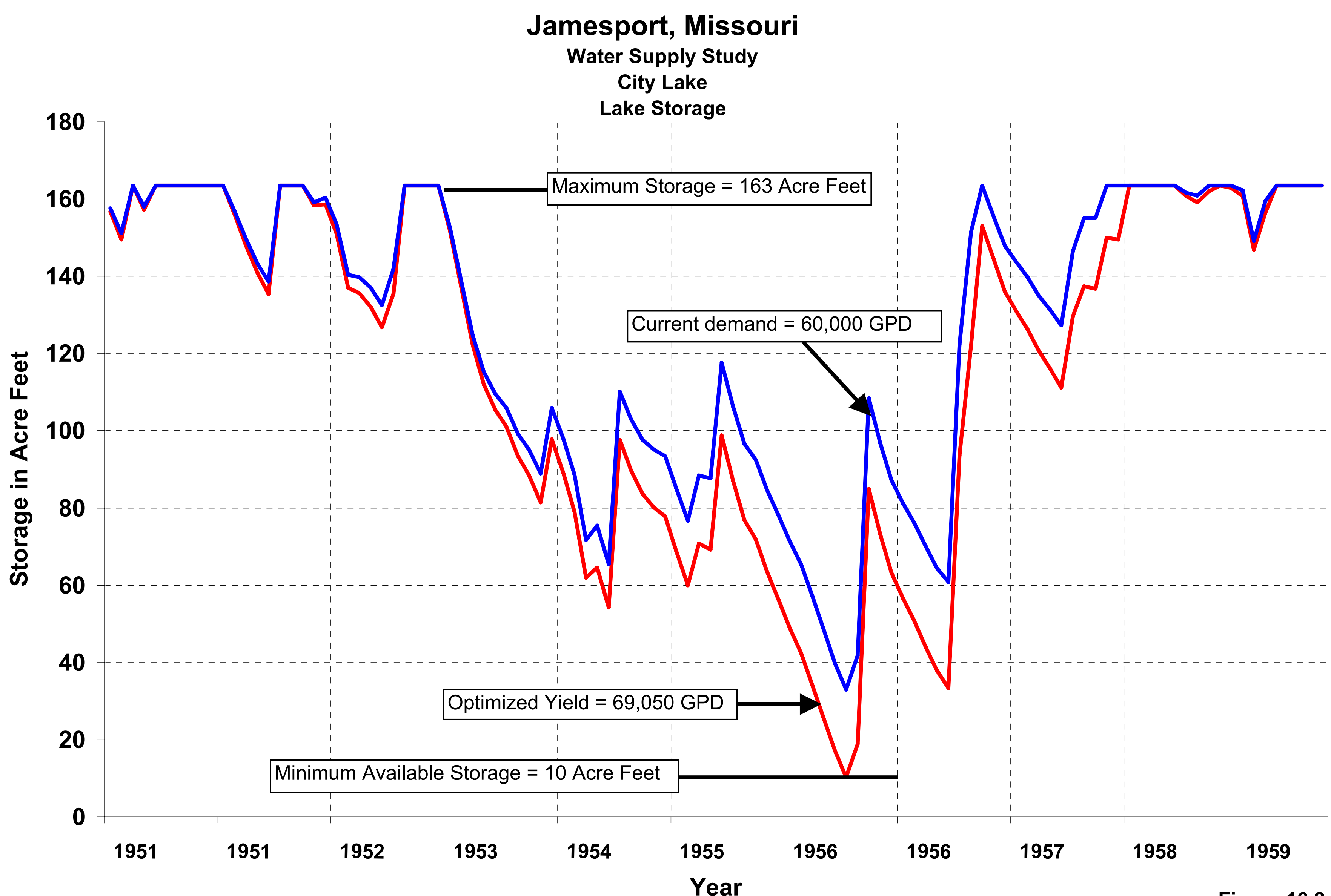

James Port, Missouri
Water Supply Study
City Lake
Surface Area
Elevation in Feet
895
890
885
880
875
870
865
0
5
10
15
20
25
Area in Acres
Spillway Elevation 889.3 Feet
Water Surface Elevation on
7/16/2000 = 889.0 Feet
Surface Area in Acres

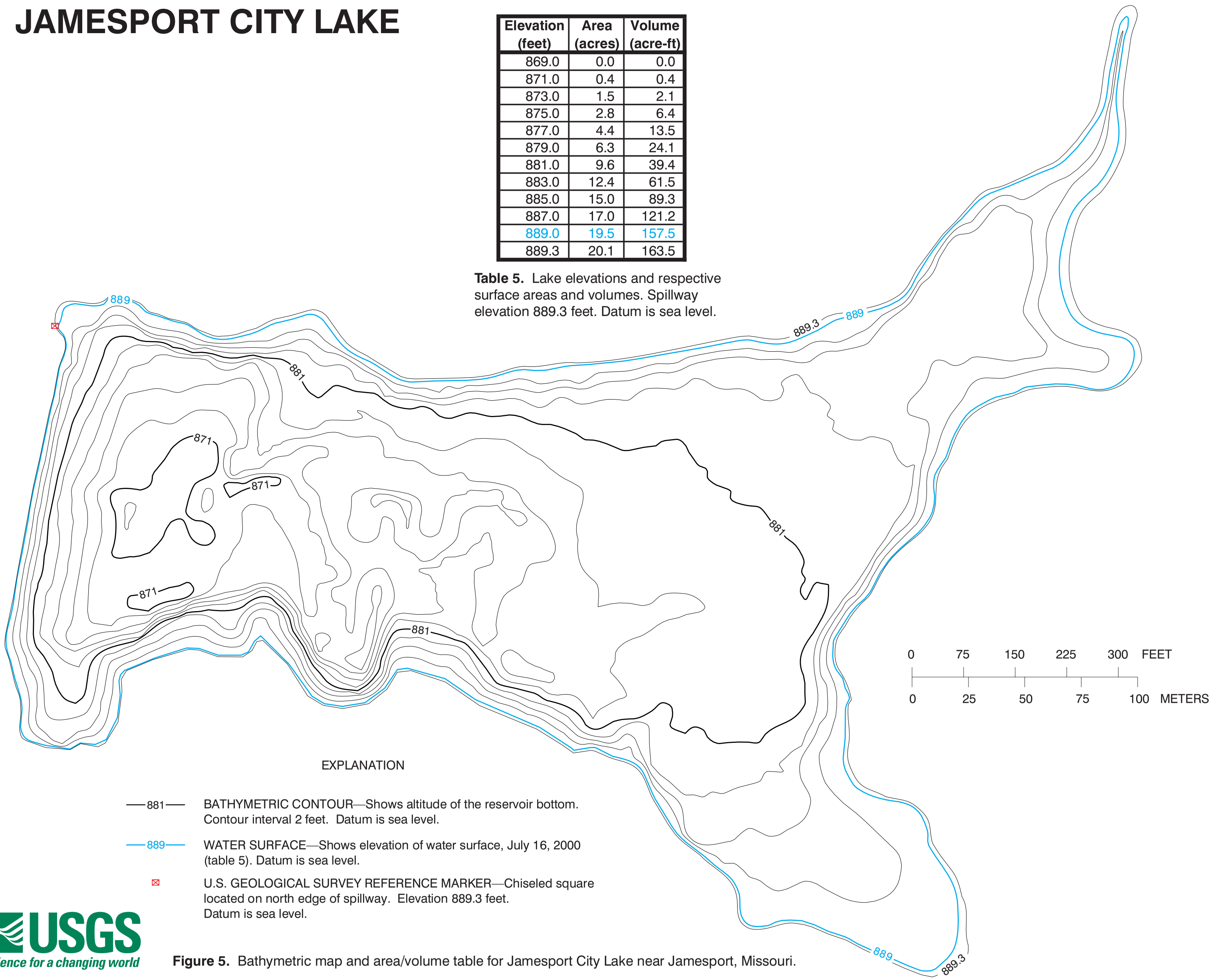
Figure 16.1.b

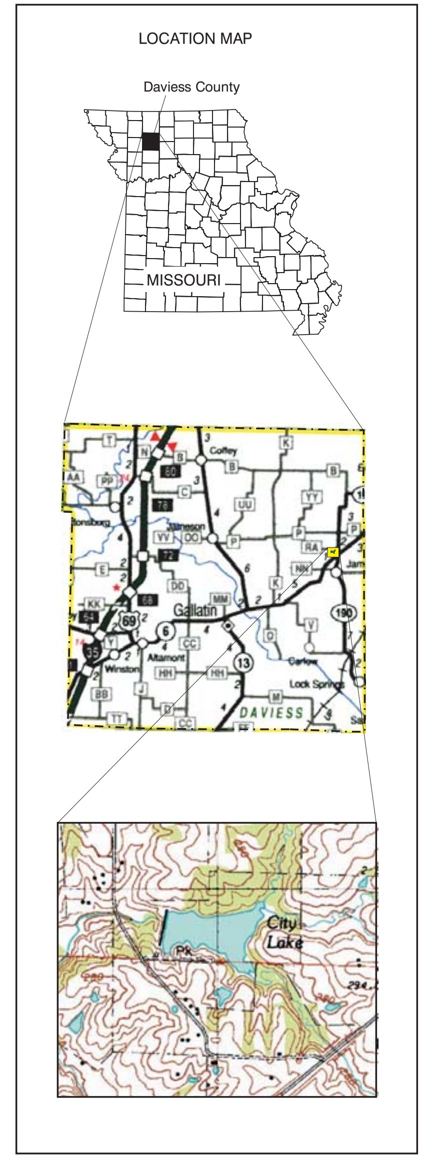

Jamesport, Missouri
Water Supply Study
City Lake
Lake Storage
Maximum Storage = 163 Acre Feet
Current demand = 60,000 GPD
Optimized Yield = 69,050 GPD
Minimum Available Storage = 10 Acre Feet
Storage in Acre Feet
180
160
140
120
100
80
60
40
20
0
1951
1951
1952
1953
1954
1955
1956
1956
1957
1958
1959
Year
Figure 16.2

JAMESPORT CITY LAKE

Elevation (feet)	Area (acres)	Volume (acre-ft)
869.0	0.0	0.0
871.0	0.4	0.4
873.0	1.5	2.1
875.0	2.8	6.4
877.0	4.4	13.5
879.0	6.3	24.1
881.0	9.6	39.4
883.0	12.4	61.5
885.0	15.0	89.3
887.0	17.0	121.2
889.0	19.5	157.5
889.3	20.1	163.5

Table 5. Lake elevations and respective surface areas and volumes. Spillway elevation 889.3 feet. Datum is sea level.





EXPLANATION

—881— BATHYMETRIC CONTOUR—Shows altitude of the reservoir bottom. Contour interval 2 feet. Datum is sea level.

—889— WATER SURFACE—Shows elevation of water surface, July 16, 2000 (table 5). Datum is sea level.

⊠ U.S. GEOLOGICAL SURVEY REFERENCE MARKER—Chiseled square located on north edge of spillway. Elevation 889.3 feet. Datum is sea level.

USGS science for a changing world

Figure 5. Bathymetric map and area/volume table for Jamesport City Lake near Jamesport, Missouri.

King City, Missouri
Water Supply Study
City Lakes (South Lake and 3 North Lakes)

King City is located in Southwest Gentry County on Highway 169, South of Stanberry.

There are four lakes in total. The South Lake is two miles Southeast of town. There are three North Lakes about one mile Northeast of town and these lakes are in series.

King City water use averages 125,000 gallon per day.

The drainage area of the South lake is 0.86 Sq. Mi.

The drainage area of the Upper North lake is 0.09 Sq. Mi.
The incremental drainage area of the Middle North Lake is 0.375 Sq. Mi.
The incremental drainage area of the Lower North Lake is 0.334 Sq. Mi.
Total drainage area of the North Lakes system is 0.799 square miles.

King City Lakes analysis consisted of using the NRCS's computer program called "RESOP". Following is the data and procedures for input to the program.

STO-AREA Elevation-Storage and Elevation-Area data were determined from July 11, 2000 survey made by USGS.

KING CITY SOUTH LAKE

Elevation (feet)	Area (acres)	Volume (acre-ft)	
1010.0	0.02	0.003	
1012.0	0.54	0.38	
1014.0	2.36	2.97	
1016.0	5.15	10.55	
1018.0	8.08	23.83	
1020.0	11.24	43.23	
1022.0	15.05	69.38	
1024.0	18.60	103.34	
1025.4	21.09	131.03	Water surface elevation on 7/19/00
1026.0	22.36	144.06	
1028.0	27.02	193.35	
1030.0	32.73	252.81	
1032.0	39.42	324.85	
1034.0	47.66	411.55	Approximate top of dam

KING CITY LAKE "NORTH"
King City #1 (See Reference Figure) (Lower Lake)

Elevation (feet)	Area (acres)	Volume (acre-ft)
1016.0	0.85	0.17
1017.0	3.82	2.17
1018.0	7.66	8.00
1019.0	9.98	16.92
1020.0	11.93	27.91
1021.0	13.54	40.65
1022.0	14.83	54.86
1023.0	16.04	70.28

1024.0	17.17	86.90	
1025.0	18.19	104.59	
1026.0	19.27	123.33	
1027.0	20.61	143.23	
1028.0	21.77	164.45	
1029.0	22.98	186.83	
1030.0	23.93	210.30	
1031.0	24.81	234.67	
1031.7	25.42	252.24	Water surface elevation on 7/19/00
1032.0	25.67	259.91	
1033.0	26.49	285.99	
1034.0	27.29	312.88	
1034.7	27.84	332.17	Top of spillway

KING CITY LAKE "NORTH"
King City #1a Small Lake - Not used for water supply.
(This lake is a sediment trap)

Elevation (feet)	Area (acres)	Volume (acre-ft)	
1031.0	0.44	0.30	
1032.0	0.86	0.94	
1032.6	1.33	1.57	Water surface elevation on 7/19/00
1033.0	1.42	2.13	
1034.0	1.62	3.65	
1034.7	1.77	4.83	

KING CITY LAKE "NORTH"
King City #2 (See Reference Figure) (Middle Lake)

Elevation (feet)	Area (acres)	Volume (acre-ft)	
1026.0	1.11	0.18	
1027.0	3.54	2.39	
1028.0	5.68	7.11	
1029.0	6.64	13.30	
1030.0	7.67	20.44	
1031.0	8.43	28.50	
1032.0	8.97	37.22	
1033.0	9.32	46.36	
1034.0	9.67	55.86	
1034.6	9.88	61.73	Water surface elevation on 7/19/00
1035.0	10.03	65.71	Spillway elevation

KING CITY LAKE "NORTH"
King City #3 (See Reference Figure) (Upper Lake)

Elevation (feet)	Area (acres)	Volume (acre-ft)
1039.0	0.26	0.10
1040.0	0.55	0.51
1041.0	0.93	1.25
1042.0	1.26	2.35
1043.0	1.65	3.79
1044.0	2.30	5.74
1045.0	2.91	8.38

1046.0	3.27	11.47
1047.0	3.50	14.87
1048.0	3.66	18.45
1049.0	3.83	22.19
1049.7	3.96	24.92 Water surface elevation on 7/19/00
1050.0	4.01	26.12
1051.0	4.28	30.25
1052.0	4.70	34.72
1053.0	5.25	39.68 Approximate top of dam

KING CITY LAKE "NORTH"

King City #3a Small Lake - Not used for water supply.

(This lake is a sediment trap)

Elevation (feet)	Area (acres)	Volume (acre-ft)
1034 0	.19	0.08
1035 0	.64	0.36 Water surface elevation on 7/19/00
1036 0	.81	1.08

	Max. Storage (Ac.Ft.)	Min. Pool Storage (Ac.Ft.)
South Lake	411	17
North Lake (Upper)	39	6
" " (Middle)	65	20
" " (Upper)	332	40

LIMITS Starting storage was considered at maximum pool.

The upper North Lake and The South Lake survey data indicate the top of dam as the upper limit and the lower and middle North lakes the spillway is listed as the upper limit. This is inconsistent with the other surveys being done during this survey contract. Because of this, it is assumed that it the upper north lake and south lakes are mislabeled in the survey data. Also, the south lake was constructed in the last ten years at which time there was surely some kind of demand study made and results of this study with maximum pool at the top survey elevation shows the present demand and the optimized demand to be very close.

The drainage area of the South Lake is 0.86 square miles.
The drainage area of the Upper North Lake is 0.09 square miles square miles.
The Incremental drainage area of the Middle North Lake is 0.375 square miles.
The Incremental drainage area of the Lower North Lake is 0.334 square miles

GENERAL The adjustment to convert from pan evaporation to lake evaporation was made for the control word EVAP. The factor was 0.76. As a result a factor of 100. was used here.

The record period of drought is in the 1950's.
Analysis began in January 1951 and ended December 1959.

SEEPAGE The reservoir seepage varied from 0 seepage near empty to a maximum of 1 inch per month when at full pool. The material in the dam is compacted earth of loamy clay soils. The lakes are shallow so that static pressure is low. As a result seepage is small.

RAINFALL Rainfall data came from the King City, Mo. rain gage. For periods of missing data the Albany gage was used to fill in the missing dates.

RUNOFF	This is the runoff into the lake from its drainage area. Monthly runoff volumes in watershed inches were determined at the White Cloud Creek Stream Gage. White Cloud Creek is located about 25 miles WNW of King City. The drainage at the gage is 6.06 square miles. Monthly runoff was compared to the rainfall and if the results did not appear reasonable, adjustments were made for that month by looking at individual rains and estimating antecedent moisture then adjusting runoff based on NRCS's runoff curve numbers.
EVAP.	Pan evaporation at the Lakeside gaging station was used as a base because it has data for year around evaporation. This data was updated with gage data from stations at Spickard, New Franklin, and Columbia. Depending on the latest data for the station nearest to King City. The adjustment factor of 0.76 to convert from pan to lake evaporation was applied at this step.
DEMAND	This was determined by city records. King City has a total daily use of 125,000 gallons per day. To determine the volume to be used from each lake, an optimized analysis was make and then the same percentages for each lake were used to distribute the 125,000 gallons per day between the four lakes for current demand.
OTHER	This refers to other inflows or outflows. Because there was nothing added or used, this control word was not used.

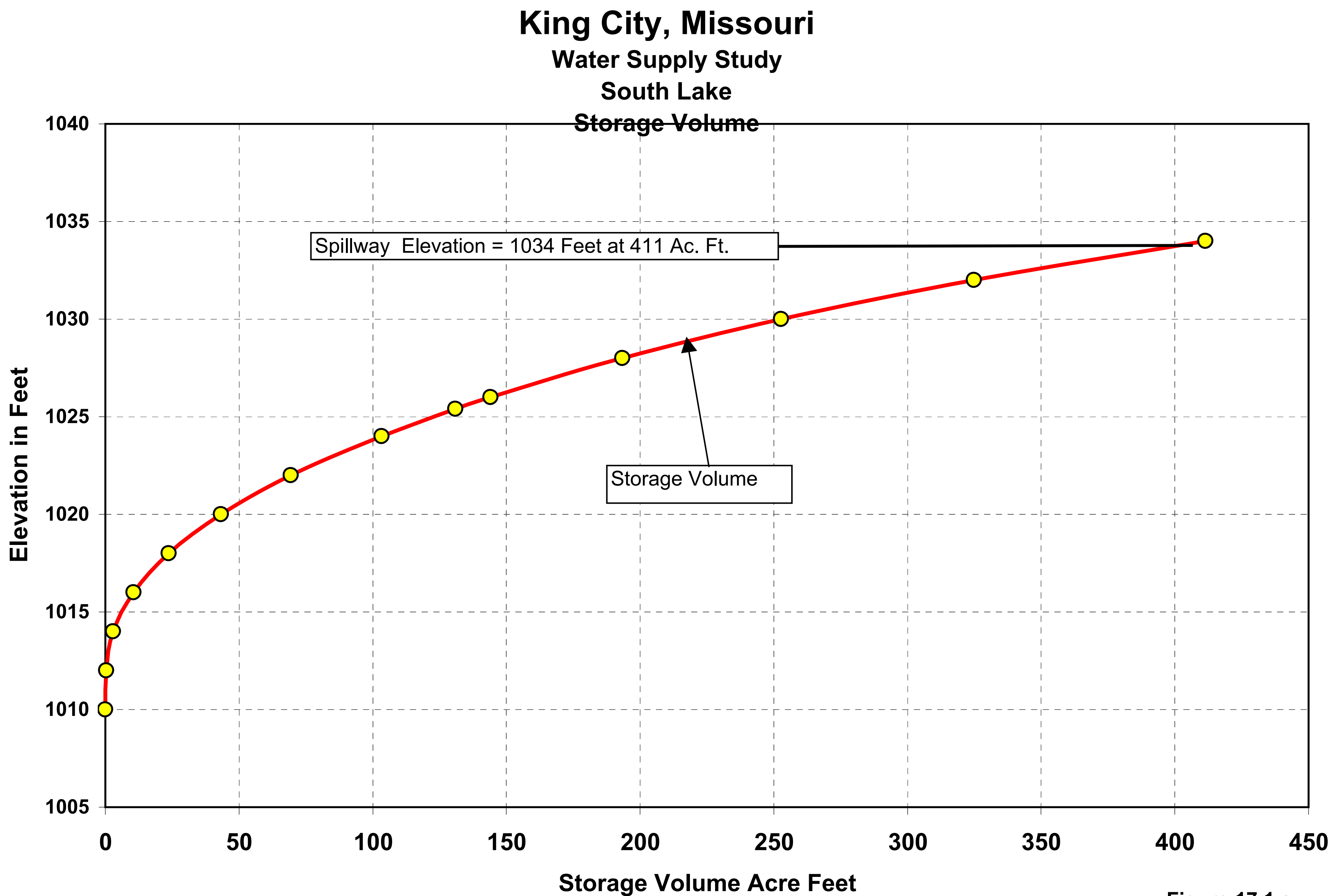

King City, Missouri
Water Supply Study
South Lake
Storage Volume
Spillway Elevation = 1034 Feet at 411 Ac. Ft.
Storage Volume
Elevation in Feet
1040
1035
1030
1025
1020
1015
1010
1005
0
50
100
150
200
250
300
350
400
450
Storage Volume Acre Feet

Figure 17.1.a

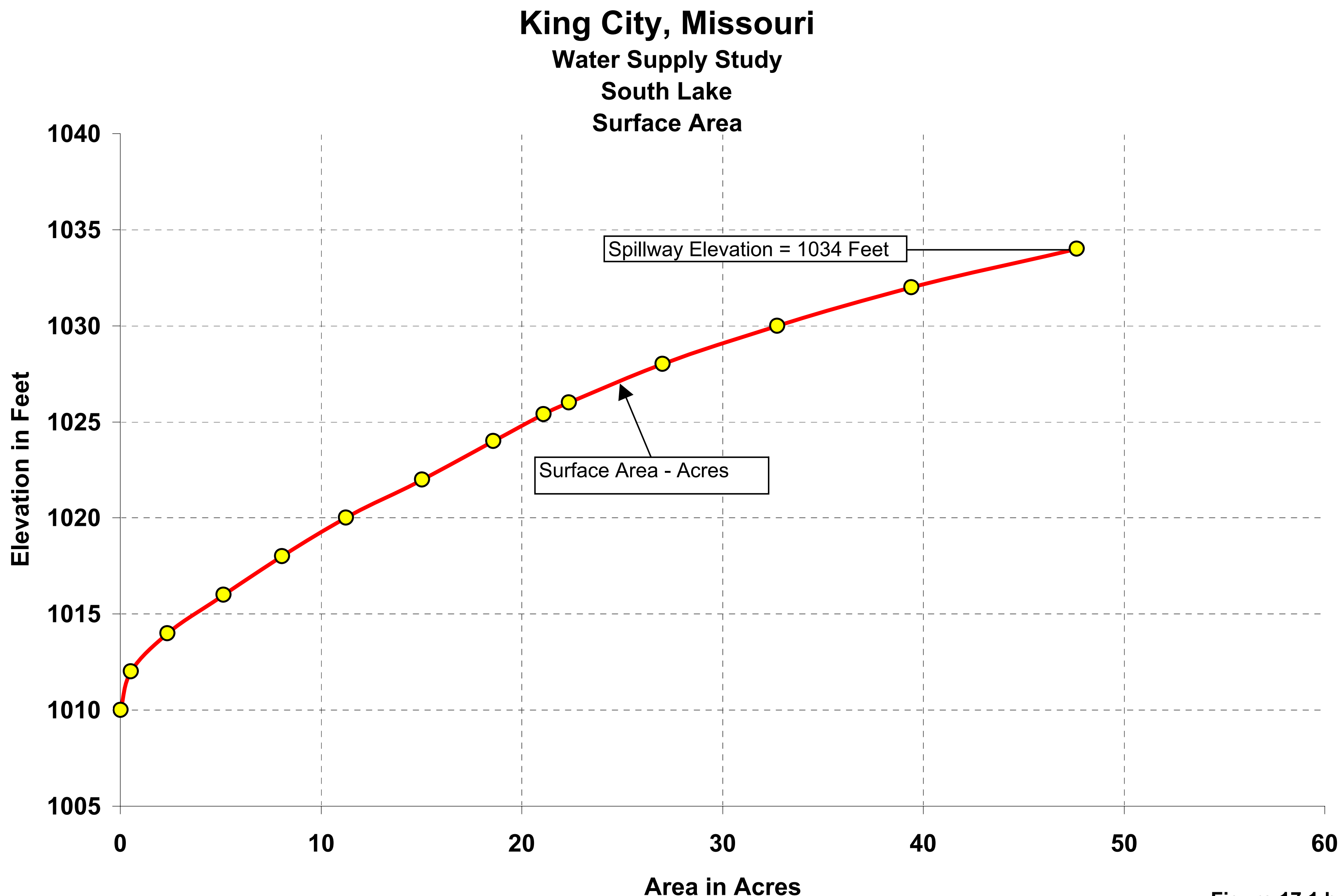

King City, Missouri
Water Supply Study
South Lake
Surface Area
Elevation in Feet
1040
1035
1030
1025
1020
1015
1010
1005
0
10
20
30
40
50
60
Area in Acres
Spillway Elevation = 1034 Feet
Surface Area - Acres

Figure 17.1.b

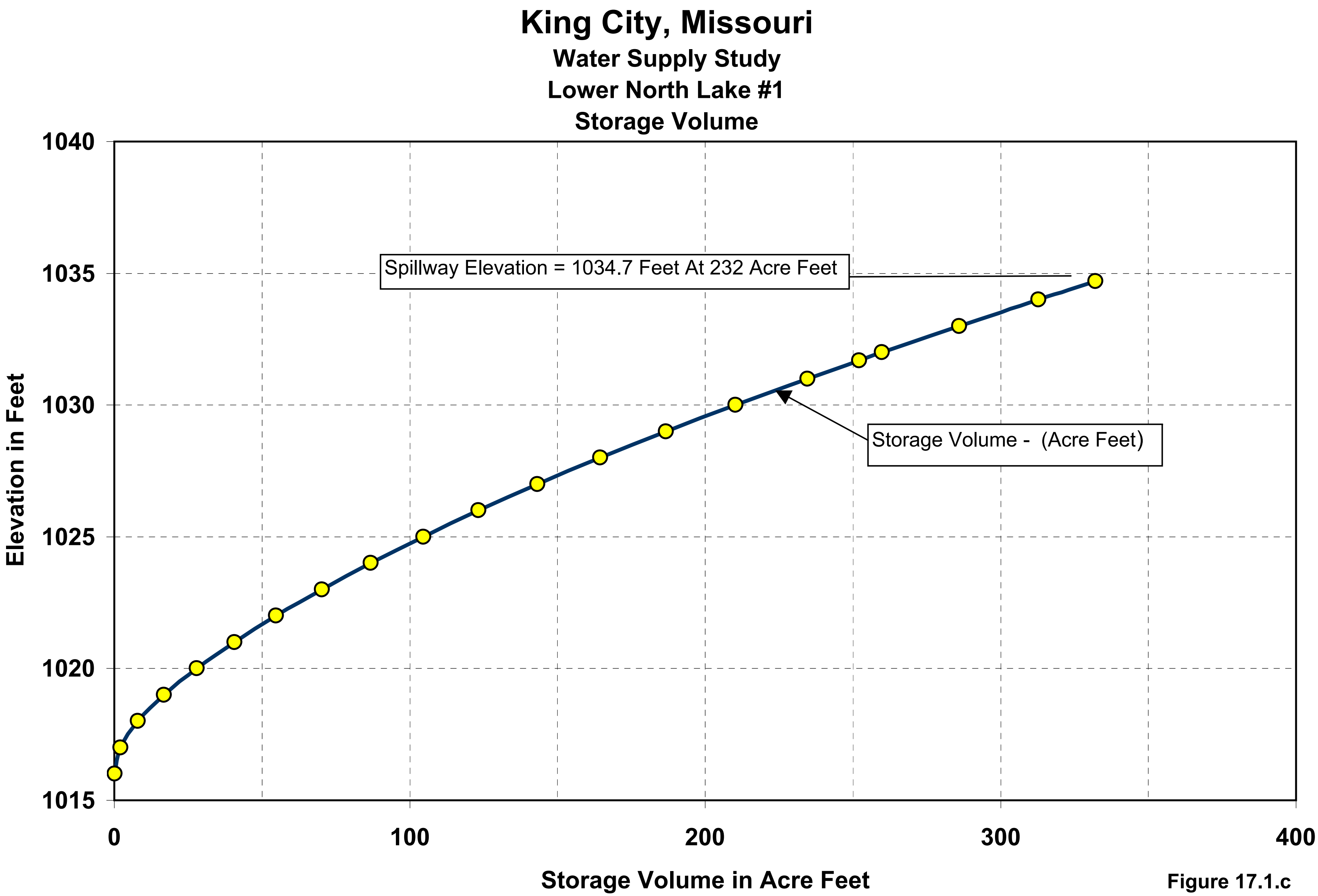

King City, Missouri
Water Supply Study
Lower North Lake #1
Storage Volume
Spillway Elevation = 1034.7 Feet At 232 Acre Feet
Storage Volume - (Acre Feet)
1040
1035
1030
1025
1020
1015
0
100
200
300
400
Elevation in Feet
Storage Volume in Acre Feet

Figure 17.1.c

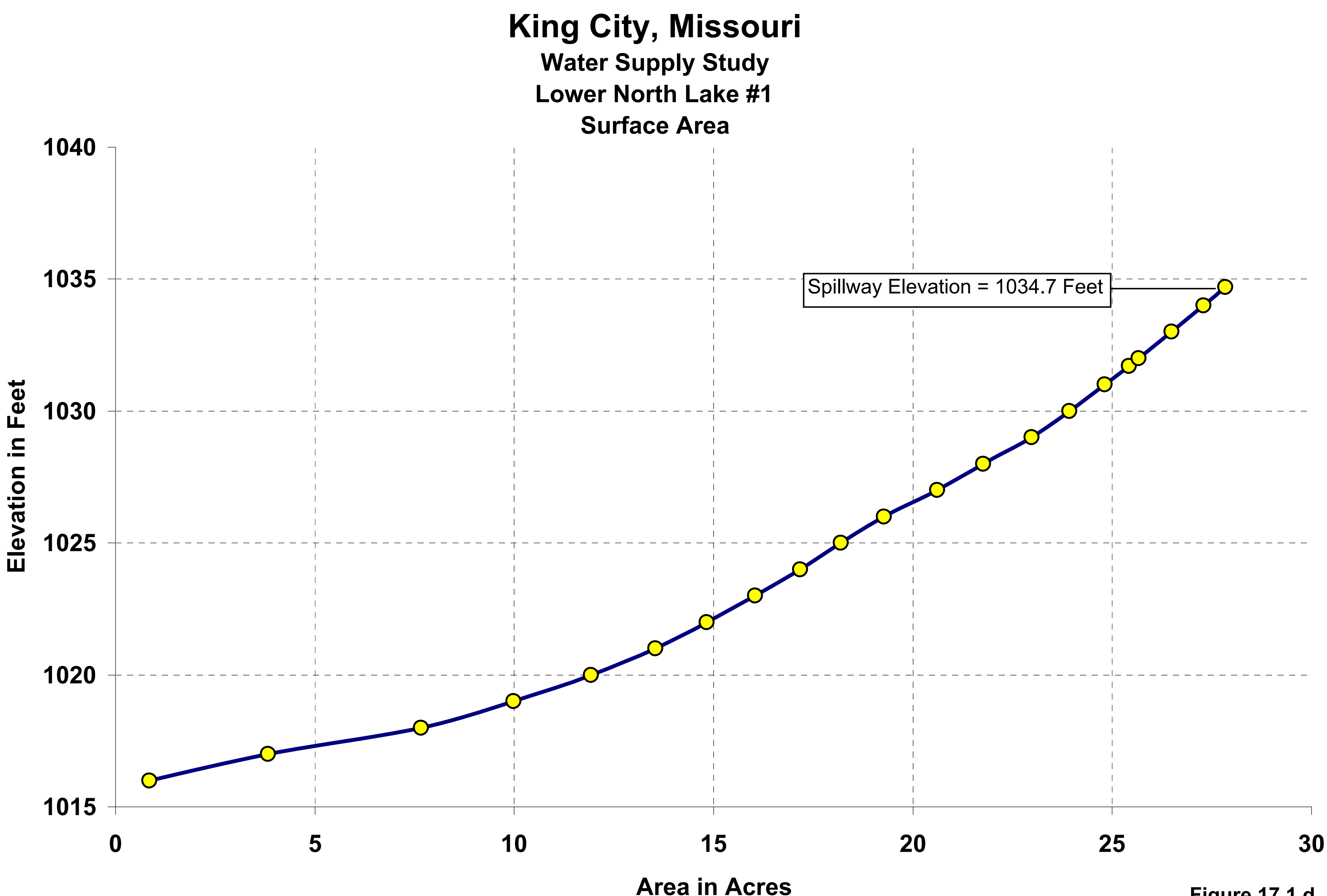

King City, Missouri
Water Supply Study
Lower North Lake #1
Surface Area
Elevation in Feet
1040
1035
1030
1025
1020
1015
0
5
10
15
20
25
30
Area in Acres
Spillway Elevation = 1034.7 Feet

Figure 17.1.d

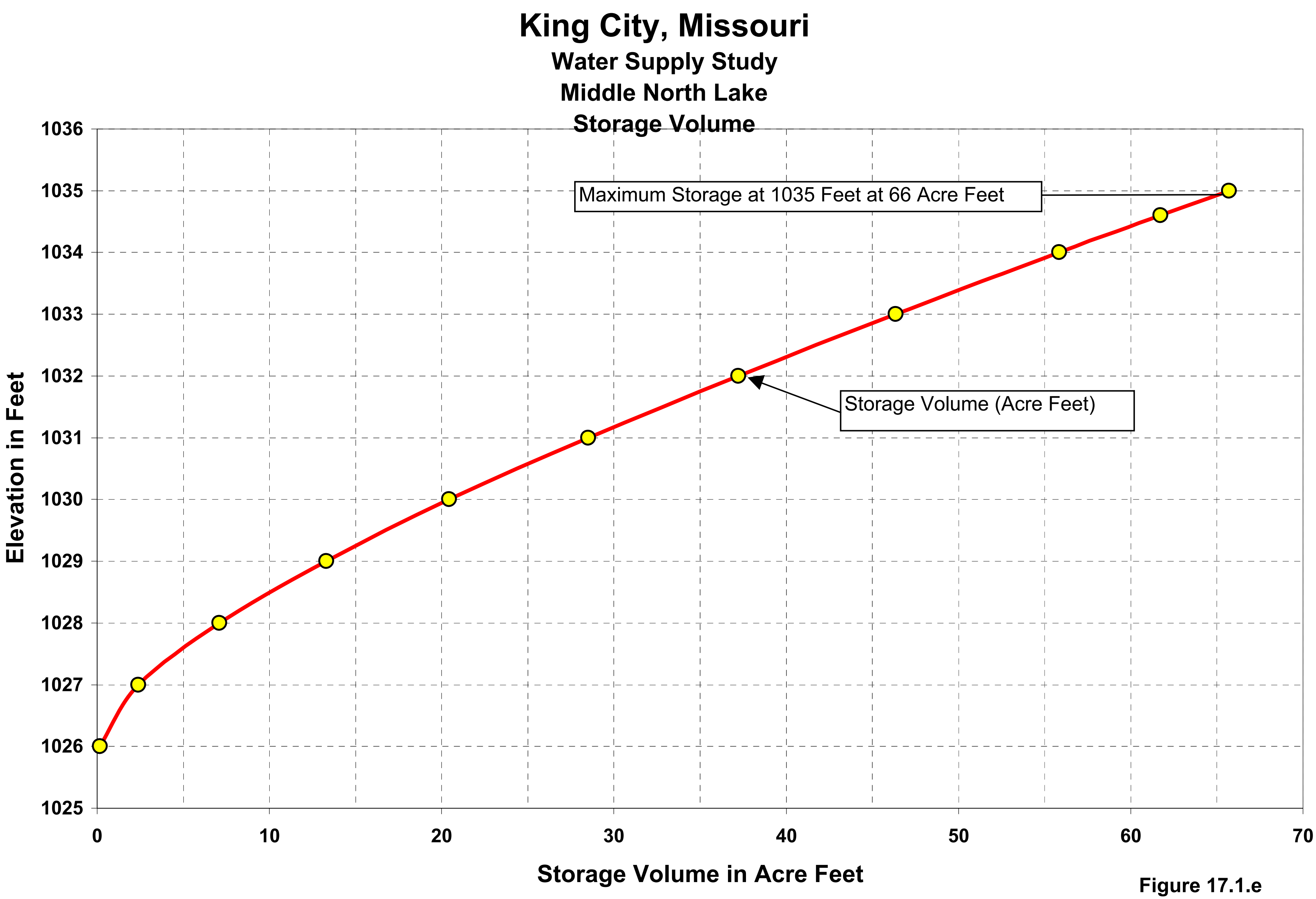

King City, Missouri
Water Supply Study
Middle North Lake
Storage Volume
Elevation in Feet
1036
1035
1034
1033
1032
1031
1030
1029
1028
1027
1026
1025
0
10
20
30
40
50
60
70
Storage Volume in Acre Feet
Maximum Storage at 1035 Feet at 66 Acre Feet
Storage Volume (Acre Feet)

Figure 17.1.e

King City, Missouri
Water Supply Study
Middle North Lake #2
Surface Area

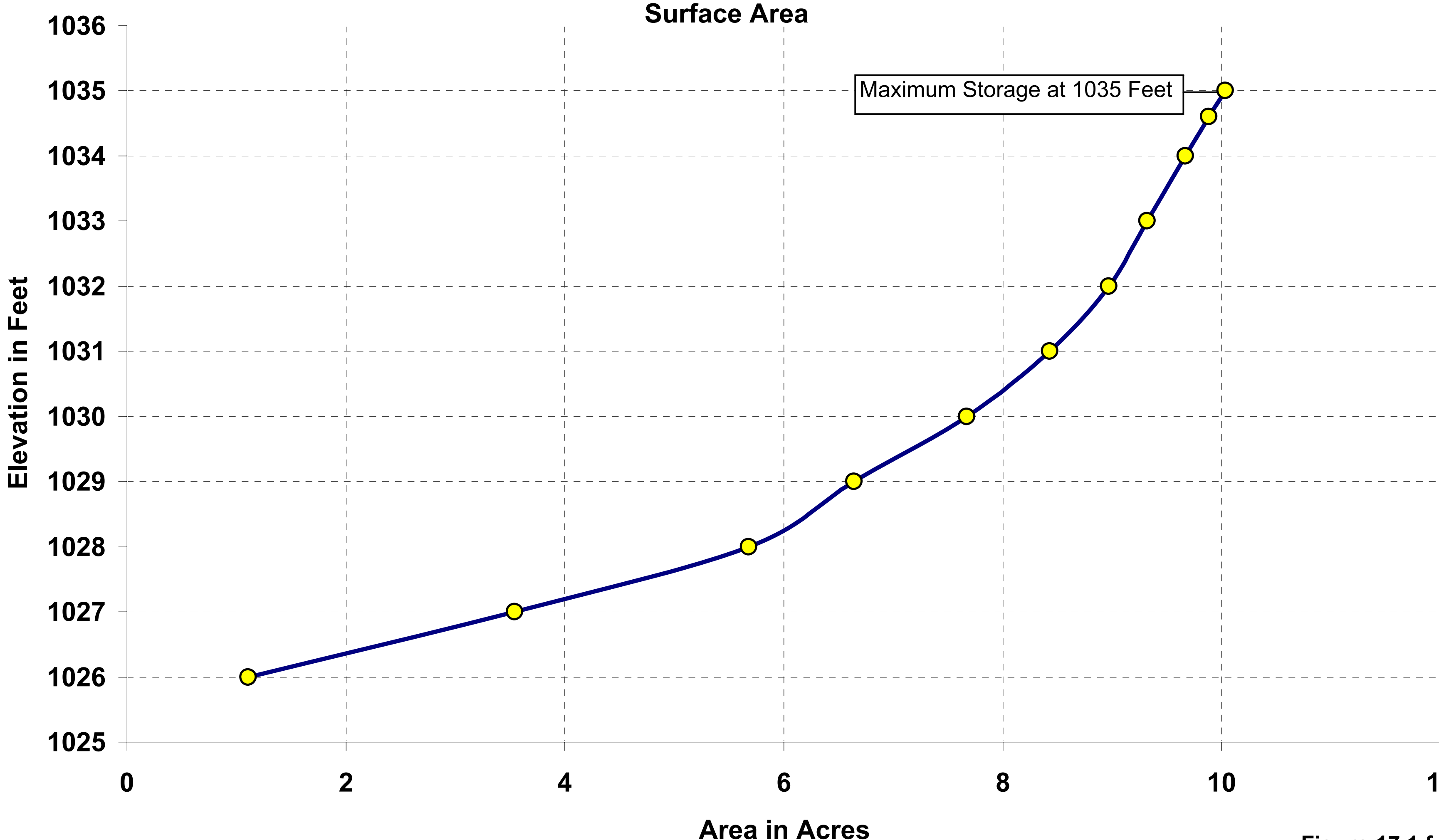


Figure 17.1.f

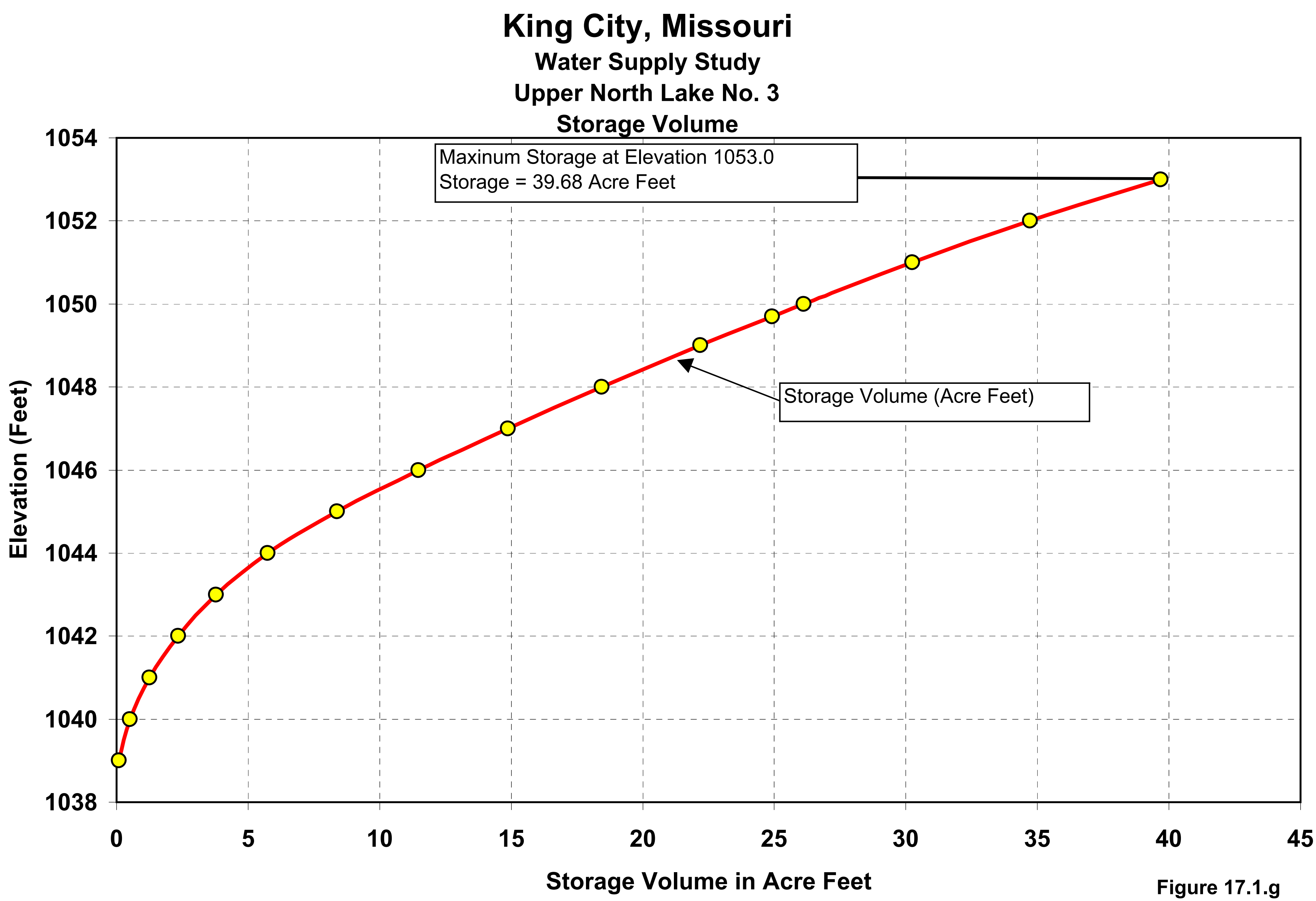

King City, Missouri
Water Supply Study
Upper North Lake No. 3
Storage Volume
Maxinum Storage at Elevation 1053.0
Storage = 39.68 Acre Feet
Storage Volume (Acre Feet)
Elevation (Feet)
1054
1052
1050
1048
1046
1044
1042
1040
1038
0
5
10
15
20
25
30
35
40
45
Storage Volume in Acre Feet

Figure 17.1.g

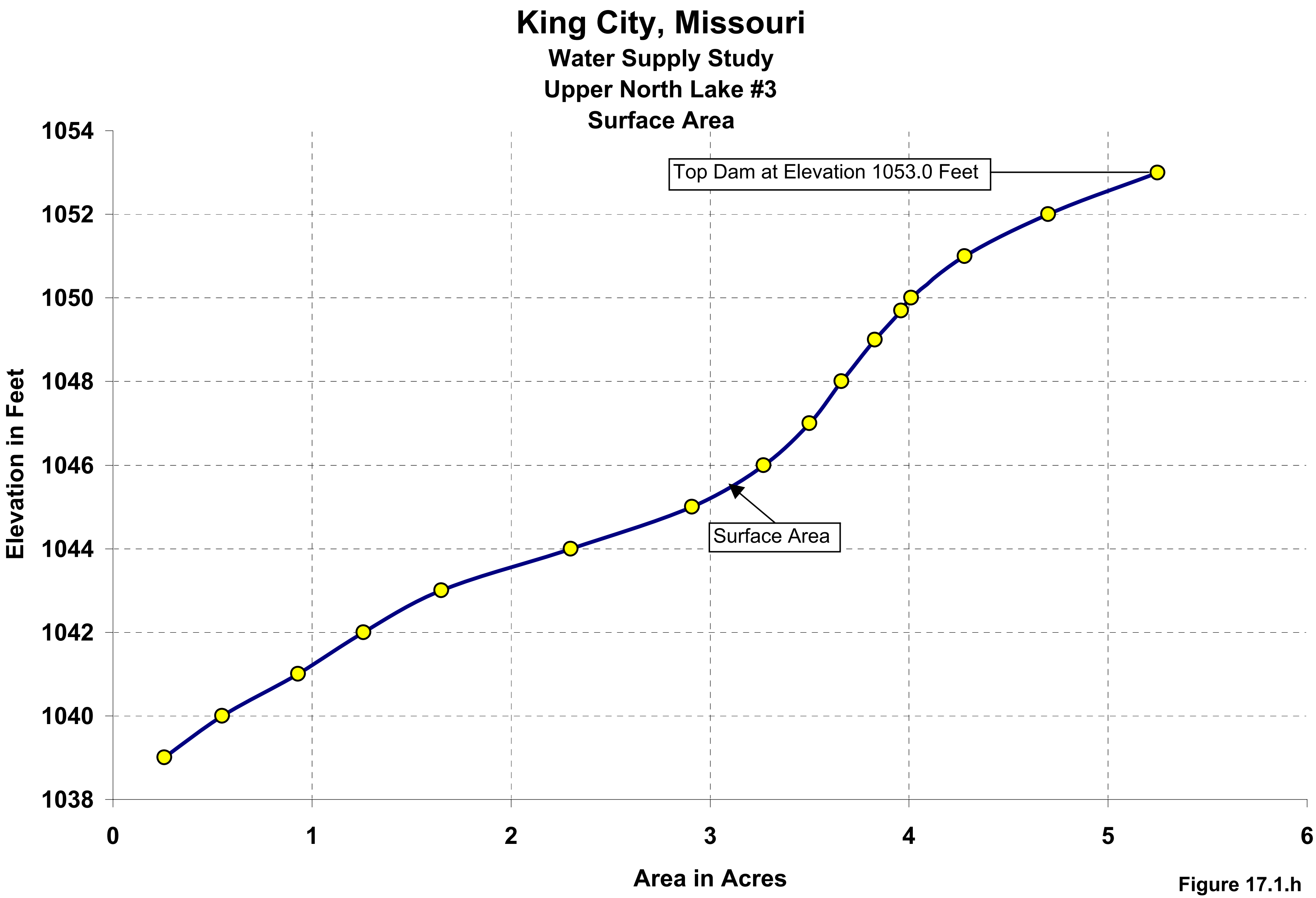

King City, Missouri
Water Supply Study
Upper North Lake #3
Surface Area
Top Dam at Elevation 1053.0 Feet
Surface Area
Elevation in Feet
1054
1052
1050
1048
1046
1044
1042
1040
1038
0
1
2
3
4
5
6
Area in Acres

Figure 17.1.h

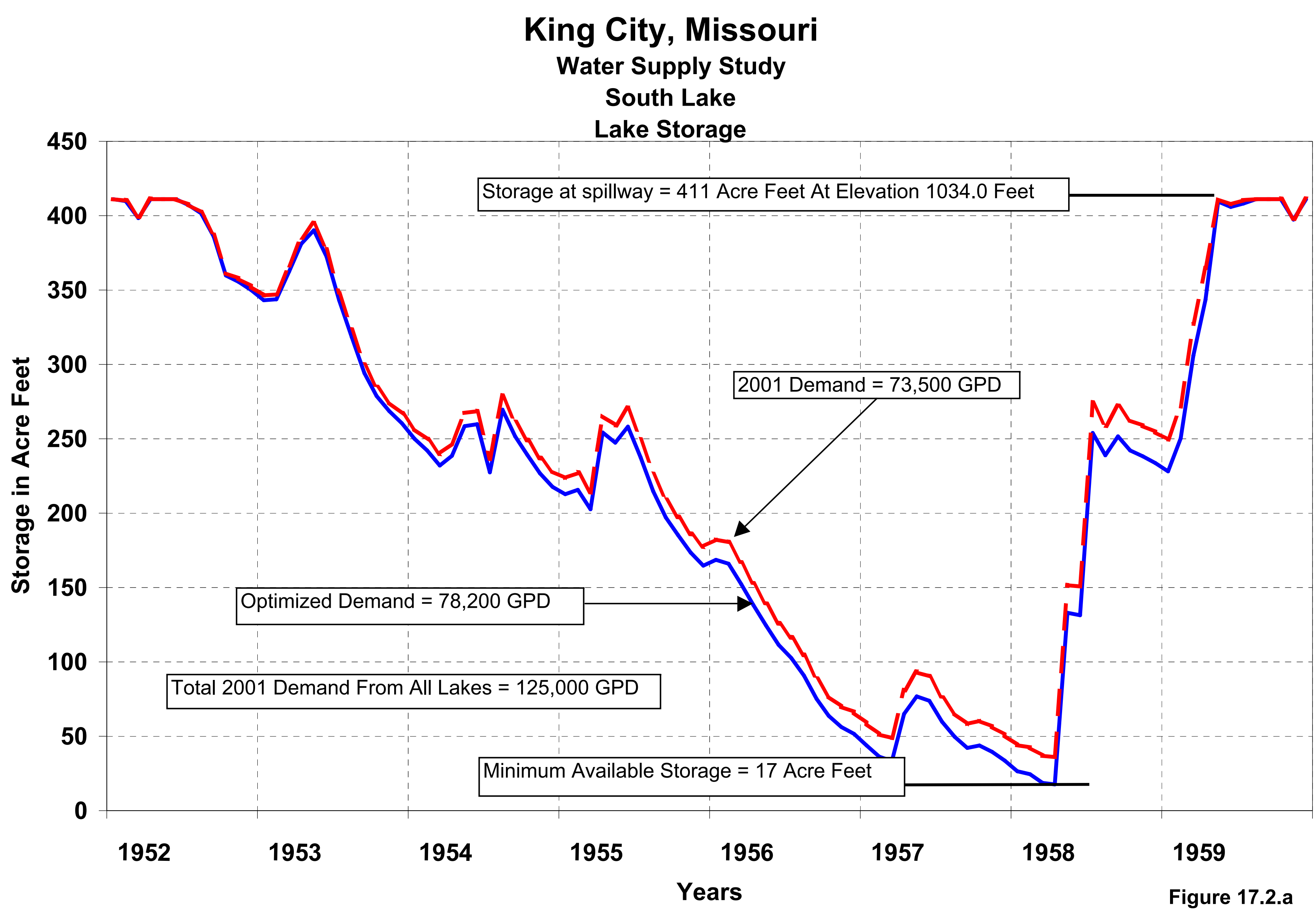

King City, Missouri
Water Supply Study
South Lake
Lake Storage
Storage in Acre Feet
450
400
350
300
250
200
150
100
50
0
Storage at spillway = 411 Acre Feet At Elevation 1034.0 Feet
2001 Demand = 73,500 GPD
Optimized Demand = 78,200 GPD
Total 2001 Demand From All Lakes = 125,000 GPD
Minimum Available Storage = 17 Acre Feet
1952
1953
1954
1955
1956
1957
1958
1959
Years

Figure 17.2.a

King City, Missouri
Water Supply Study
Lower North Lake No. 1
Lake Storage

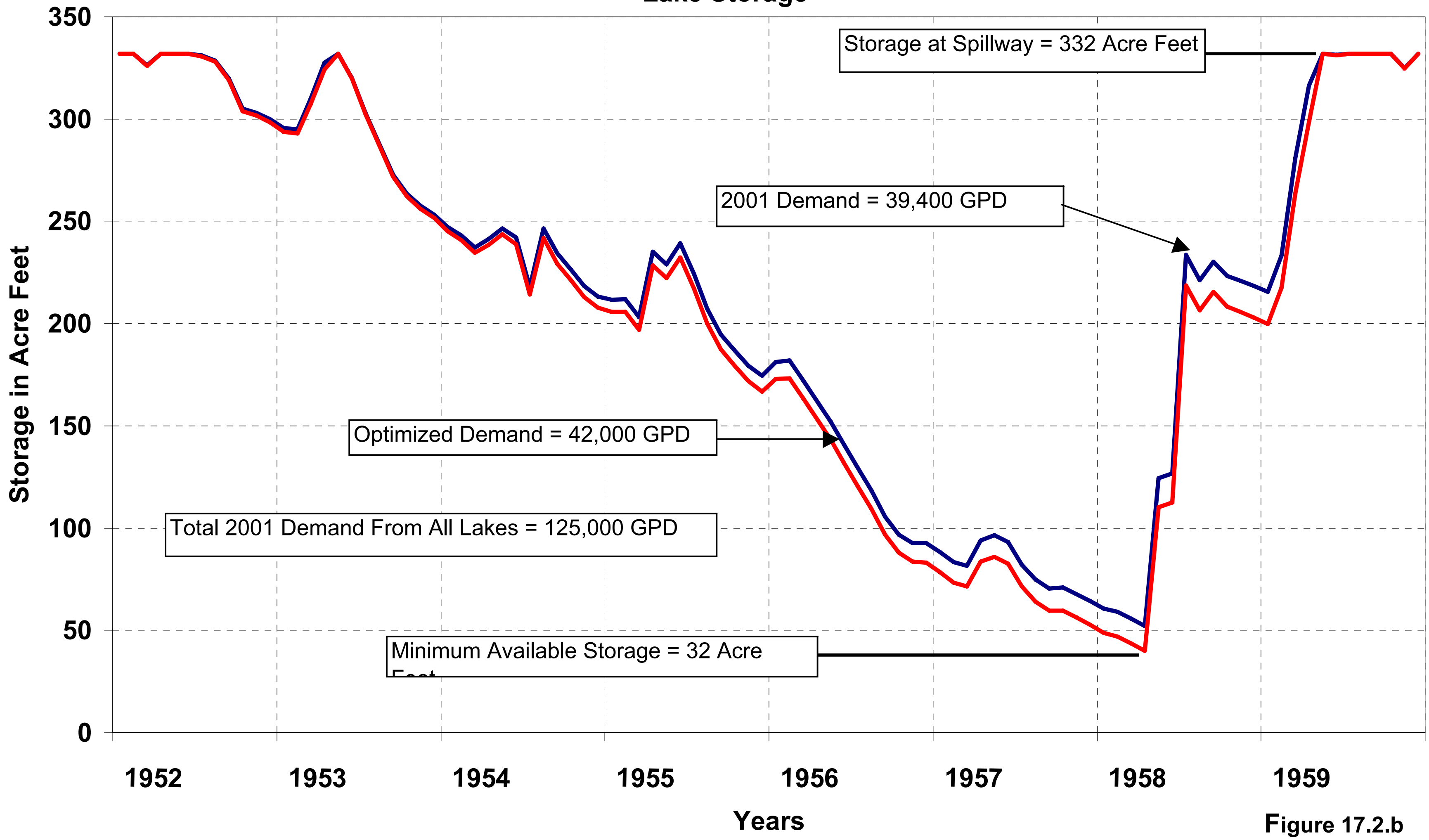


Figure 17.2.b

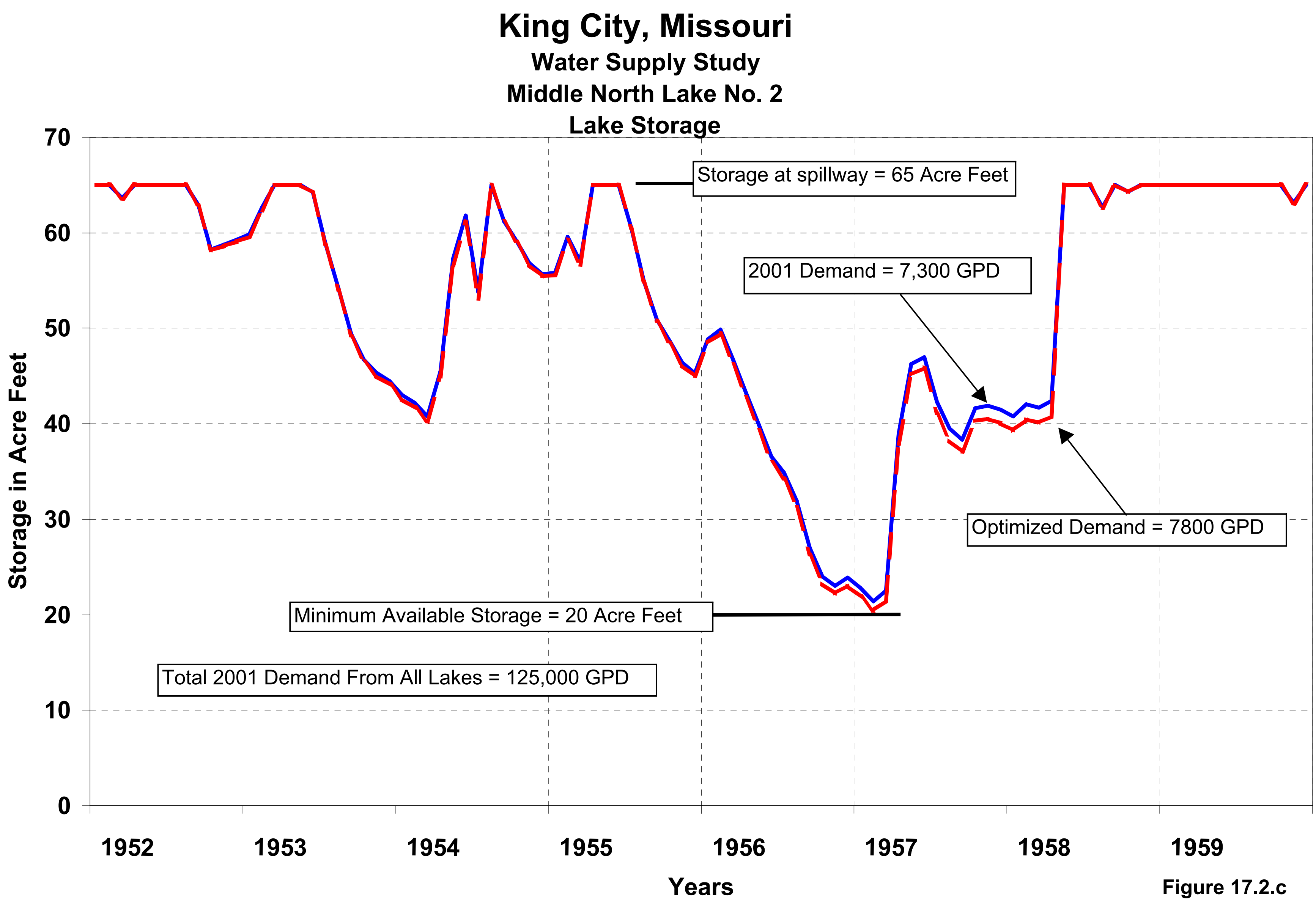

King City, Missouri
Water Supply Study
Middle North Lake No. 2
Lake Storage
Storage in Acre Feet
70
60
50
40
30
20
10
0
1952
1953
1954
1955
1956
1957
1958
1959
Years
Storage at spillway = 65 Acre Feet
2001 Demand = 7,300 GPD
Optimized Demand = 7800 GPD
Minimum Available Storage = 20 Acre Feet
Total 2001 Demand From All Lakes = 125,000 GPD

Figure 17.2.c

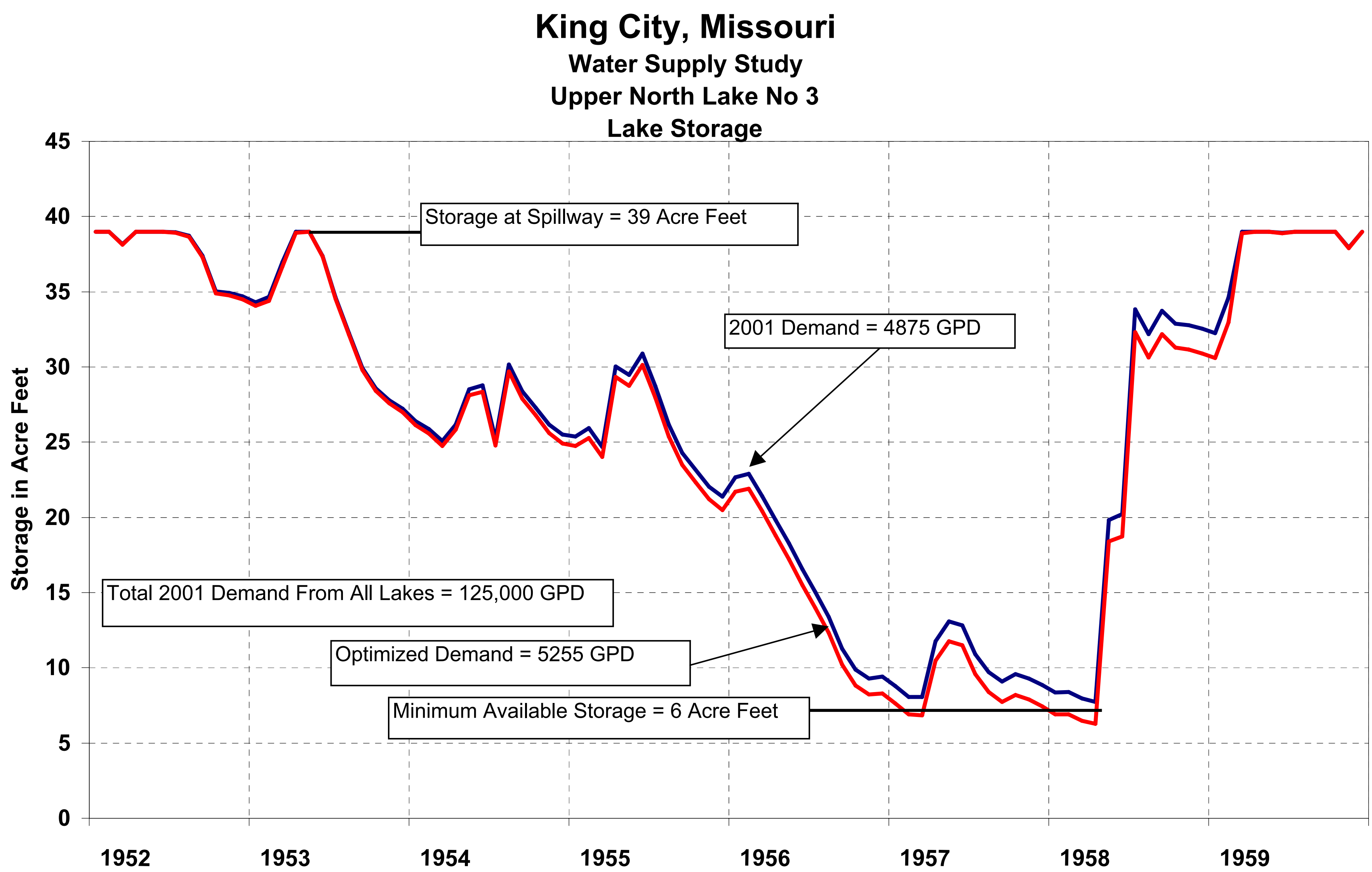

King City, Missouri
Water Supply Study
Upper North Lake No 3
Lake Storage
Storage in Acre Feet
45
40
35
30
25
20
15
10
5
0
Storage at Spillway = 39 Acre Feet
2001 Demand = 4875 GPD
Total 2001 Demand From All Lakes = 125,000 GPD
Optimized Demand = 5255 GPD
Minimum Available Storage = 6 Acre Feet
1952
1953
1954
1955
1956
1957
1958
1959
Years

Figure 17.2.d

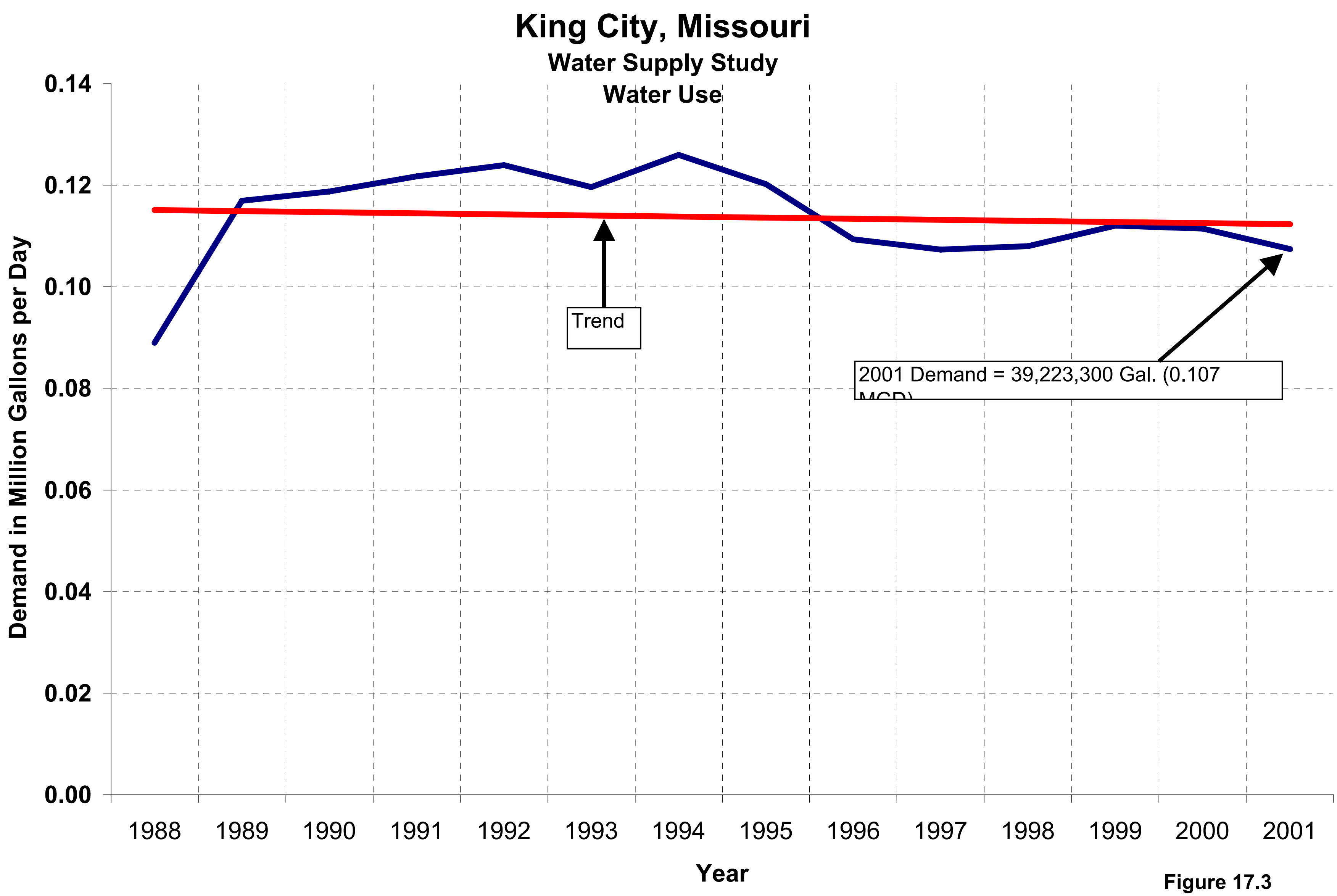
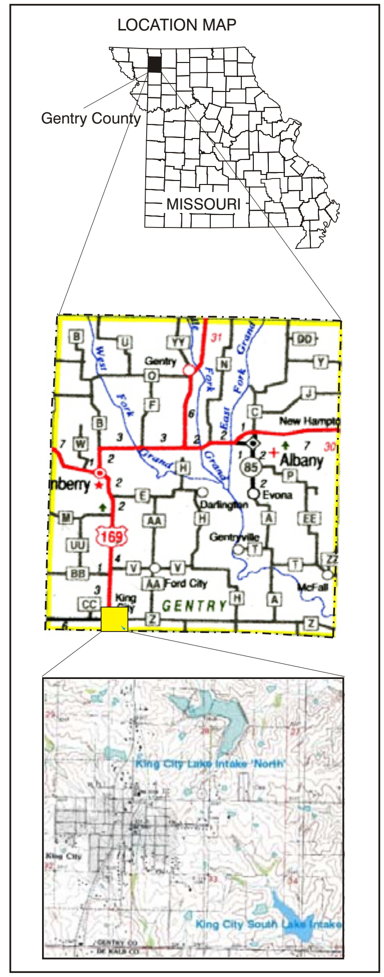

King City, Missouri
Water Supply Study
Water Use
Demand in Million Gallons per Day
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
Trend
2001 Demand = 39,223,300 Gal. (0.107
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
Year

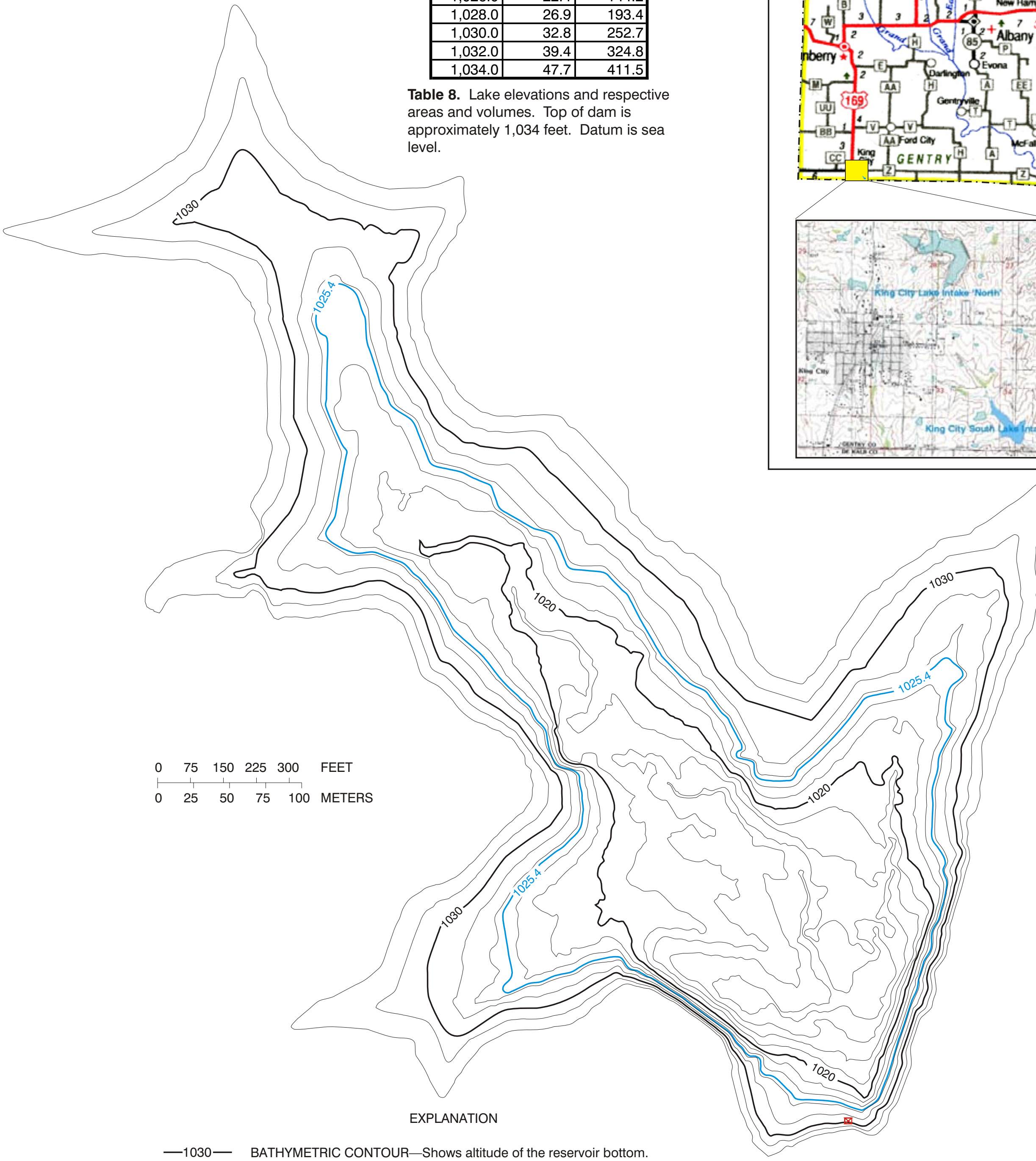
Figure 17.3

KING CITY SOUTH LAKE



Elevation (feet)	Area (acres)	Volume (acre-ft)
1,012.0	0.6	0.4
1,014.0	2.4	3.0
1,016.0	5.2	10.6
1,018.0	8.1	23.9
1,020.0	11.3	43.4
1,022.0	15.1	69.5
1,024.0	18.6	103.5
1,025.4	21.1	131.2
1,026.0	22.4	144.2
1,028.0	26.9	193.4
1,030.0	32.8	252.7
1,032.0	39.4	324.8
1,034.0	47.7	411.5

Table 8. Lake elevations and respective areas and volumes. Top of dam is approximately 1,034 feet. Datum is sea level.



EXPLANATION

—1030— BATHYMETRIC CONTOUR—Shows altitude of the reservoir bottom. Contour interval 2 feet. Datum is sea level.

—1025.4— WATER SURFACE—Shows elevation of water surface, July 19, 2000 (table 7).Datum is sea level.

⊠ U.S. GEOLOGICAL SURVEY REFERENCE MARKER—Chiseled square located on east side of boat ramp (unstable surface). Elevation 1029.8 feet. Datum is sea level.

USGS
science for a changing world

Figure 7. Bathymetric map and table of areas/volumes of the King City South Lake near King City, Missouri.

Lamar, Missouri
Water Supply Study
City Lake

Lamar is in west central Missouri, in Barton County.

Lamar water supply comes from a city owned lake located about 1.5 miles Southeast of Lamar on a tributary to Spring River. During drought periods their water supply is supplemented by a well.

The drainage area of the lake is 4.77 square miles.

Average annual rainfall is 37.2 inches. Annual rainfall for 1953 through 1957 is 21.45, 35.52, 34.61, 23.14, and 48.20 inches.

Lamar Lake analysis consisted of using the NRCS's computer program "RESOP". This program analyses remaining stored water at the end of each month by summing gains and losses.

Two analysis were made:

1. First run was with the 2001 demand.
2. The lake was analyzed for the optimum daily use without emptying the lake during the evaluation period.

Following is the data procedures and consideration for input to the "RESOP" program.

STO-AREA Elevation-Storage and Elevation-Area data were determined from June 26, 2002 survey made by USGS.

Lamar Lake

Elevation (feet)	Area (acres)	Storage (ac-ft)	
870.0	0.73	0.54	
930.0	0.06	0.06	
932.0	0.14	0.26	
934.0	1.51	1.05	
936.0	8.43	10.39	
938.0	20.05	37.38	
940.0	36.18	93.37	
942.0	50.58	180.12	
944.0	65.53	296.15	
946.0	80.64	441.95	
948.0	95.73	617.85	
950.0	112.00	825.55	
952.0	125.97	1063.64	
954.0	142.38	1329.90	
955.7	156.37	1582.55	W.S. and Spillway Elev. on 5/22/02 (full pool)

LIMITS Full pool storage 1582 Ac.Ft.
Minimum pool storage 35 Ac.Ft.

Starting storage was considered at full pool.

The drainage area of the lake is 4.77 square miles.

GENERAL	The adjustment to convert from pan evaporation to lake evaporation was made for the control word EVAP. The factors were monthly values. As a result a factor of 100 was used. The record period of drought is in the 1950's. Analysis began in January 1951 and ended December 1959.
SEEPAGE	The reservoir seepage varied from 0 seepage near empty to a maximum of 2.0 inches per month at full pool. The seepage rate is a best estimate based on history of the reservoir, soil type, material of the core of the dam and compaction of the earth fill. The material in the dam is compacted earth of clayey soils.
RAINFALL	Rainfall data came from the Lamar, Mo. rain gage for the period 1951 through 1959.
RUNOFF	This is the runoff into the lake from its drainage area. Monthly runoff volumes in watershed inches were determined for the Cedar Creek Gage near Pleasant View. In cases where rainfall to runoff values did not appear reasonable, adjustments were made for that month by looking at individual rains and estimating antecedent moisture then, adjusting runoff based on NRCS's runoff curve numbers.
EVAP.	Pan evaporation at the Lakeside gaging station was used as a base because it has data for year around evaporation. All other stations only measure data between April through November. Lakeside data was updated during these months with gage data from stations at New Franklin, and Columbia. Depending on the latest data for the station nearest to Lamar.
DEMAND	This was determined by city records. Lamar used a total of 175,144,800 gallons during 2001for an average of 479,850 gallons per day.

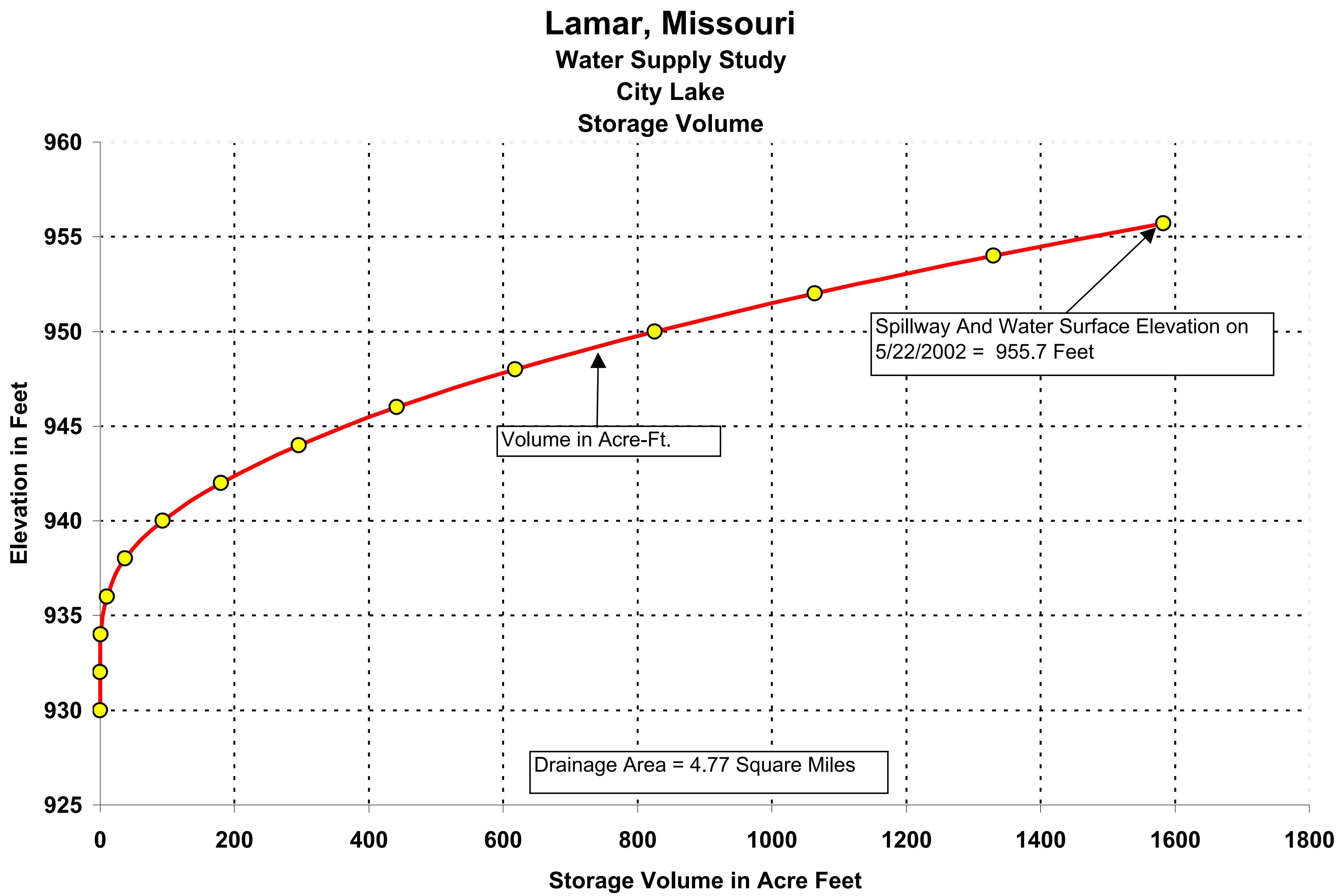

Lamar, Missouri
Water Supply Study
City Lake
Storage Volume
960
955
950
945
940
935
930
925
Elevation in Feet
0
200
400
600
800
1000
1200
1400
1600
1800
Storage Volume in Acre Feet
Volume in Acre-Ft.
Spillway And Water Surface Elevation on 5/22/2002 = 955.7 Feet
Drainage Area = 4.77 Square Miles

Figure 18.1.a

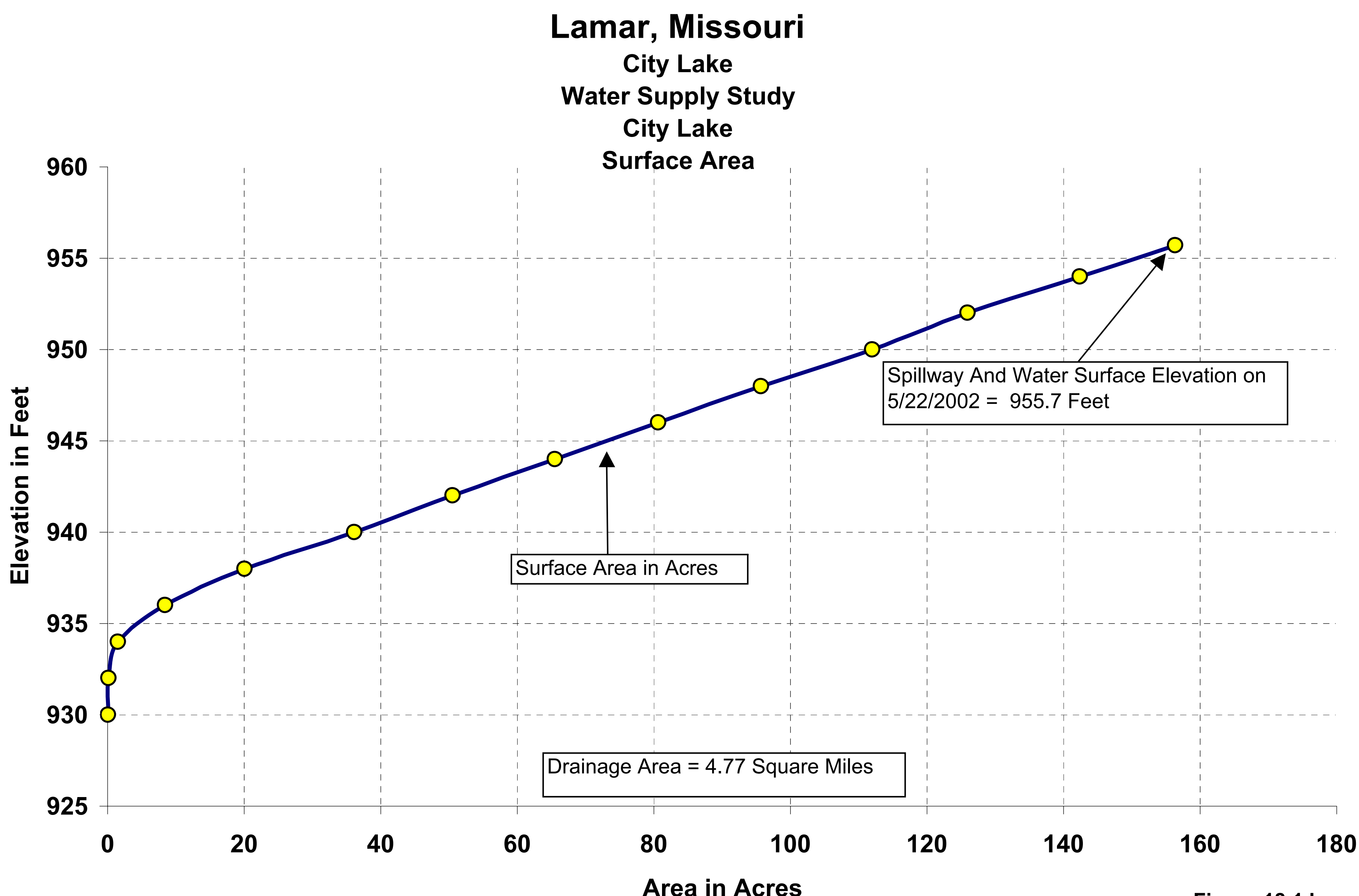

Lamar, Missouri
City Lake
Water Supply Study
City Lake
Surface Area
Elevation in Feet
960
955
950
945
940
935
930
925
0
20
40
60
80
100
120
140
160
180
Area in Acres
Spillway And Water Surface Elevation on
5/22/2002 = 955.7 Feet
Surface Area in Acres
Drainage Area = 4.77 Square Miles

Figure 18.1.b

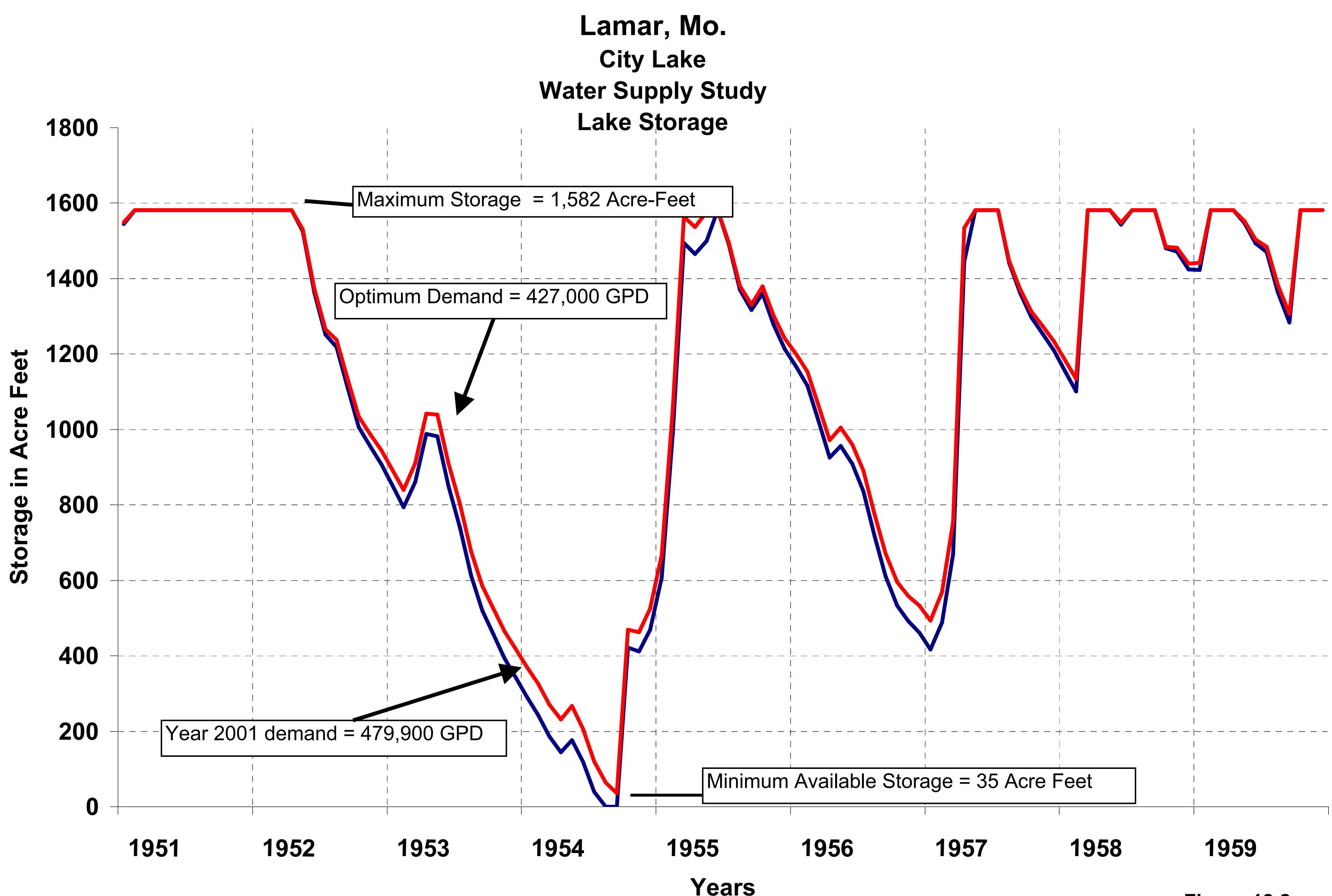

Lamar, Mo.
City Lake
Water Supply Study
Lake Storage
Storage in Acre Feet
1800
1600
1400
1200
1000
800
600
400
200
0
Maximum Storage = 1,582 Acre-Feet
Optimum Demand = 427,000 GPD
Year 2001 demand = 479,900 GPD
Minimum Available Storage = 35 Acre Feet
1951
1952
1953
1954
1955
1956
1957
1958
1959
Years

Figure 18.2

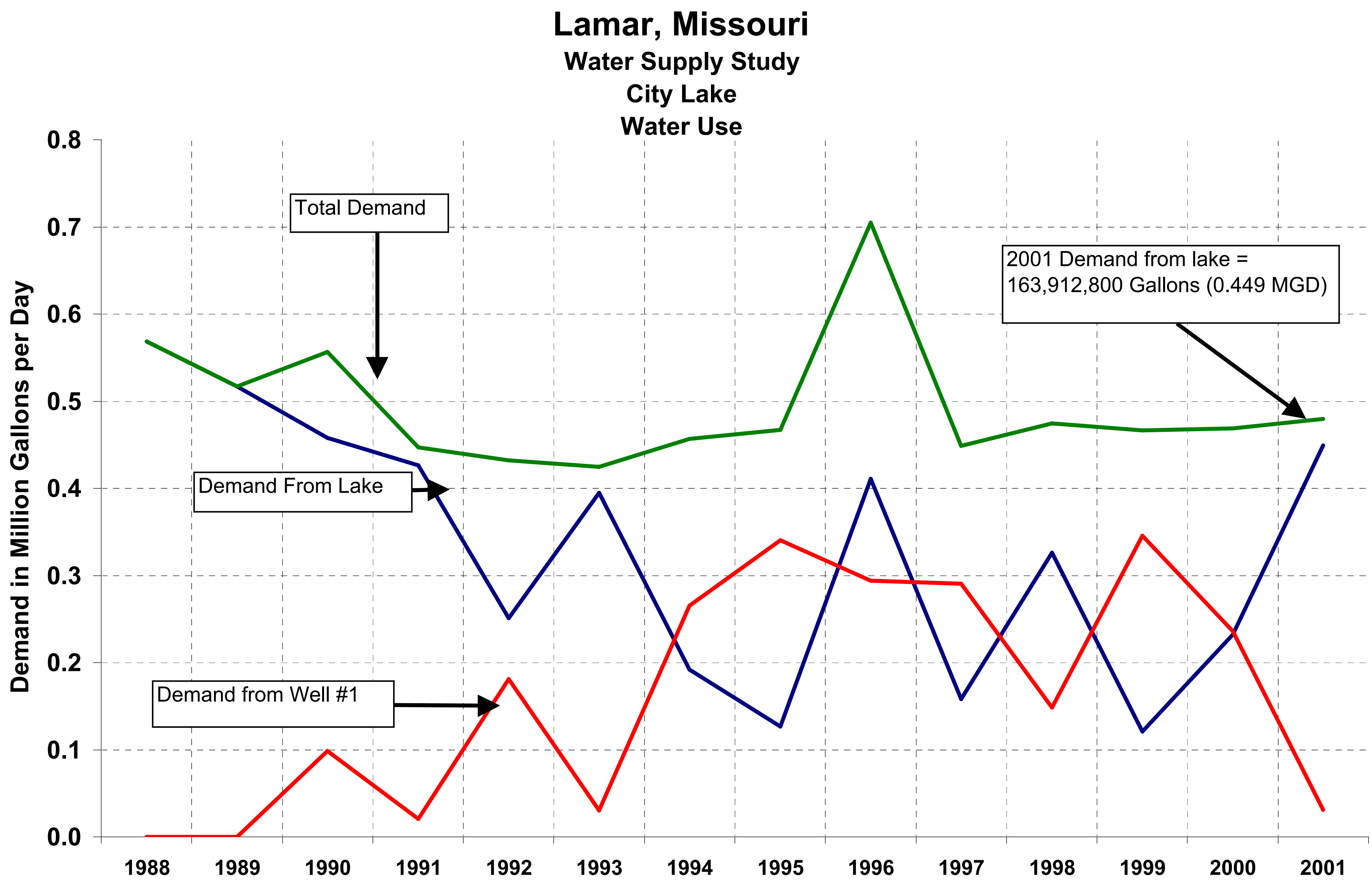
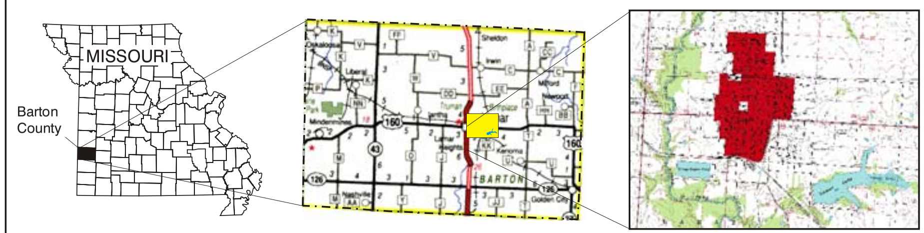

Lamar, Missouri
Water Supply Study
City Lake
Water Use
Total Demand
2001 Demand from lake =
163,912,800 Gallons (0.449 MGD)
Demand From Lake
Demand from Well #1
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Demand in Million Gallons per Day
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
Year

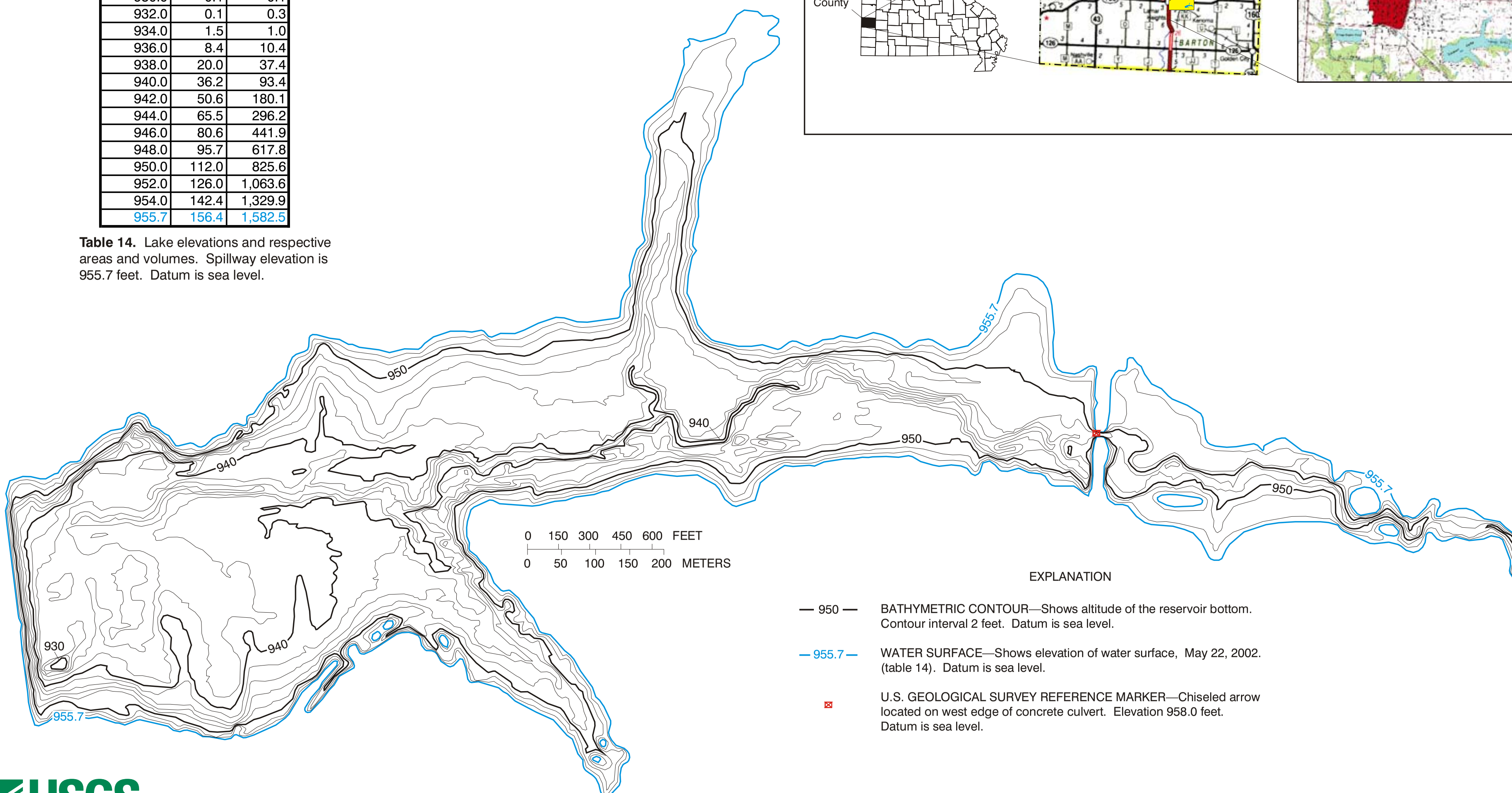
Figure 18.3

LAMAR LAKE

Elevation (feet)	Area (acres)	Volume (acre-ft)
930.0	0.1	0.1
932.0	0.1	0.3
934.0	1.5	1.0
936.0	8.4	10.4
938.0	20.0	37.4
940.0	36.2	93.4
942.0	50.6	180.1
944.0	65.5	296.2
946.0	80.6	441.9
948.0	95.7	617.8
950.0	112.0	825.6
952.0	126.0	1,063.6
954.0	142.4	1,329.9
955.7	156.4	1,582.5

Table 14. Lake elevations and respective areas and volumes. Spillway elevation is 955.7 feet. Datum is sea level.





EXPLANATION

— 950 — BATHYMETRIC CONTOUR—Shows altitude of the reservoir bottom. Contour interval 2 feet. Datum is sea level.

— 955.7 — WATER SURFACE—Shows elevation of water surface, May 22, 2002. (table 14). Datum is sea level.

U.S. GEOLOGICAL SURVEY REFERENCE MARKER—Chiseled arrow located on west edge of concrete culvert. Elevation 958.0 feet. Datum is sea level.

USGS science for a changing world

Figure 14. Bathymetric map and table of areas/volumes of Lamar Lake near Lamar, Missouri.

Marceline, Missouri
Water Supply Study

Marceline is located in Southeast Linn County in North Central Missouri.

Marceline has two lakes that can provide water to the city. They also have plans to pump from Mussel Fork Creek if needed.

Mussel Fork Creek intake location is East of Marceline and has a drainage of 146.71 square miles. The watershed shape is long and narrow, like many of North Missouri streams. Downstream of this location, at drainage area 267 square miles, is a stream gage site. Records were kept from October 1948 through September 1951 and again Oct 1962 through February 1990. For the 1950's, it was necessary to use the Locust Creek gage. Gage data was adjusted to the intake point by the drainage area ratio. Analysis of the data indicates that flow in Mussel Fork at the intake location would be so low during drought periods that withdraw would probably not be possible. Pumping was not considered part of this operation plan.

The 7-day Q-10 low flow needed to meet in-stream flow requirements is near zero.

A frequency analysis prepared to determine mean monthly discharges at the intake shows the 100 year(1%), 50 year(2%), and 25 year(4%) chance of non-excedence. These low flows are shown in figure 7. Low flows are 1 cubic feet per second or less for about half of the months.

The main lake is located approximately 4 miles SSW of Marceline and has a drainage area of 3.73 square miles. The surface area at the top of the dam is approximately 189 acres.

The older North Lake is used only if the water supply becomes critical. This North Lake has a drainage Area of 271 Acres. The lake has approximately 80 acres surface area at top of dam elevation. This lake was not surveyed. Storage-Area relationships were proportioned based on the main larger lake. The lake was assumed to be 18 feet deep when full.

Average annual rainfall for the last 50 years is 38.8 inches at Brookfield.
Annual rainfall during the drought period 1953 through 1957 was 7.6, 38.7, 34.1, 23.4, and 48.2 inches.

Marceline used 447,726 gallon per day in year 2000.
Optimum demand for the main lake is 412,000 gallon per day.
The old lake could be expected to supply 60,000 gallon per day.

Following is the data derivation by control word for use in the "RESOP" computer program.

STO-AREA Elevation-Storage and Elevation-Area data were determined from May 19, 2000 survey made by USGS.

Marceline City Lake (New)			Old Lake (North) not surveyed		
Elevation (feet)	Area (acres)	Storage (ac-ft)	Assumed Elev.	Estimated Area(Ac)	Estimated Volume(ac.Ft.)
729.0	0	0	100	0.0	0.0
730.0	5	3	100.5	2.1	0.6
732.0	13	20	101.6	5.5	4.8
734.0	21	55	102.7	8.9	12.7
736.0	31	106	103.8	13.1	24.7
738.0	41	178	104.9	17.4	41.4
740.0	53	272	106.0	22.4	63.3
742.0	64	389	107.1	27.1	90.4

744.0	75	528	108.2	31.7	122.7
746.0	85	688	109.3	36.0	159.8
748.0	97	870	110.4	41.1	202.1
750.0	110	1080	111.5	46.6	250.1
752.0	122	1310	112.6	51.6	304.0
754.0	135	1570	113.7	57.1	363.6
754.5	139	1630	114.0	58.8	379.5
756.0	151	1850	114.8	63.9	40.0
756.9	160	1990	115.3	67.7	462.5 Assumed Spillway
760	189		117.0	80.0	588.1

Water surface 7/12/03 = 754.5 feet
Spillway Elevation = 756.9 feet

LIMITS Marceline City Lake (New) Max. pool storage 1990 Ac.Ft.
Minimum pool storage 200 Ac.Ft.

Old (North) Lake Max pool storage 462 Ac.Ft.
Minimum pool storage 60 Ac.Ft.

GENERAL The adjustment factor of 0.76 to convert from pan evaporation to lake evaporation was applied prior to entering the data for the control word EVAP. As a result a factor of 100 is applied.

The record period of drought is in the 1950's, analysis began in January 1951 and ended December 1959.

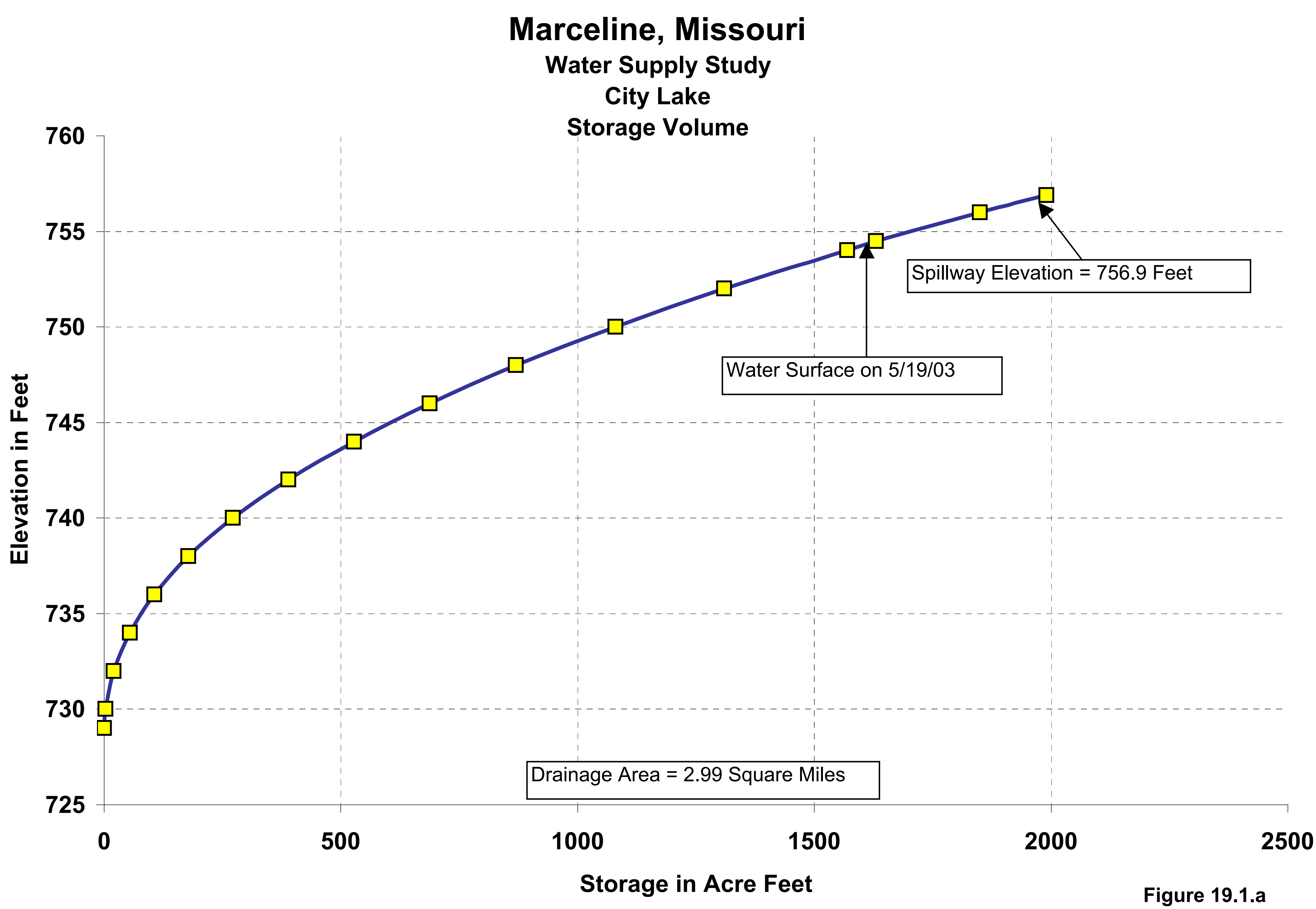
SEEPAGE The reservoir seepage varied from 0 seepage near empty to a maximum of 3.0 inch per month, per surface area when lake is full. The material in the dam is compacted earth of clayey soils.

RAINFALL Rainfall data came from the Brookfield, Missouri. rain gage.

RUNOFF This is the runoff into the lake from its drainage area. Monthly runoff volumes in watershed inches was determined at the Linneus gage on Locust creek and adjusted based on drainage area. When runoff did not appear reasonable when compared to rainfall it was necessary to examine daily rainfall values for that month. Antecedent moisture was estimated for each rainfall event and adjustments to NRCS runoff curve number was made to arrive at runoff for each storm.

EVAP. -- Pan evaporation at the Lakeside gaging station was used as a base because it has some data for year around evaporation. This data was updated with gage data from stations at Spickard, New Franklin, and Columbia. Depending on the latest data for the station nearest to Marceline.

DEMAND -- This was determined by city records. They used 447,726 gallons per day in year 2000. Only an optimized run was made for the old lake.



Marceline, Missouri
Water Supply Study
City Lake
Storage Volume
Elevation in Feet
760
755
750
745
740
735
730
725
0
500
1000
1500
2000
2500
Storage in Acre Feet
Spillway Elevation = 756.9 Feet
Water Surface on 5/19/03
Drainage Area = 2.99 Square Miles

Figure 19.1.a

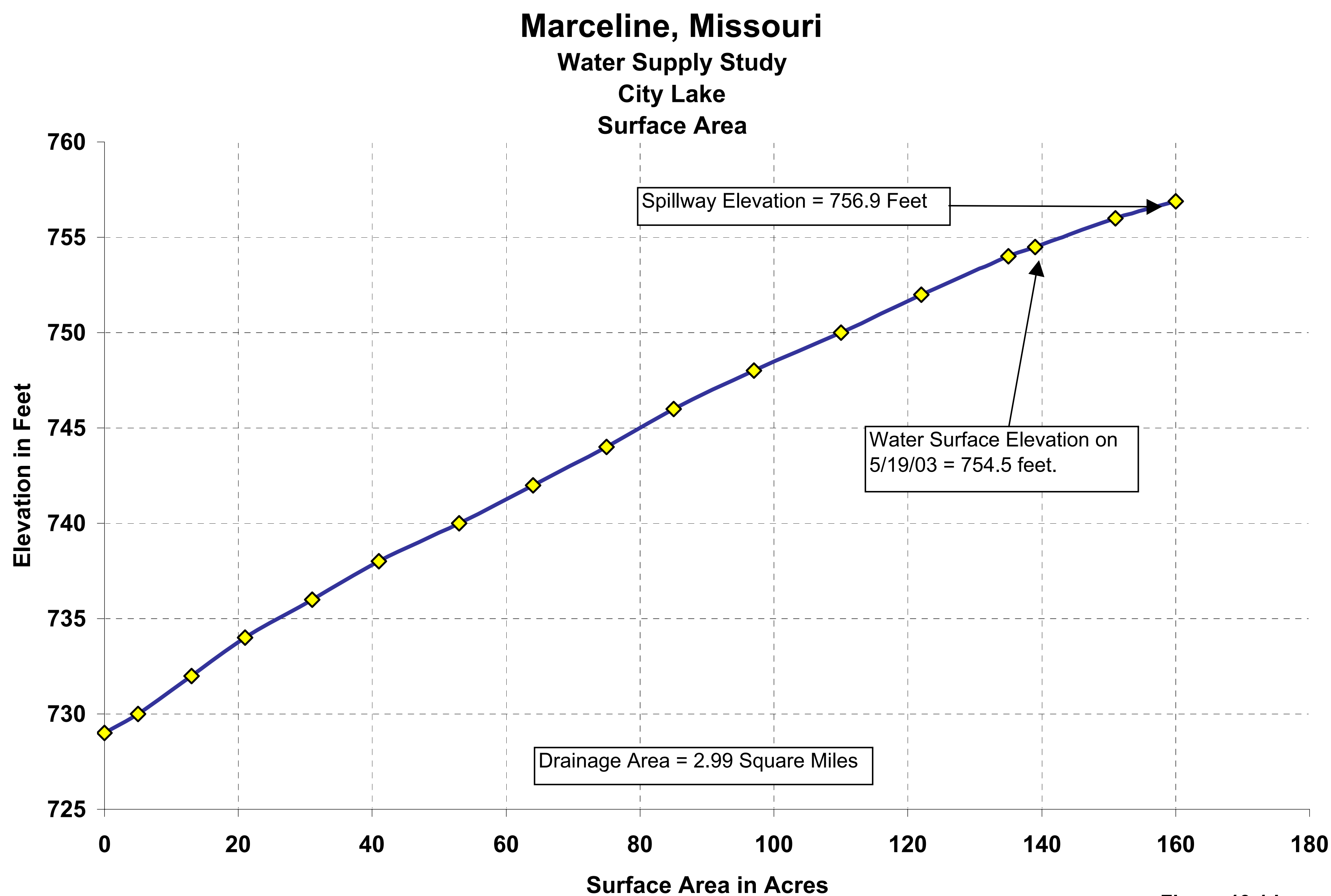

Marceline, Missouri
Water Supply Study
City Lake
Surface Area
Spillway Elevation = 756.9 Feet
Water Surface Elevation on
5/19/03 = 754.5 feet.
Drainage Area = 2.99 Square Miles
Elevation in Feet
760
755
750
745
740
735
730
725
0
20
40
60
80
100
120
140
160
180
Surface Area in Acres

Figure 19.1.b

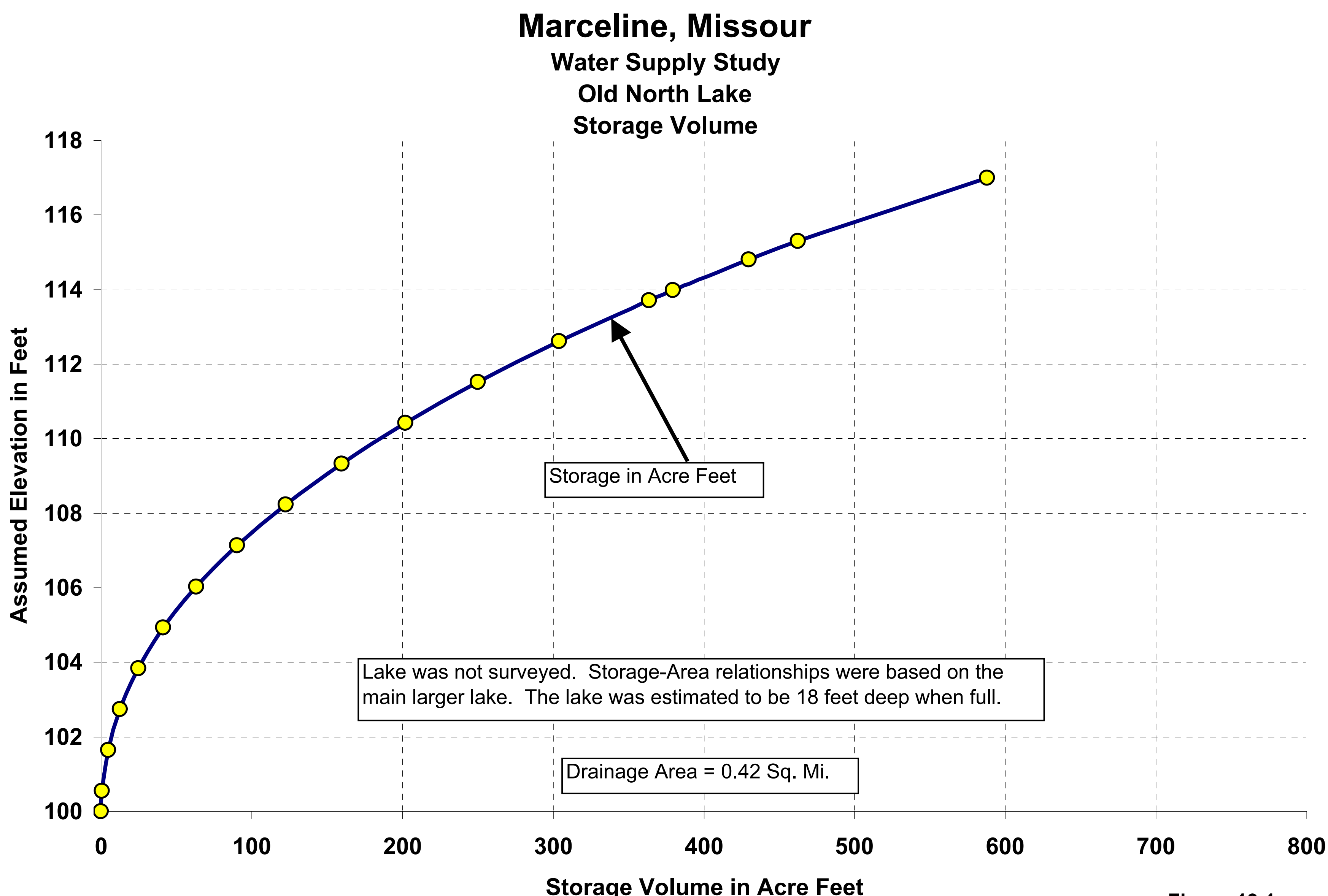
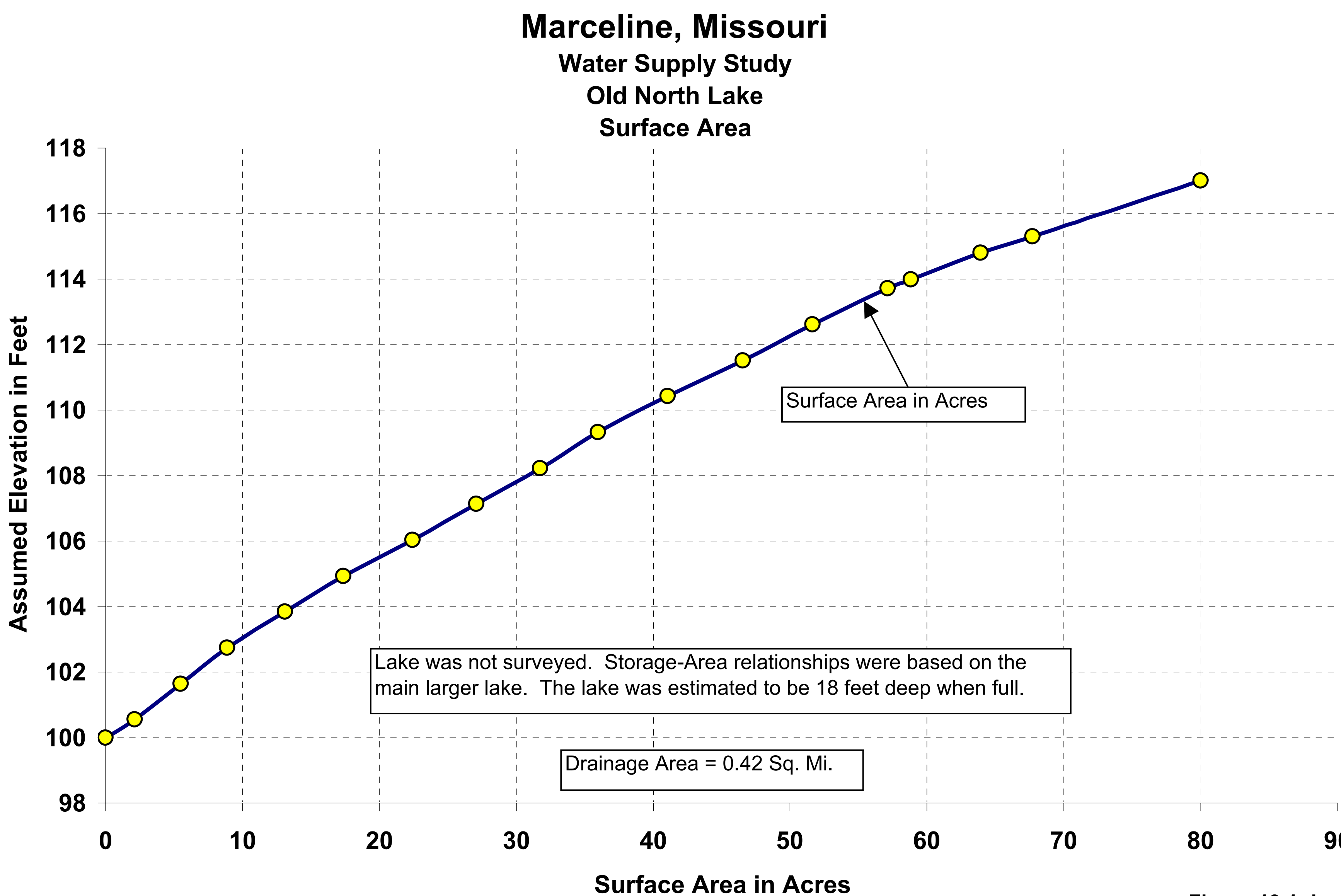

Marceline, Missour
Water Supply Study
Old North Lake
Storage Volume
Assumed Elevation in Feet
118
116
114
112
110
108
106
104
102
100
0
100
200
300
400
500
600
700
800
Storage Volume in Acre Feet
Storage in Acre Feet
Lake was not surveyed. Storage-Area relationships were based on the main larger lake. The lake was estimated to be 18 feet deep when full.
Drainage Area = 0.42 Sq. Mi.

Figure 19.1.c



Marceline, Missouri
Water Supply Study
Old North Lake
Surface Area
Assumed Elevation in Feet
118
116
114
112
110
108
106
104
102
100
98
0
10
20
30
40
50
60
70
80
90
Surface Area in Acres
Surface Area in Acres
Lake was not surveyed. Storage-Area relationships were based on the main larger lake. The lake was estimated to be 18 feet deep when full.
Drainage Area = 0.42 Sq. Mi.

Figure 19.1.d

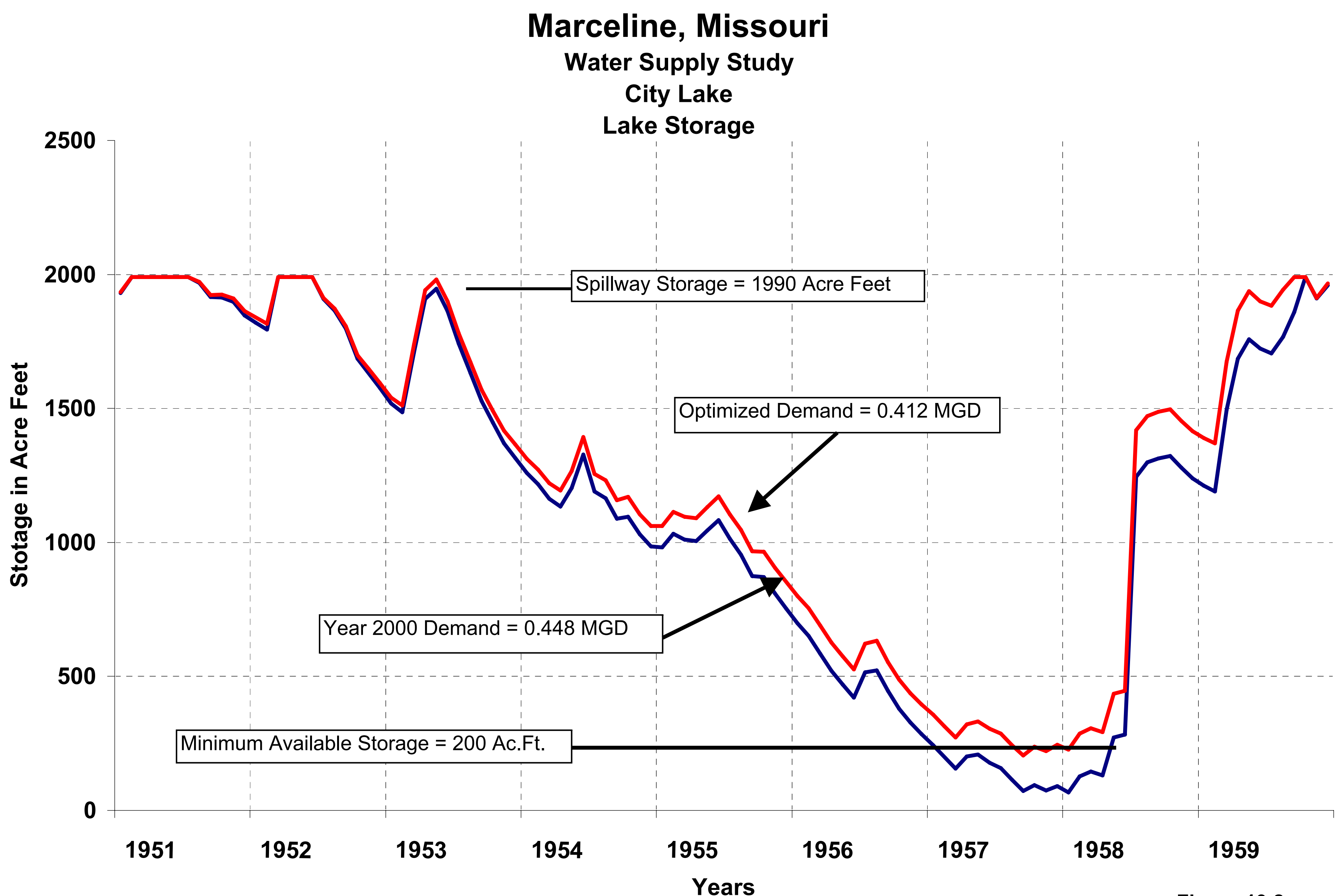

Marceline, Missouri
Water Supply Study
City Lake
Lake Storage
Stotage in Acre Feet
2500
2000
1500
1000
500
0
1951
1952
1953
1954
1955
1956
1957
1958
1959
Years
Spillway Storage = 1990 Acre Feet
Optimized Demand = 0.412 MGD
Year 2000 Demand = 0.448 MGD
Minimum Available Storage = 200 Ac.Ft.

Figure 19.2.a

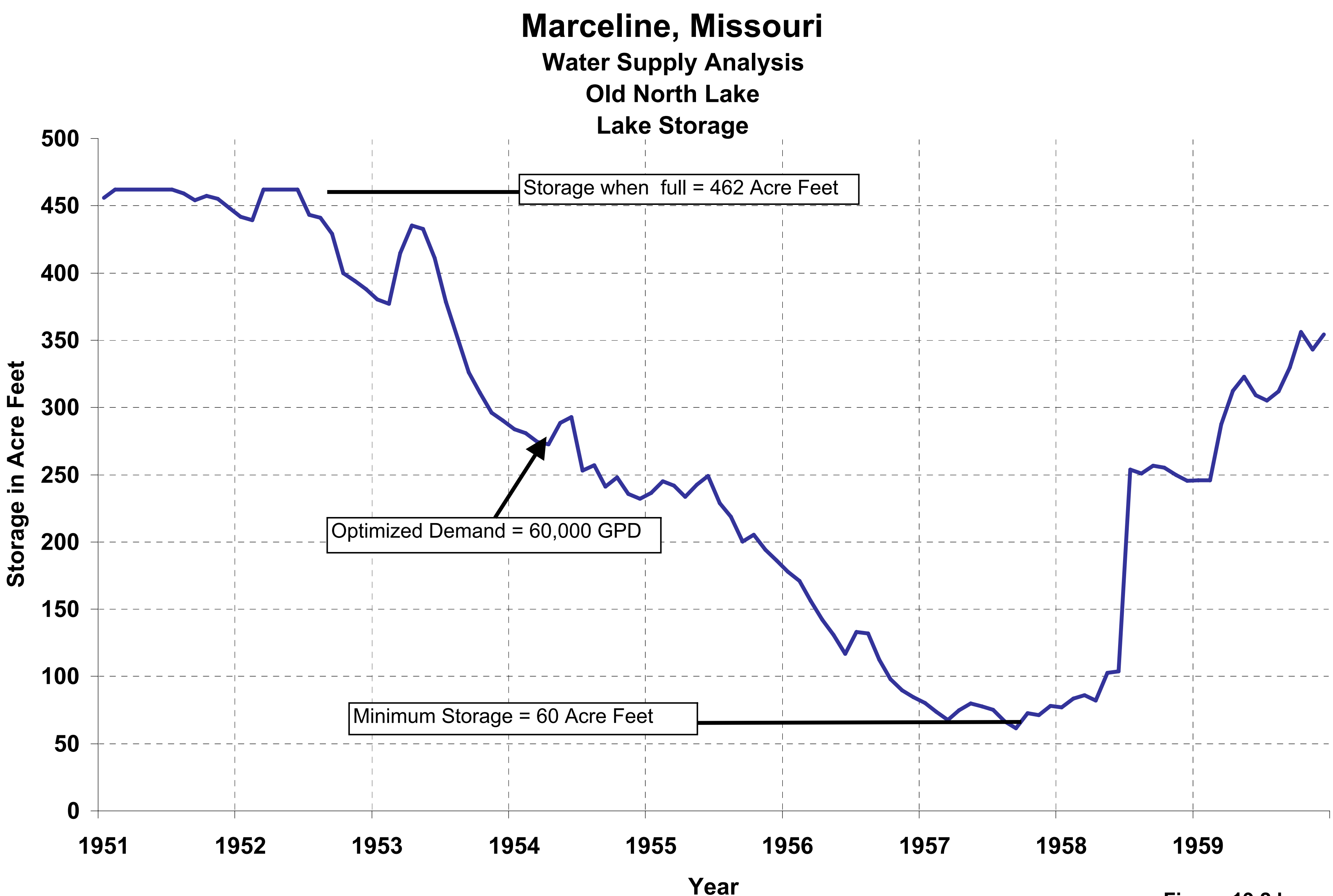
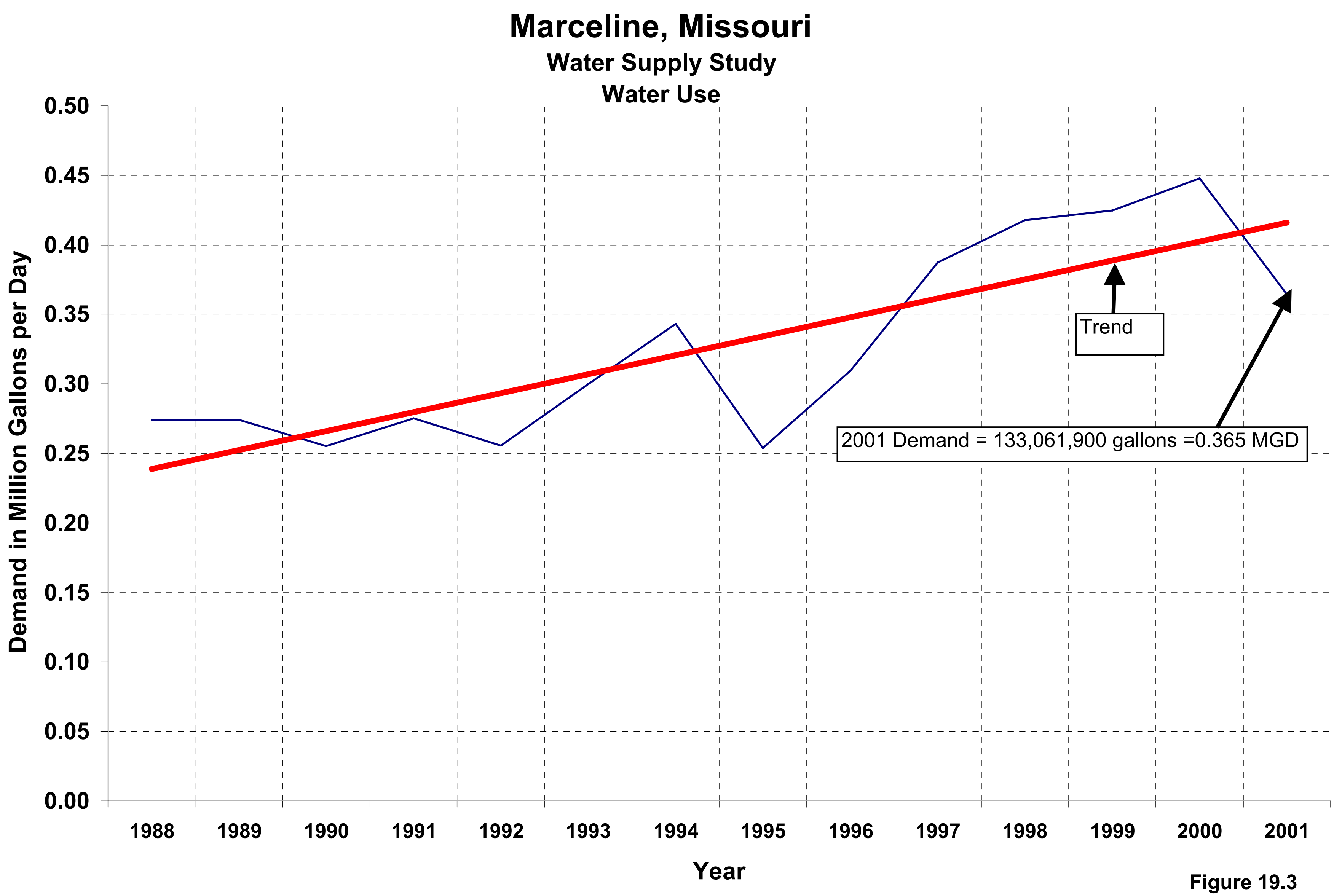

Marceline, Missouri
Water Supply Analysis
Old North Lake
Lake Storage
Storage in Acre Feet
500
450
400
350
300
250
200
150
100
50
0
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year
Storage when full = 462 Acre Feet
Optimized Demand = 60,000 GPD
Minimum Storage = 60 Acre Feet

Figure 19.2.b



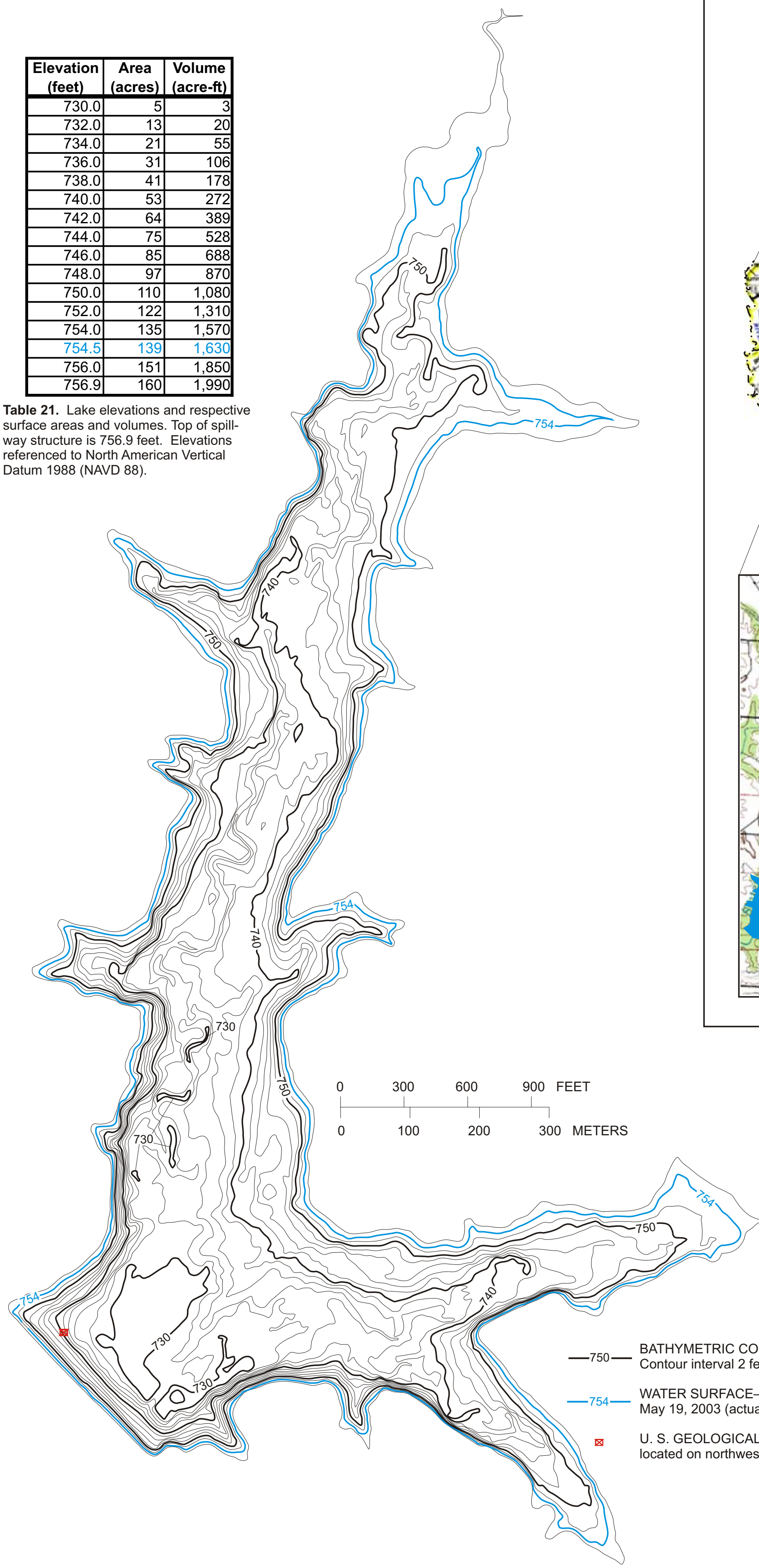
Marceline, Missouri
Water Supply Study
Water Use
Demand in Million Gallons per Day
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
Year
Trend
2001 Demand = 133,061,900 gallons =0.365 MGD

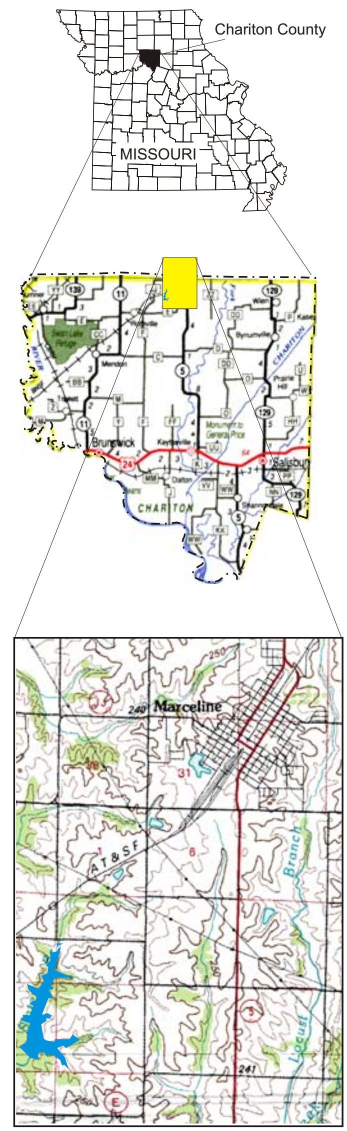
Figure 19.3

MARCELINE LAKE

Elevation (feet)	Area (acres)	Volume (acre-ft)
730.0	5	3
732.0	13	20
734.0	21	55
736.0	31	106
738.0	41	178
740.0	53	272
742.0	64	389
744.0	75	528
746.0	85	688
748.0	97	870
750.0	110	1,080
752.0	122	1,310
754.0	135	1,570
754.5	139	1,630
756.0	151	1,850
756.9	160	1,990

Table 21. Lake elevations and respective surface areas and volumes. Top of spillway structure is 756.9 feet. Elevations referenced to North American Vertical Datum 1988 (NAVD 88).





EXPLANATION

750 BATHYMETRIC CONTOUR—Shows altitude of the reservoir bottom. Contour interval 2 feet.

754 WATER SURFACE—Shows approximate elevation of water surface, May 19, 2003 (actual is 754.5 feet, table 21).

U. S. GEOLOGICAL SURVEY REFERENCE MARKER—Chiseled arrow located on northwest side of intake tower. Elevation 764.1 feet.

USGS science for a changing world

Figure 21. Bathymetric map and table of areas/volumes of the Marceline Lake (New) near Marceline, Missouri.

In cooperation with Missouri Department of Natural Resources

Memphis, Missouri
Water Supply Study
Lake Show Me and Memphis Old Lake

Memphis Missouri is located in Scotland County, in northeast Missouri.

Memphis water supply comes from the city owned “Lake Show Me” and an older lake. The lakes are located 2 miles southwest of Memphis in the North Fabius watershed.

Memphis Lake analysis consisted of using the NRCS's computer program called "RESOP". There are two lakes in series. Lake Show Me, the larger lake, is upstream of the old lake. The old lake is not currently being used for water supply. This analysis consisted of evaluating the lake system in series with the current water demand coming only from the new lake. Both lakes were also evaluated for their optimized yield.

In year 2000, Memphis used 153,276,495 gallons of water.

Following are considerations for data input to the "RESOP" program.

STO-AREA Elevation-Storage and Elevation-Area data were determined from June 19, 2001 survey made by USGS for the old lake and the new lake was surveyed on June 3, 2002.

Memphis Lake “Lake Show Me”

Elevation (feet)	Area (acres)	Storage (ac-ft)
728	1.91	1.01
730	6.38	9.16
732	11.70	27.13
734	17.30	55.95
736	23.22	96.36
738	30.40	149.42
740	38.47	218.33
742	46.46	303.00
744	57.07	406.47
746	68.04	531.36
748	79.01	678.14
750	91.64	848.42
752	104.93	1044.60
754	119.12	1268.72
756	133.85	1521.70
758	149.19	1804.49
760	165.59	2119.03
762	181.47	2465.87
764	198.60	2845.44
766	214.18	3258.52
768	228.70	3701.31
769.8	244.93	4125.81
770	246.53	4174.95
772	262.08	4683.47
774	278.41	5223.82

Water Surface and Spillway
Elevation on 6/3/02 = 769.8
Emergency Spillway Elevation 774.0

Memphis Old Lake

Elevation (feet)	Area (acres)	Storage (ac-ft)
706	0.81	0.58
708	2.26	3.65
710	8.42	12.48
712	19.94	40.68
714	27.81	89.59
715	30.09	118.59
716	32.04	149.63
718	40.49	219.51
720	50.12	309.39
721	57.50	364.87

Water Surface and Spillway
Elevation on 6/19/01 = 718.0
Top of Dam = 721.0

LIMITS **Lake Show Me**

Full Pool storage 4125.8 Ac.Ft.

Minimum Pool storage 50 Ac.Ft. at approximate elevation 734.

Old Lake

Full Pool storage 219.5 Ac.Ft.

Minimum Pool storage 10 Ac.Ft. at approximate elevation 710.

Starting storage was considered at full pool.

The drainage area of the upper lake is 2.66 square miles.
The drainage area of the lower lake is 1.51 square miles.
Total drainage area of the two lakes is 4.17 square miles.

GENERAL The adjustment factor of 0.76 to convert from pan evaporation to lake evaporation was applied prior to entering the data for the control word EVAP. As a result a factor of 100 is used.

The record period of drought is in the 1950's.
Analysis began in January 1951 and ended December 1959.

SEEPAGE

Lake Show Me

The reservoir seepage varied from 0 seepage near empty to a maximum of 2.0 inches per month at full pool. The seepage rate is a best estimate based on history of the reservoir, soil type, material of the core of the dam and compaction of the earth fill. The material in the dam is compacted earth of clayey soils.

When full the lake is about 40 feet deep, as a result the static pressure is fairly high and seepage is moderate.

Old Lake

The reservoir seepage varied from 0 seepage near empty to a maximum of 1.25 inch per month when at full pool. The material in the dam earth of clayey soils. This is an old dam and soil compaction is not as good as the Lake Show Me.

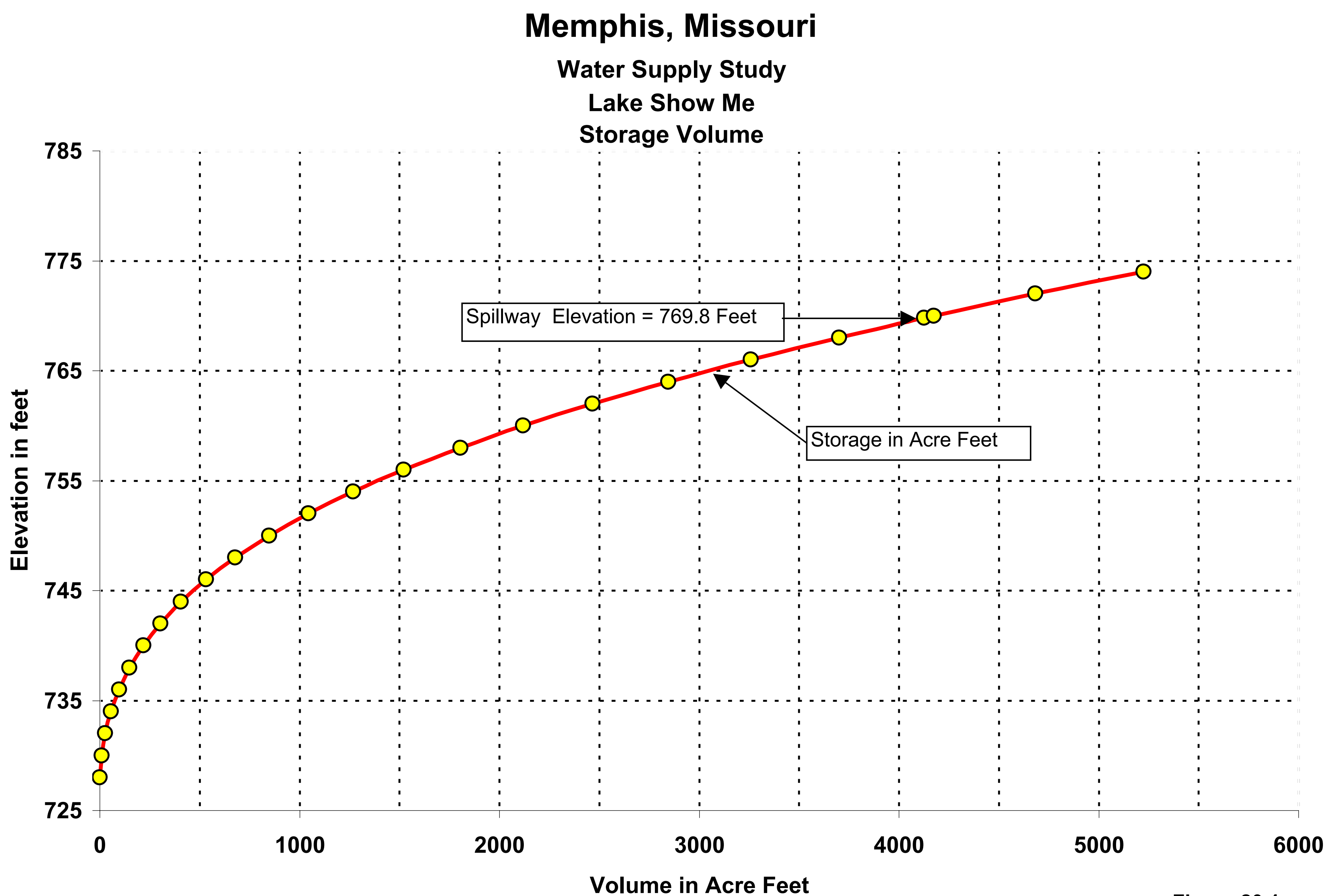
RAINFALL Rainfall data came from the Memphis, Mo. rain gage.

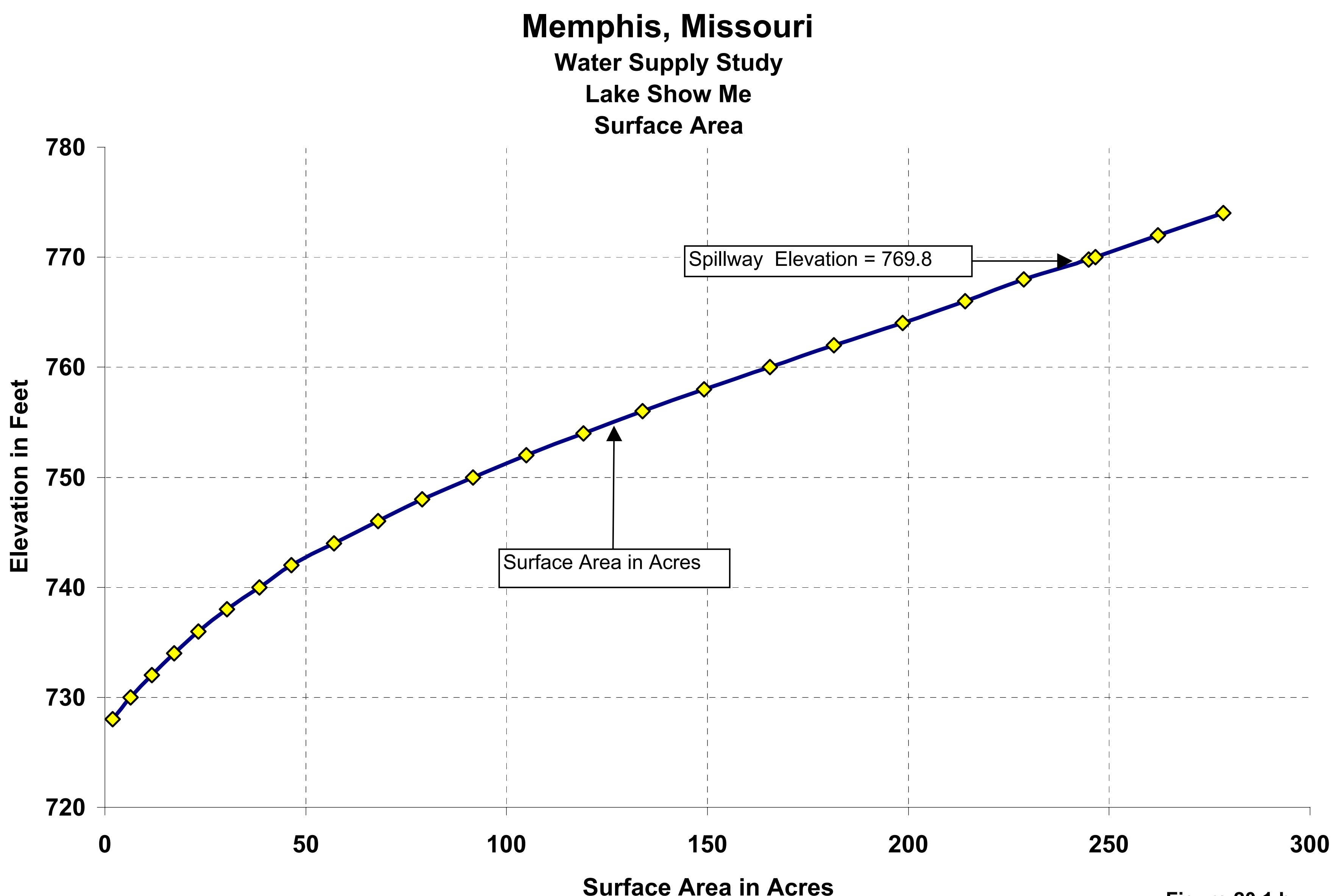
RUNOFF This is the runoff into the lake from its drainage area. Monthly runoff volumes in watershed inches were determined at the Middle Fabious stream gage, near Baring. The Gage is located approximately 8 miles south of Memphis.

EVAP. Pan evaporation at the Lakeside gaging station was used as a base because it has data for year around evaporation. All other stations only measure data between April through November. Lakeside data was updated during these months with gage data from stations at Spickard, New Franklin, and Columbia. Depending on the latest data for the station nearest to Memphis.

DEMAND Year 2000 records show the daily usage at 0.4199 Million Gallons per Day.

OTHER Because there is no other inflow to the lake this control word was not used.


Memphis, Missouri
Water Supply Study
Lake Show Me
Storage Volume
Spillway Elevation = 769.8 Feet
Storage in Acre Feet
Elevation in feet
785
775
765
755
745
735
725
0
1000
2000
3000
4000
5000
6000
Volume in Acre Feet
Figure 20.1.a



Memphis, Missouri
Water Supply Study
Lake Show Me
Surface Area
Elevation in Feet
780
770
760
750
740
730
720
0
50
100
150
200
250
300
Surface Area in Acres
Spillway Elevation = 769.8
Surface Area in Acres

Figure 20.1.b

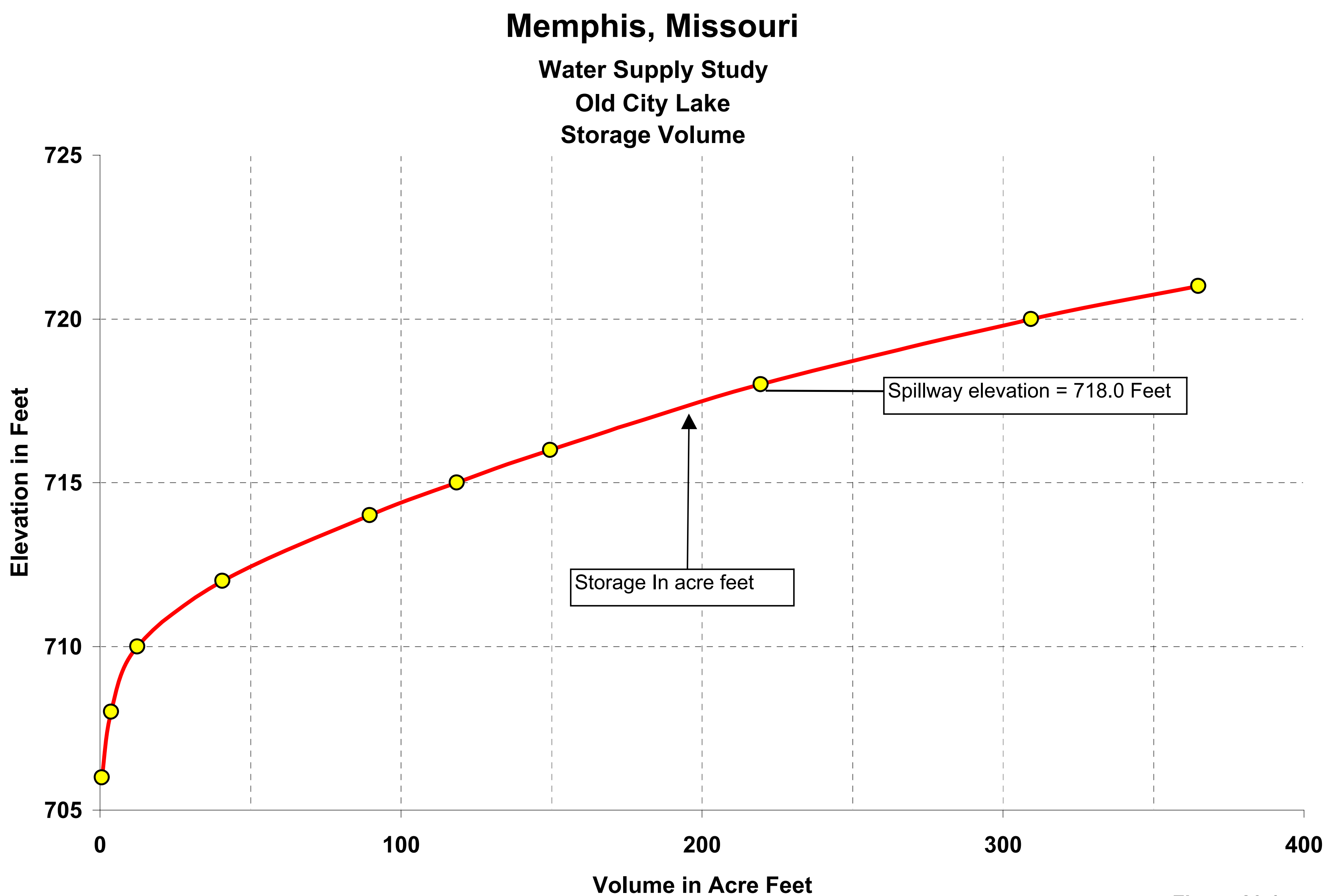

Memphis, Missouri
Water Supply Study
Old City Lake
Storage Volume
Elevation in Feet
725
720
715
710
705
0
100
200
300
400
Volume in Acre Feet
Storage In acre feet
Spillway elevation = 718.0 Feet

Figure 20.1.c

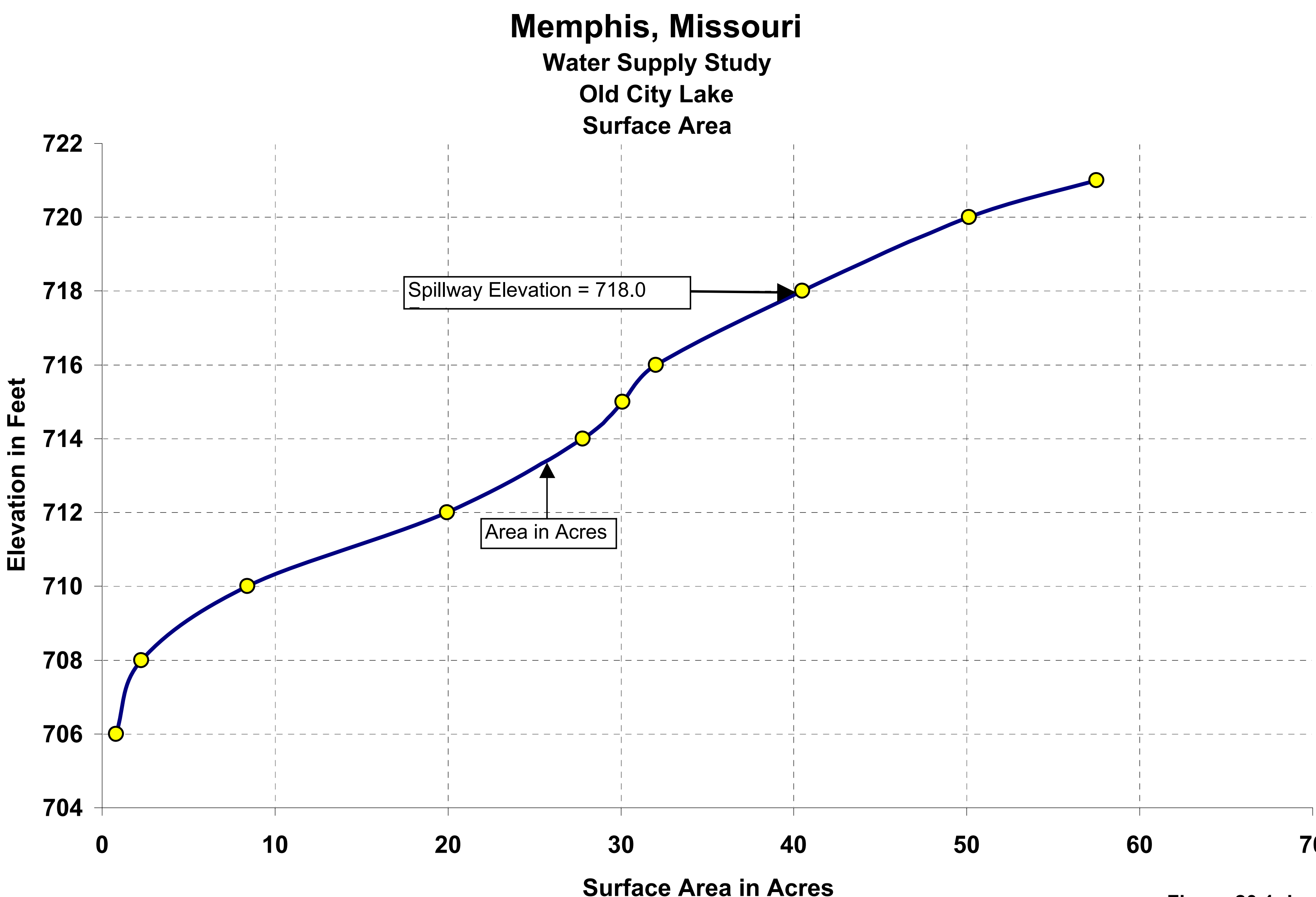
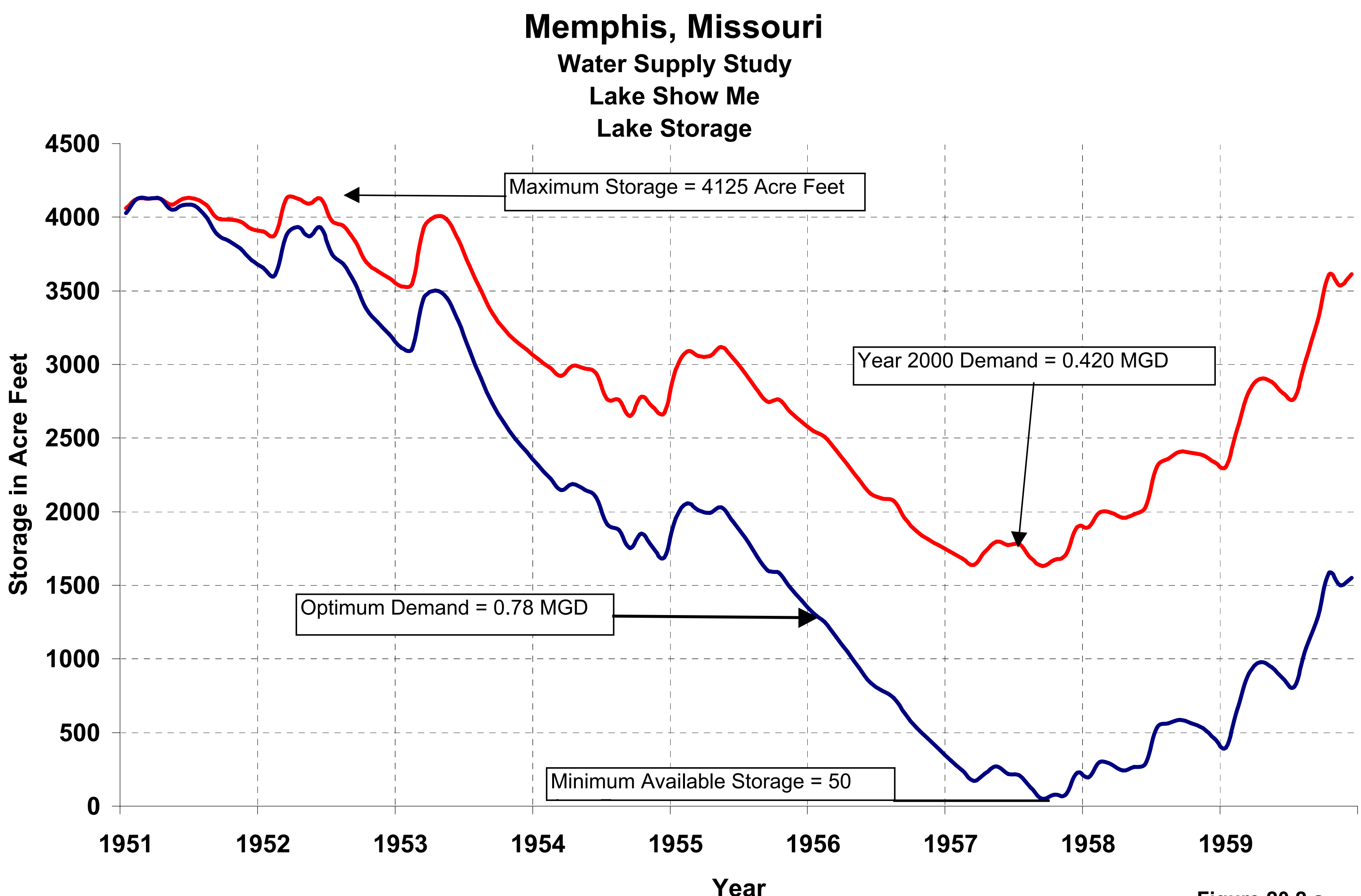

Memphis, Missouri
Water Supply Study
Old City Lake
Surface Area
Spillway Elevation = 718.0
Area in Acres
Elevation in Feet
722
720
718
716
714
712
710
708
706
704
0
10
20
30
40
50
60
70
Surface Area in Acres

Figure 20.1.d



Memphis, Missouri
Water Supply Study
Lake Show Me
Lake Storage
Storage in Acre Feet
4500
4000
3500
3000
2500
2000
1500
1000
500
0
Maximum Storage = 4125 Acre Feet
Year 2000 Demand = 0.420 MGD
Optimum Demand = 0.78 MGD
Minimum Available Storage = 50
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year

Figure 20.2.a

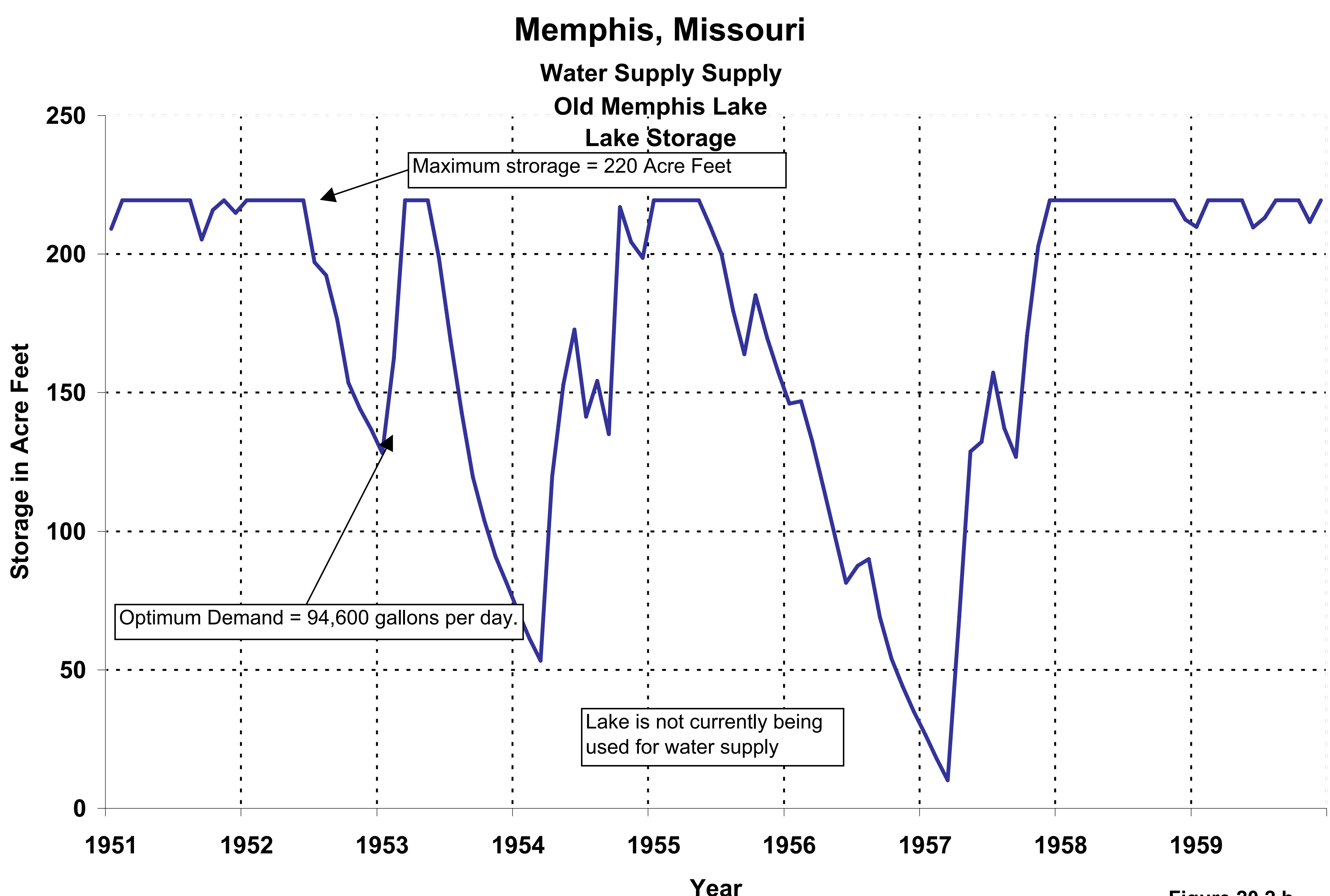

Memphis, Missouri
Water Supply Supply
Old Memphis Lake
Lake Storage
Maximum strorage = 220 Acre Feet
Optimum Demand = 94,600 gallons per day.
Lake is not currently being used for water supply
Storage in Acre Feet
0
50
100
150
200
250
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year

Figure 20.2.b

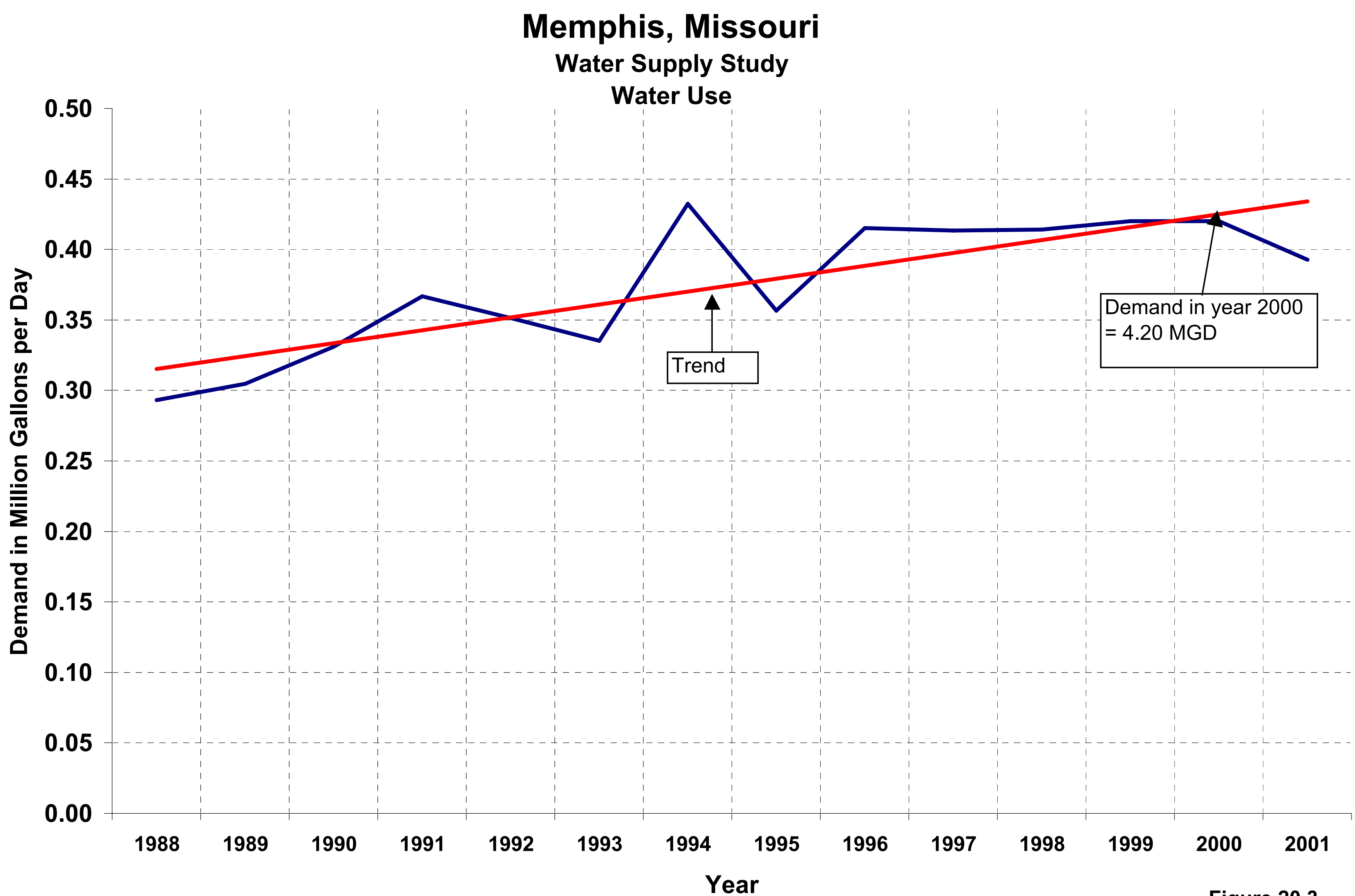
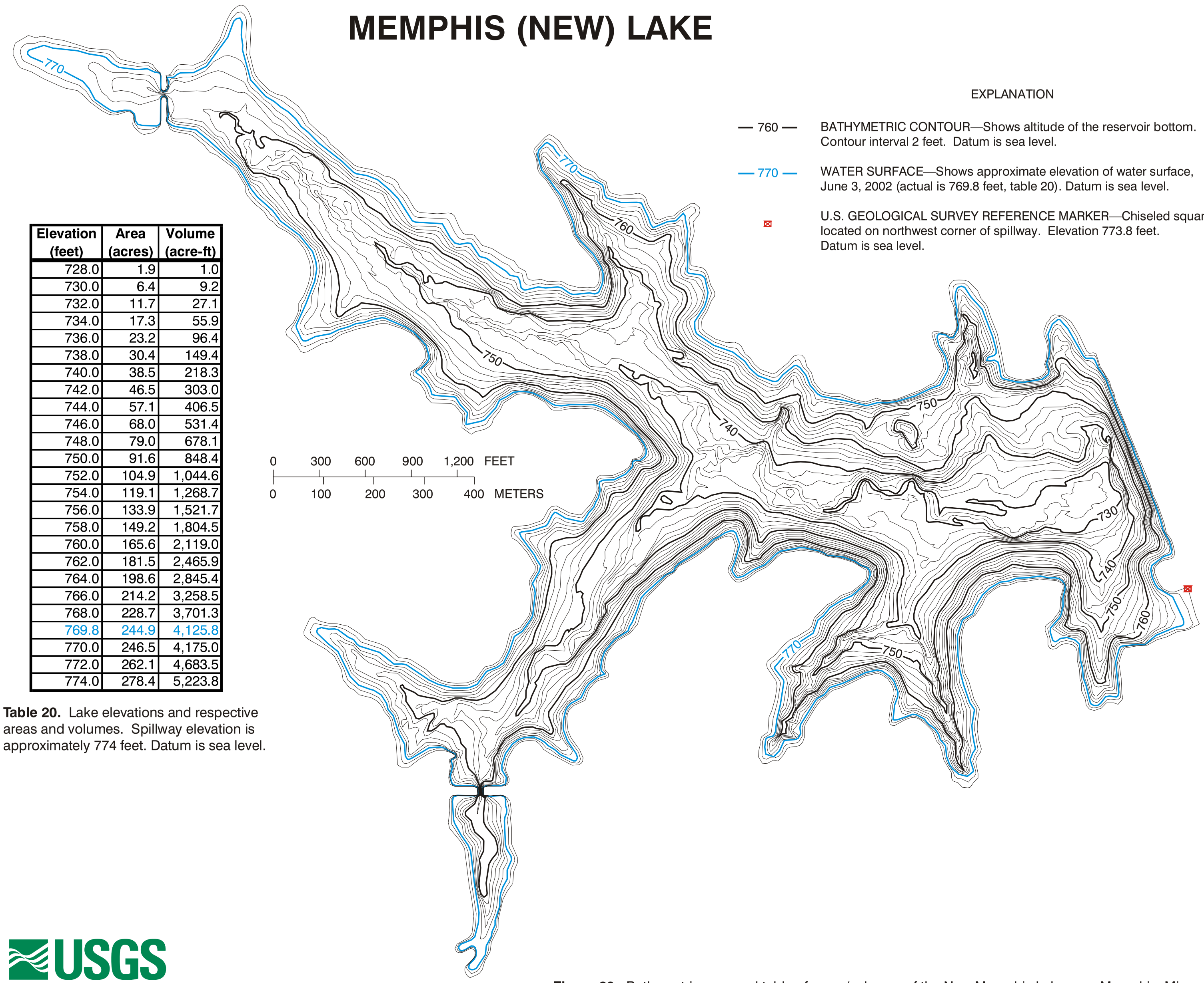

Memphis, Missouri
Water Supply Study
Water Use
Demand in Million Gallons per Day
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
Year
Trend
Demand in year 2000
= 4.20 MGD

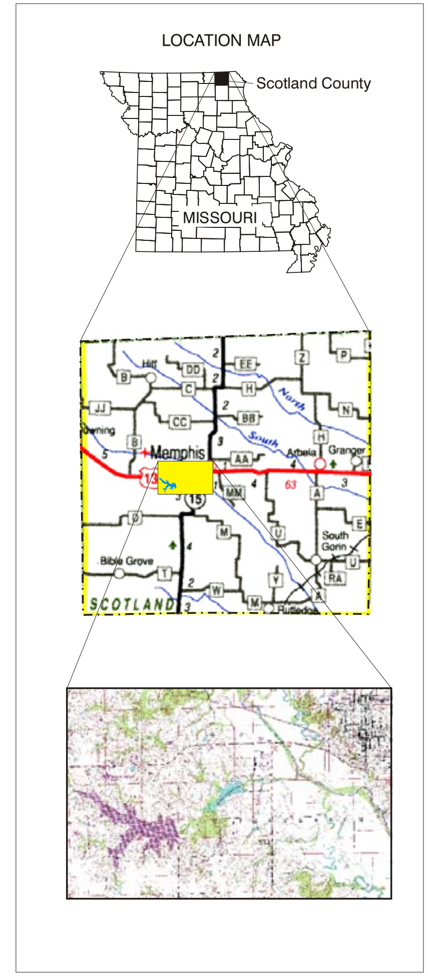
Figure 20.3

MEMPHIS (NEW) LAKE

Elevation (feet)	Area (acres)	Volume (acre-ft)
728.0	1.9	1.0
730.0	6.4	9.2
732.0	11.7	27.1
734.0	17.3	55.9
736.0	23.2	96.4
738.0	30.4	149.4
740.0	38.5	218.3
742.0	46.5	303.0
744.0	57.1	406.5
746.0	68.0	531.4
748.0	79.0	678.1
750.0	91.6	848.4
752.0	104.9	1,044.6
754.0	119.1	1,268.7
756.0	133.9	1,521.7
758.0	149.2	1,804.5
760.0	165.6	2,119.0
762.0	181.5	2,465.9
764.0	198.6	2,845.4
766.0	214.2	3,258.5
768.0	228.7	3,701.3
769.8	244.9	4,125.8
770.0	246.5	4,175.0
772.0	262.1	4,683.5
774.0	278.4	5,223.8

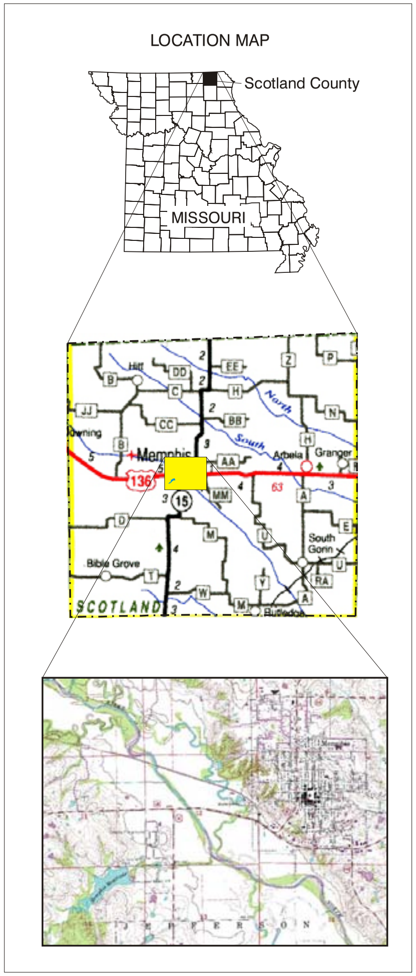
Table 20. Lake elevations and respective areas and volumes. Spillway elevation is approximately 774 feet. Datum is sea level.



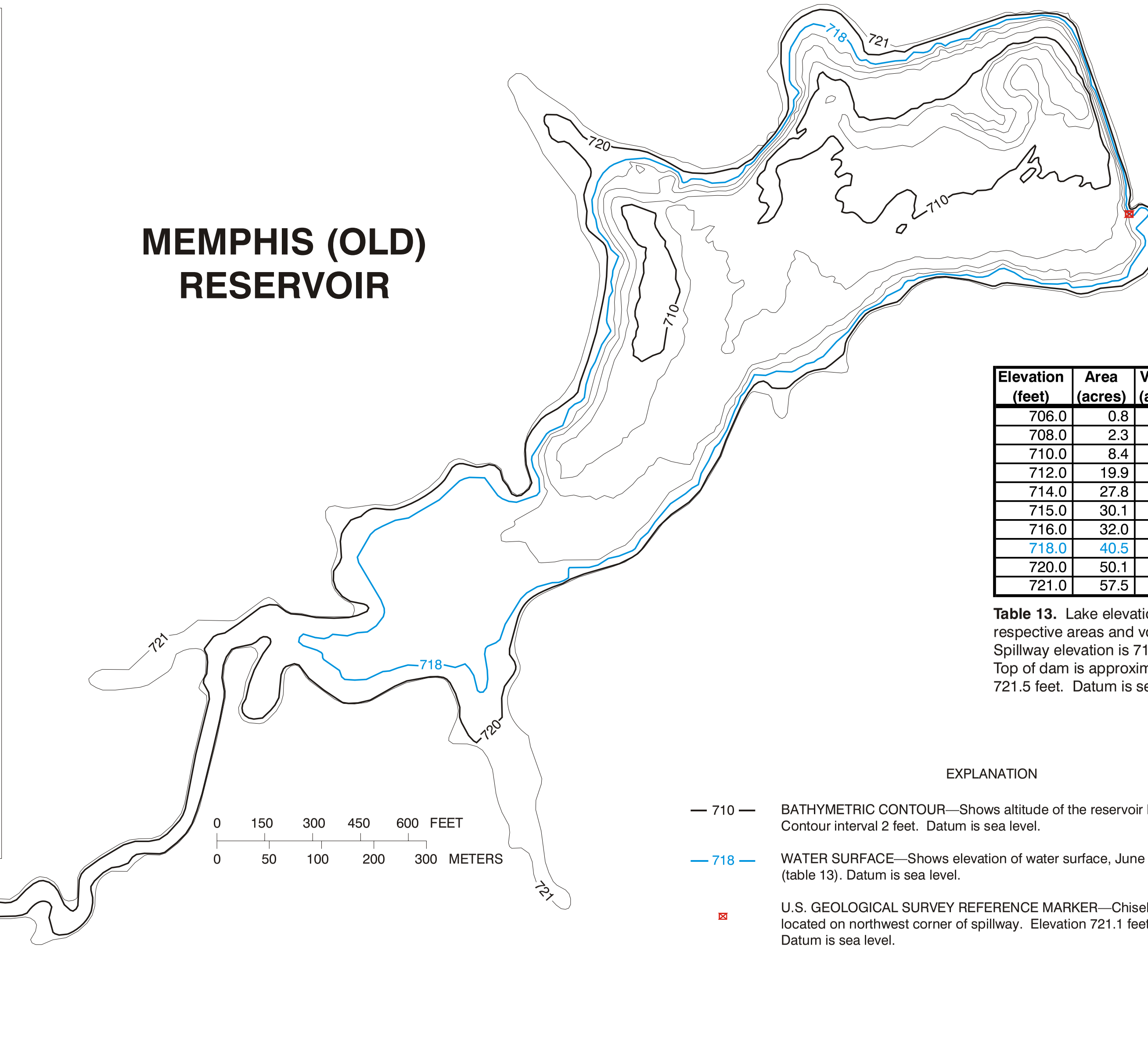


USGS
science for a changing world

Figure 20. Bathymetric map and table of areas/volumes of the New Memphis Lake near Memphis, Missouri.



MEMPHIS (OLD) RESERVOIR



Elevation (feet)	Area (acres)	Volume (acre-ft)
706.0	0.8	0.6
708.0	2.3	3.7
710.0	8.4	12.5
712.0	19.9	40.7
714.0	27.8	89.6
715.0	30.1	118.6
716.0	32.0	149.6
718.0	40.5	219.5
720.0	50.1	309.4
721.0	57.5	364.9

Table 13. Lake elevations and respective areas and volumes. Spillway elevation is 718.0 feet. Top of dam is approximately 721.5 feet. Datum is sea level.

EXPLANATION

— 710 — BATHYMETRIC CONTOUR—Shows altitude of the reservoir bottom. Contour interval 2 feet. Datum is sea level.

— 718 — WATER SURFACE—Shows elevation of water surface, June 19, 2001 (table 13). Datum is sea level.

⊠ U.S. GEOLOGICAL SURVEY REFERENCE MARKER—Chiseled square located on northwest corner of spillway. Elevation 721.1 feet. Datum is sea level.

Figure 13. Bathymetric map and table of areas/volumes of the Old Memphis Reservoir near Memphis, Missouri.

Middle Fork Grand River
Stanberry, Missouri
Water Supply Study

Middle Fork Lake is privately owned by "Middle Fork Water Company" to supply water to Stanberry and other communities, as well as rural water district. The lake is located on a tributary to Middle Fork Grand River about 10 miles north east of Stanberry.

The average daily use is about 350,000 gallons per day.

The drainage area of the lake is 4037 acres (6.3 square miles).

Middle Fork Lake analysis consisted of using the NRCS's computer program called "RESOP". Following is the data and procedures for input to the program.

STO-AREA Elevation-Storage and Elevation-Area data were determined from July 26, 2000 survey made by USGS.

Middle Fork Grand River Lake

Elevation (feet)	Area (acres)	Storage (ac-ft)	
868.0	0.12	0.08	
870.0	1.70	0.99	Intake elevation
872.0	5.70	7.32	
874.0	14.23	27.49	
876.0	24.36	65.35	
878.0	35.20	125.05	
880.0	48.37	208.90	
882.0	58.86	316.71	
884.0	69.36	443.30	
884.1	71.44	450.30	Water Surface on 7/26/2000
886.0	86.65	599.87	
888.0	108.97	794.15	
890.0	138.51	1040.67	
892.0	175.09	1352.91	
893.4	206.11	1625.01	

Spillway Elevation = 893.4 Feet mean sea level
Intake Elevation = 870. Feet mean sea level

LIMITS Maximum Pool storage 1625 Ac.Ft.
Minimum Pool storage 20 Ac.Ft.

Starting storage was considered at measured pool (7/26/2000).

The drainage area of the lake is 4037 acres (6.3 square miles).

GENERAL The adjustment to convert from pan evaporation to lake evaporation was made for the control word EVAP. The factors were monthly values. As a result a factor of 100 was used.

The record period of drought is in the 1950's.
Analysis began in January 1951 and ended December 1959.

SEEPAGE The reservoir seepage varied from 0 seepage near empty to a maximum of 2.5 inch per month when at full pool. The material in the dam is compacted earth of clayey soils.

RAINFALL — Rainfall data came from the White Cloud Creek near Maryville, MO. rain gage for the period 1952 through 1960.

RUNOFF — This is the runoff into the lake from its drainage area. Monthly runoff volumes in watershed inches were determined at the White Cloud Creek stream gage. The drainage area is 6.0 square miles. White Cloud Creek gage is located west of Maryville.

EVAP. -- Pan evaporation at the Lakeside gaging station were used as a base because it has data for year around evaporation. This data was updated with gage data from stations at Spickard. The average data from 1952 and 1961 were used when there are no data available from both stations. The monthly adjustment factors to convert from pan to lake evaporation was applied at this step.

DEMAND — Determined from city records. The average daily use is about 350,000 gallons per day and maximum is 450,000 GPD. (from Bill Hills)

MIDDLE FORK GRAND RIVER

Water Supply Study

Regional Water Supply Lake

Storage Volume

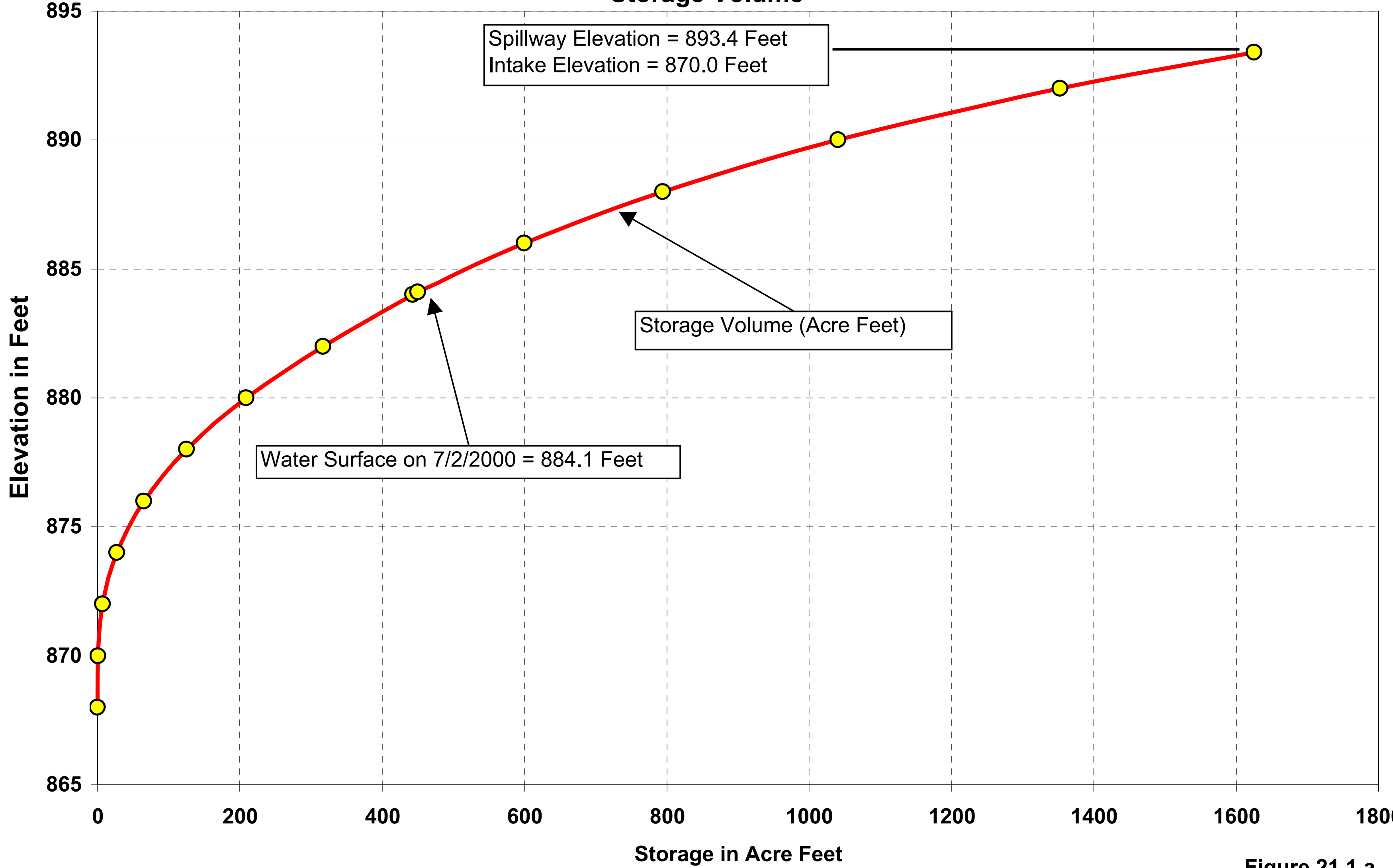


Figure 21.1.a

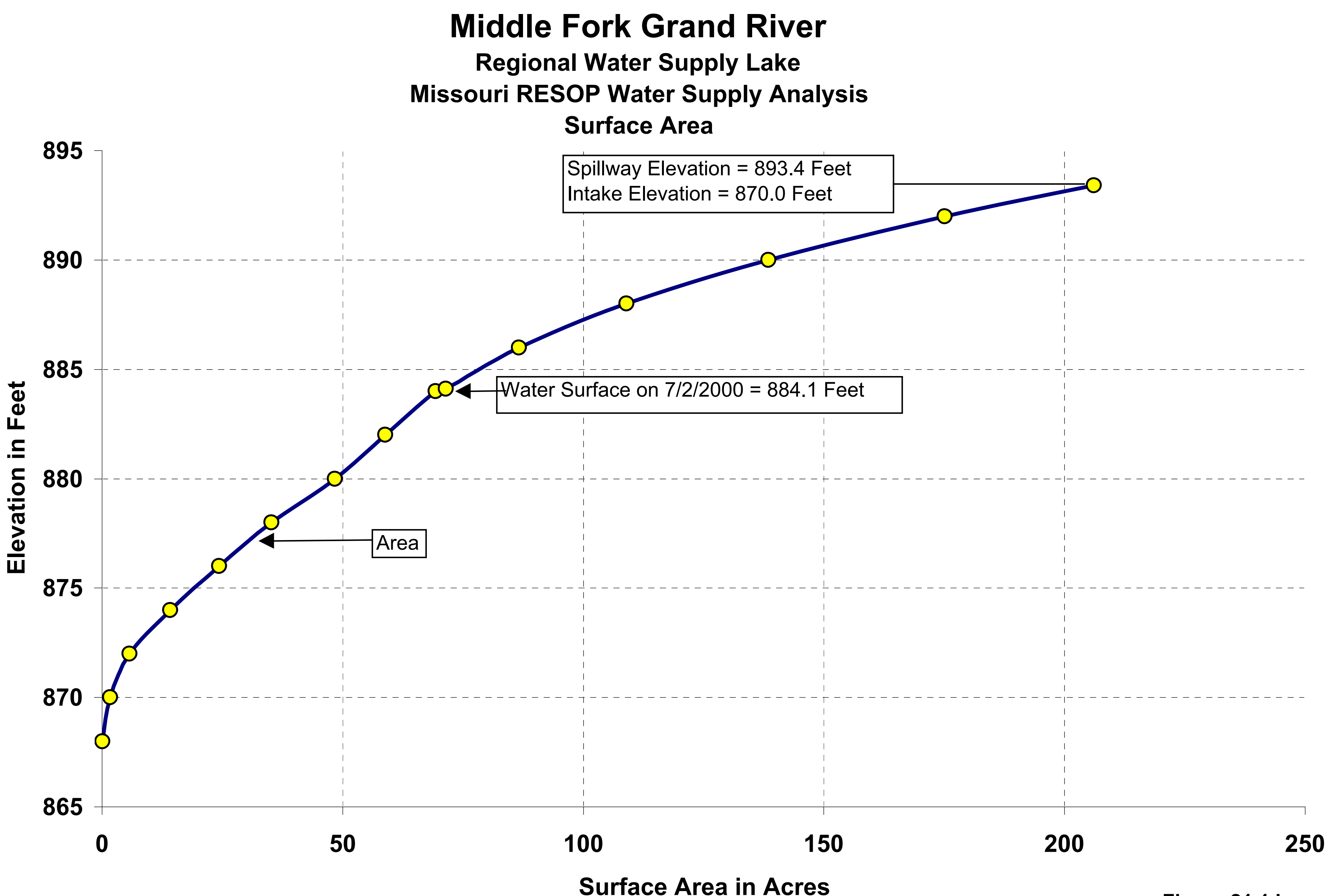
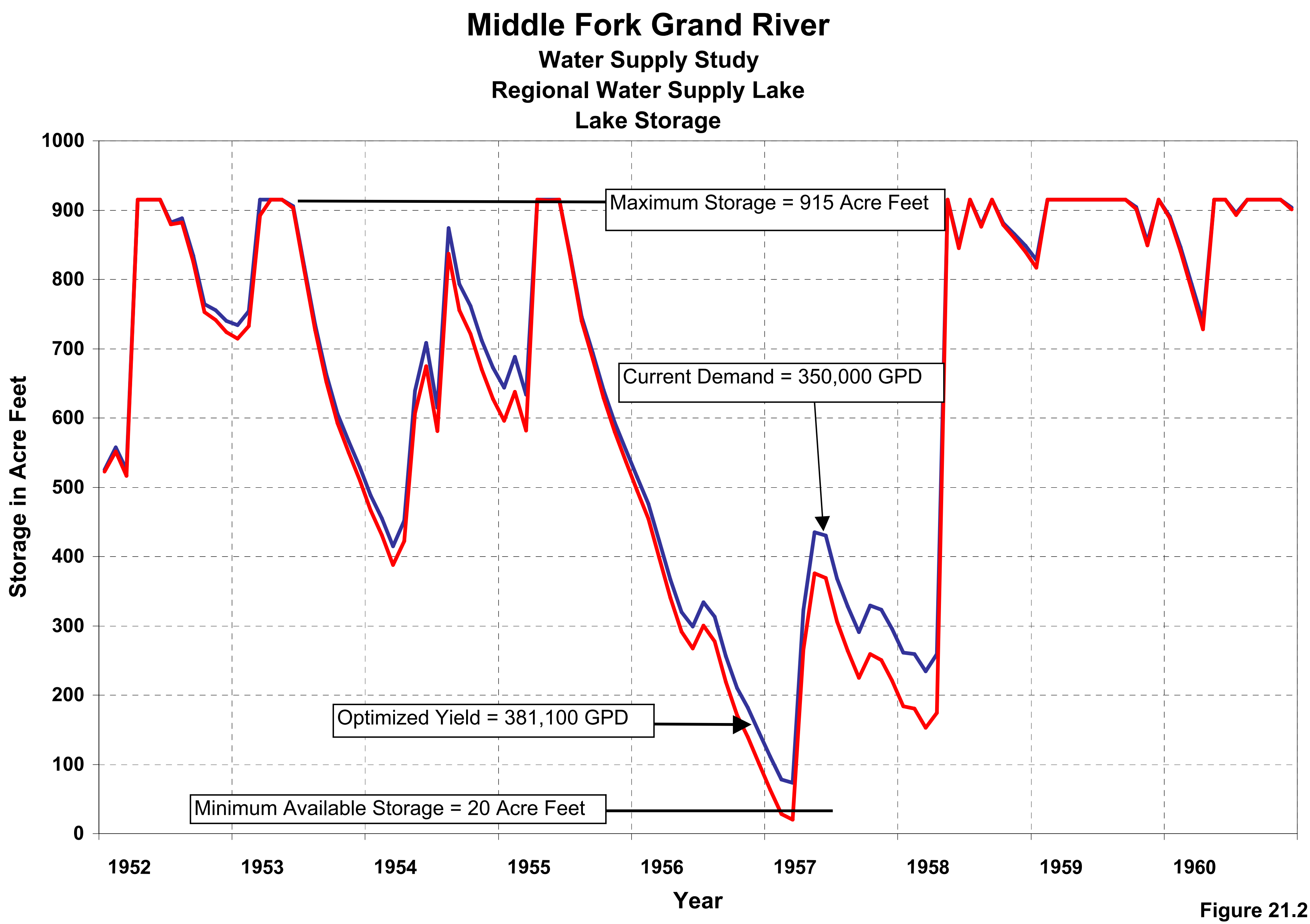

Middle Fork Grand River
Regional Water Supply Lake
Missouri RESOP Water Supply Analysis
Surface Area
Spillway Elevation = 893.4 Feet
Intake Elevation = 870.0 Feet
Water Surface on 7/2/2000 = 884.1 Feet
Area
Elevation in Feet
895
890
885
880
875
870
865
0
50
100
150
200
250
Surface Area in Acres

Figure 21.1.b



Middle Fork Grand River
Water Supply Study
Regional Water Supply Lake
Lake Storage
Storage in Acre Feet
1000
900
800
700
600
500
400
300
200
100
0
Maximum Storage = 915 Acre Feet
Current Demand = 350,000 GPD
Optimized Yield = 381,100 GPD
Minimum Available Storage = 20 Acre Feet
1952
1953
1954
1955
1956
1957
1958
1959
1960
Year

Figure 21.2

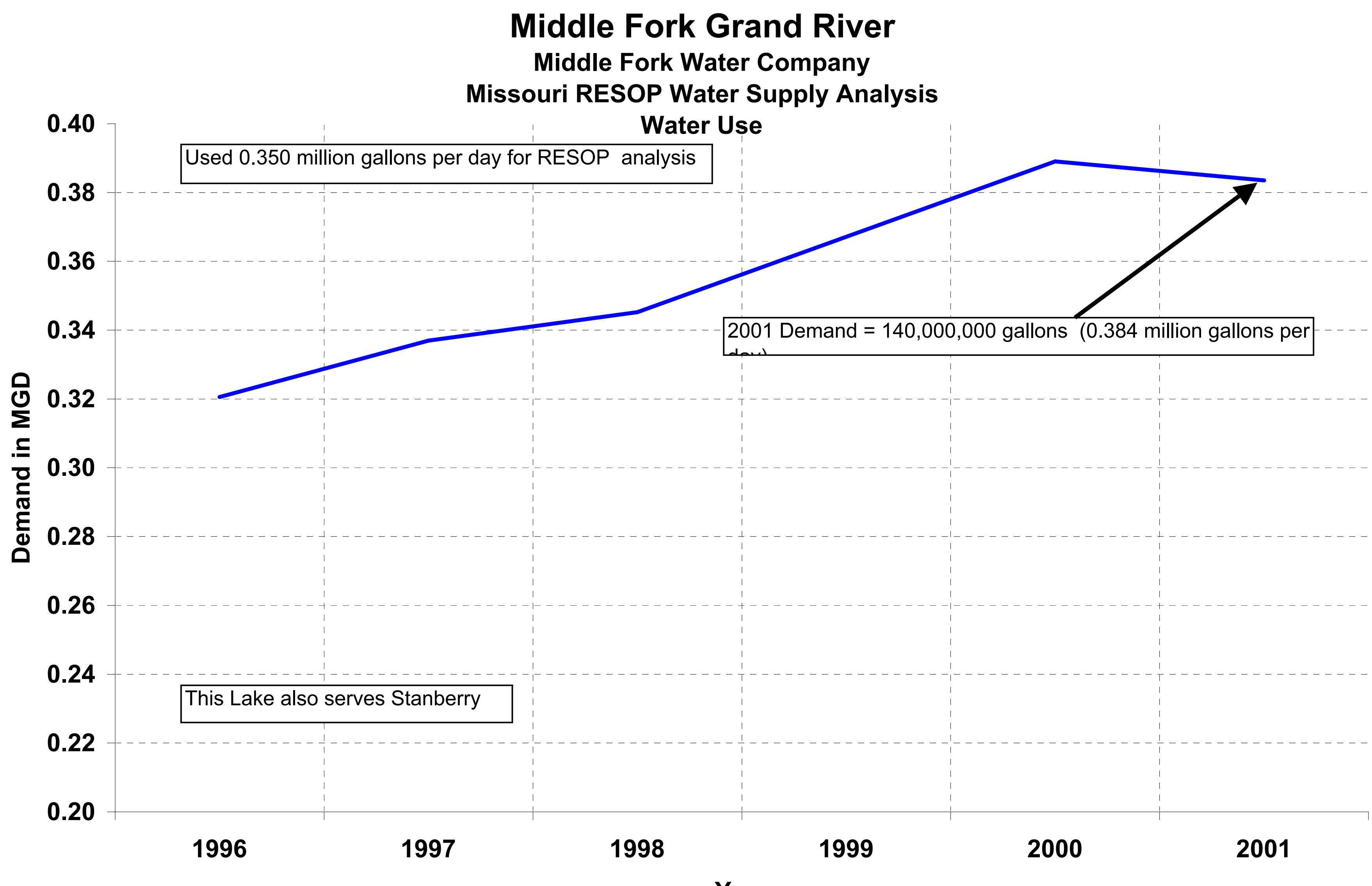
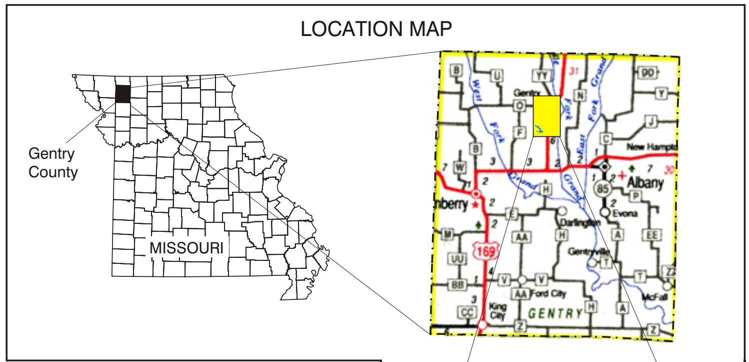

Middle Fork Grand River
Middle Fork Water Company
Missouri RESOP Water Supply Analysis
Water Use
Used 0.350 million gallons per day for RESOP analysis
2001 Demand = 140,000,000 gallons (0.384 million gallons per
This Lake also serves Stanberry
Demand in MGD
0.40
0.38
0.36
0.34
0.32
0.30
0.28
0.26
0.24
0.22
0.20
1996
1997
1998
1999
2000
2001
Year

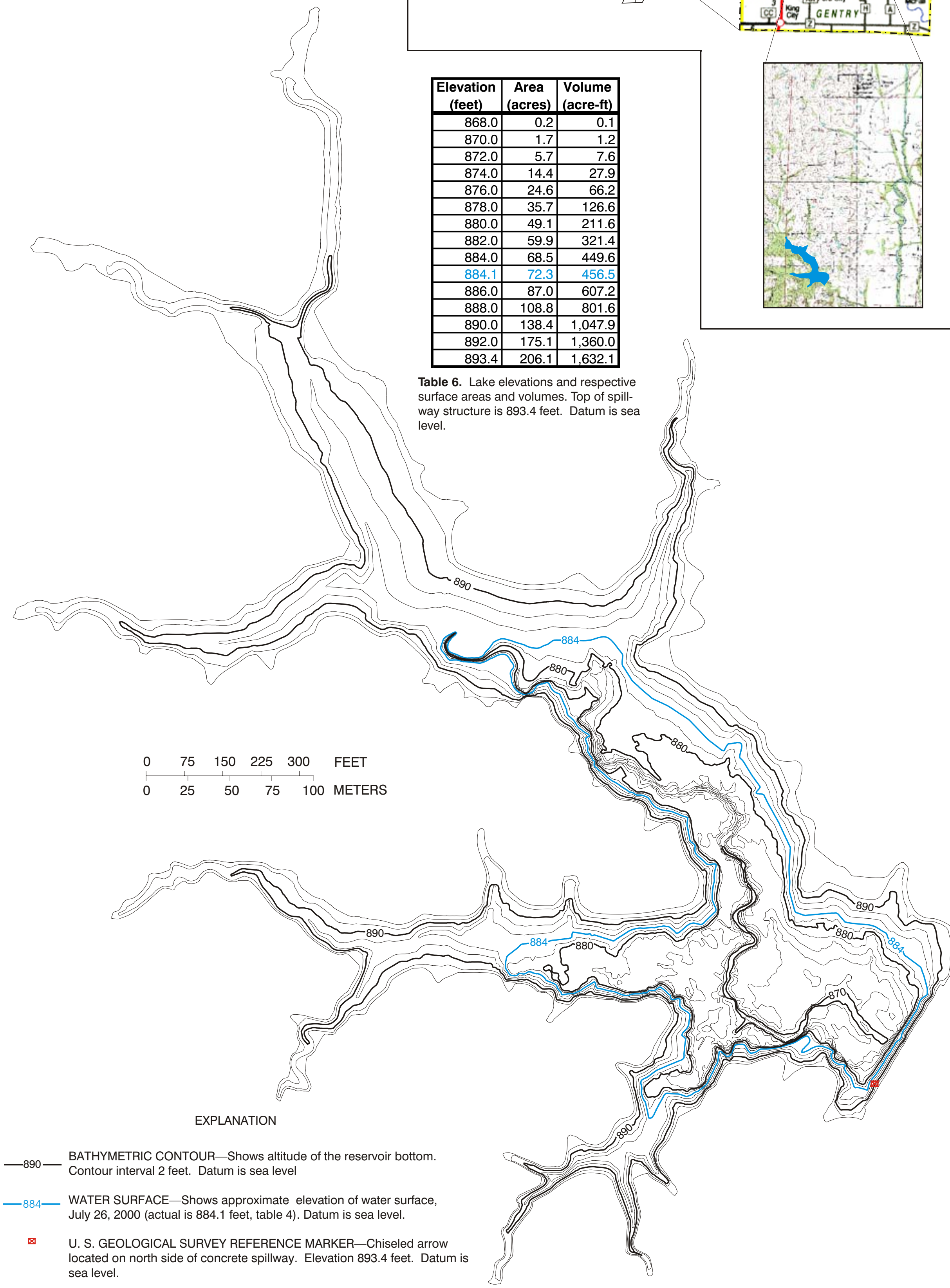
Figure 21.3

STANBERRY LAKE



Elevation (feet)	Area (acres)	Volume (acre-ft)
868.0	0.2	0.1
870.0	1.7	1.2
872.0	5.7	7.6
874.0	14.4	27.9
876.0	24.6	66.2
878.0	35.7	126.6
880.0	49.1	211.6
882.0	59.9	321.4
884.0	68.5	449.6
884.1	72.3	456.5
886.0	87.0	607.2
888.0	108.8	801.6
890.0	138.4	1,047.9
892.0	175.1	1,360.0
893.4	206.1	1,632.1

Table 6. Lake elevations and respective surface areas and volumes. Top of spillway structure is 893.4 feet. Datum is sea level.



EXPLANATION

—890— BATHYMETRIC CONTOUR—Shows altitude of the reservoir bottom. Contour interval 2 feet. Datum is sea level

—884— WATER SURFACE—Shows approximate elevation of water surface, July 26, 2000 (actual is 884.1 feet, table 4). Datum is sea level.

⊠ U. S. GEOLOGICAL SURVEY REFERENCE MARKER—Chiseled arrow located on north side of concrete spillway. Elevation 893.4 feet. Datum is sea level.

USGS
science for a changing world

Figure 6. Bathymetric map and area/volume table of Middle Fork Water Company Lake Intake near Stanberry, Missouri.

Milan, Missouri
Water Supply Study
Elmwood Lake and Golf Course Lake

Milan is located in central Sullivan County Missouri with East Locust Creek flowing along the eastern boundary of the city.

Milan has two reservoirs that are available for use as water supply. The larger one is Elmwood Lake, which is located about 2 miles North of Milan on a tributary to East Locust Creek. Golf Course Lake is an older lake and is located near the city a short distance East of East Locust Creek.

At the time of this report, year 2000, Milan was experiencing severe water shortage. They had nearly emptied both lakes and were pumping from Locust Creek at a site west of Milan. They were using an average of 1.65 million gallon per day. A 3000-gallon per minute pump was used for pumping from Locust Creek. Pumping only occurred when flow in Locust Creek was sufficient to allow pumping plus allow flow to pass downstream for in-stream flow requirements.

Lake surveys of Elmwood Lake and Golf Course Lake were made by the NRCS in year 2000. The drainage area of Elmwood Lake is 6.41 square miles and Golf Course Lake's drainage area is 1.06 square miles.

Storage in Elmwood Lake has been increased in recent years to provide water to two meat processing plants in addition to the cities needs, a rural water district has been removed from the system to conserve water. Before The lake was modified, it had significant leakage. Leakage has now been greatly reduced.

The optimum demand from Lake Elmwood averages 737,500 gallon per day, and Golf Course Lake can be expected to yield and average of 115,930 gallon per day. The total for both lakes is 853,430 gallons per day. This is far short of the demand, 1.65 million gallon per day, placed on the system. Capacities of the lakes are 2503 acre-feet for Elmwood and 555 acre-feet for Golf Course Lake.

Following is the data and procedures for input to the "RESOP" program.

STO-AREA -- Elevation-Storage and Elevation-Area data were determined from May 2000 survey made by NRCS. Elmwood and Golf Course Lakes were surveyed

Elmwood Lake			Golf Course Lake		
Elevation (feet)	Area (acres)	Storage (ac-ft)	Elevation (feet)	Area (acres)	Storage (ac-ft)
842	0.25	0	64	0.21	0
844	0.93	1.19	66	2.61	2.82
846	1.60	3.72	68	4.89	10.31
848	4.58	9.91	70	7.95	23.16
850	20.04	34.53	72	11.00	42.11
852	32.17	86.75	74	14.67	67.77
854	46.45	165.37	76	17.88	100.32
856	63.37	275.19	78	20.97	139.17
858	78.34	416.91	80	25.02	185.15
860	94.06	589.32	82	29.54	239.70
862	113.13	796.51	84	34.70	303.94
864	137.94	1047.59	84.6	36.41	325.27
866	154.61	1340.14	86	38.63	377.80
868	170.09	1664.84	88	41.96	458.4
870	202.02	2036.95	90.1	50.24	555.21
872.2	221.85	2503.21			

	Elmwood Lake	Golf Course Lake
Normal Pool Elev.	= 872.2	= 90.1
May 25,2000 water elev.	= 864.0	May 2000 water elev. 84.6

LIMITS Elmwood Reservoir Max. Pool storage 2503 Ac.Ft.
Minimum Pool storage 417 Ac.Ft.

Minimum pool storage determination for Elmwood Reservoir.
e-mail from Steve McIntosh to Jerry Lane dated 4/24/2000.
Minimum storage from an old survey is 658 ac.ft. at elevation. 858.
At elev. 858 from new survey data, minimum storage is 417 Ac.Ft.

Golf Course Res. Maximum Pool storage 555 Ac.Ft.
Minimum Pool storage 162 Ac.Ft.

Minimum Pool Storage determination for Golf Course Reservoir.

E-mail from Steve McIntosh to Jerry Lane dated 4/24/2000.
Established storage of 176 acre feet as the minimum, this is at assumed elevation 79. At elevation 79 from new survey data minimum storage is 162 acre feet.

GENERAL Record period of drought is in the 1950's.
Analysis began in Jan. 1951 and ended December 1959

SEEPAGE For Elmwood Lake, seepage varied from 0 seepage near empty to a maximum of 3 inches per month when at full pool. Golf Course Lake allowed for seepage of 1.5 inches when full.

RAINFALL Rainfall data came from the Milan, Missouri rain gage.

RUNOFF This is the runoff into the lake from its drainage area. Monthly runoff volumes in watershed inches was determined at the Linneus gage on Locust creek. When runoff did not appear reasonable when compared to rainfall it was necessary to examine daily rainfall values for that month. Antecedent moisture was estimated for each rainfall event and adjustments to NRCS runoff curve number was made to arrive at runoff for each storm.

EVAP. Pan evaporation at the Lakeside gaging station was used as a base because it has data for year around evaporation. This data was updated with gage data from stations at Spickard, New Franklin, and Columbia. Depending on the latest data for the station nearest to Milan.

DEMAND This was determined by city records.
Break down of usage:
Determined from e-mail from Everett Baker to Deana Cash on Feb. 4, 2000.

Milan Production			
PWSD#1	300,000 GPD	=	0.92 Ac.Ft.
Con. Ag.	353,000 GPD	=	1.08 Ac.Ft.
City Use	297,000 GPD	=	0.91 Ac.Ft.
	-----------		-----------
Finished Water	950,000 GPD	=	2.91 Ac.Ft.
Raw Water to PSF	700,000 GPD	=	2.15 Ac.Ft.
	-----------		------------
Total Use	1.65 MGD		5.06 Ac.Ft.
From Elmwood Res.	1.25 MGD		3.83 Ac.Ft.
From Golf Course	400,000 GPD		1.23 Ac.Ft.

When the Golf Course Reservoir water supply became depleted is was necessary to take all the water from Elmwood Reservoir. Golf Course Reservoir emptied rather quickly.

OTHER This refers to the volume of water pumped from Locust creek into Elmwood Reservoir.

Determination of the volume of water available for pumping was made using daily discharges at the stream gage at Linneus. The drainage area at Linneus is 550 square miles and the drainage area at the point of pumping is 225 square miles. The daily discharge rates at the point of pumping were reduced by a ratio of 225/550. Pumping was only planned for flows above 10 cfs. The maximum rate of pumping was 3000 gallons per minute or 6.68 cfs. It was necessary to have continuous pumping when enough flow was in Locust Creek

Milan, Missouri
Water Supply Study
Shatto Lake
Private Lake

Shatto Lake is a small private lake at the south side of Milan, in central Sullivan County, Missouri. It was investigated to determine the amount of emergency water supply that is available.

This lake 34-acre lake has a very small drainage area, 173 acres, too small to provide much water. This privately owned 35-acre lake is 40 feet deep and the owners have not been successful in sealing off a leak at the base of the dam.

Because there is no daily demand placed on this lake only an optimized run was made. The daily volume of water available is 83,000 gallon per day. By removing water at this rate the lake would be emptied and have no opportunity to refill until some time after the 1950's.

Shatto Lake analysis consisted of using the NRCS's computer program "RESOP". This program analyzes remaining stored water at the end of each month by summing gains and losses.

STO-AREA Elevation-Storage and Elevation-Area data were determined from May 2000 survey made by USGS.

SHATTO LAKE

Elevation (feet)	Area (acres)	Volume (acre-ft)
846.0	0.19	0.18
848.0	0.47	0.74
850.0	1.15	2.44
852.0	1.89	5.48
854.0	2.59	9.96
856.0	3.24	15.78
858.0	4.27	23.28
860.0	5.45	33.01
862.0	6.86	45.26
864.0	8.42	60.51
866.0	10.03	78.93
868.0	11.57	100.56
870.0	13.08	125.19
872.0	14.62	152.90
874.0	16.40	183.80
876.0	18.60	218.80
878.0	20.56	258.00
880.0	22.38	300.92
882.0	24.22	347.55
884.0	25.75	397.51
886.0	27.33	450.55
888.0	29.00	506.92
890.0	30.49	566.41
890.3	30.76	575.59
892.0	32.02	628.98
893.0	32.80	661.37
894.0	33.51	694.53
895.6	34.68	749.08

LIMITS	Maximum Pool storage	661 Ac.Ft.
	Minimum Pool storage	80 Ac.Ft.

Starting storage was considered full pool.

The drainage area of the lake is 0.27 square miles.

GENERAL — Record period of drought is in the 1950's. Analysis began in January 1951 and ended December 1959.

SEEPAGE — For Shatto Lake, seepage is high. For this study, seepage varied from 0 near empty to a maximum of 3 inches per month when at full pool.

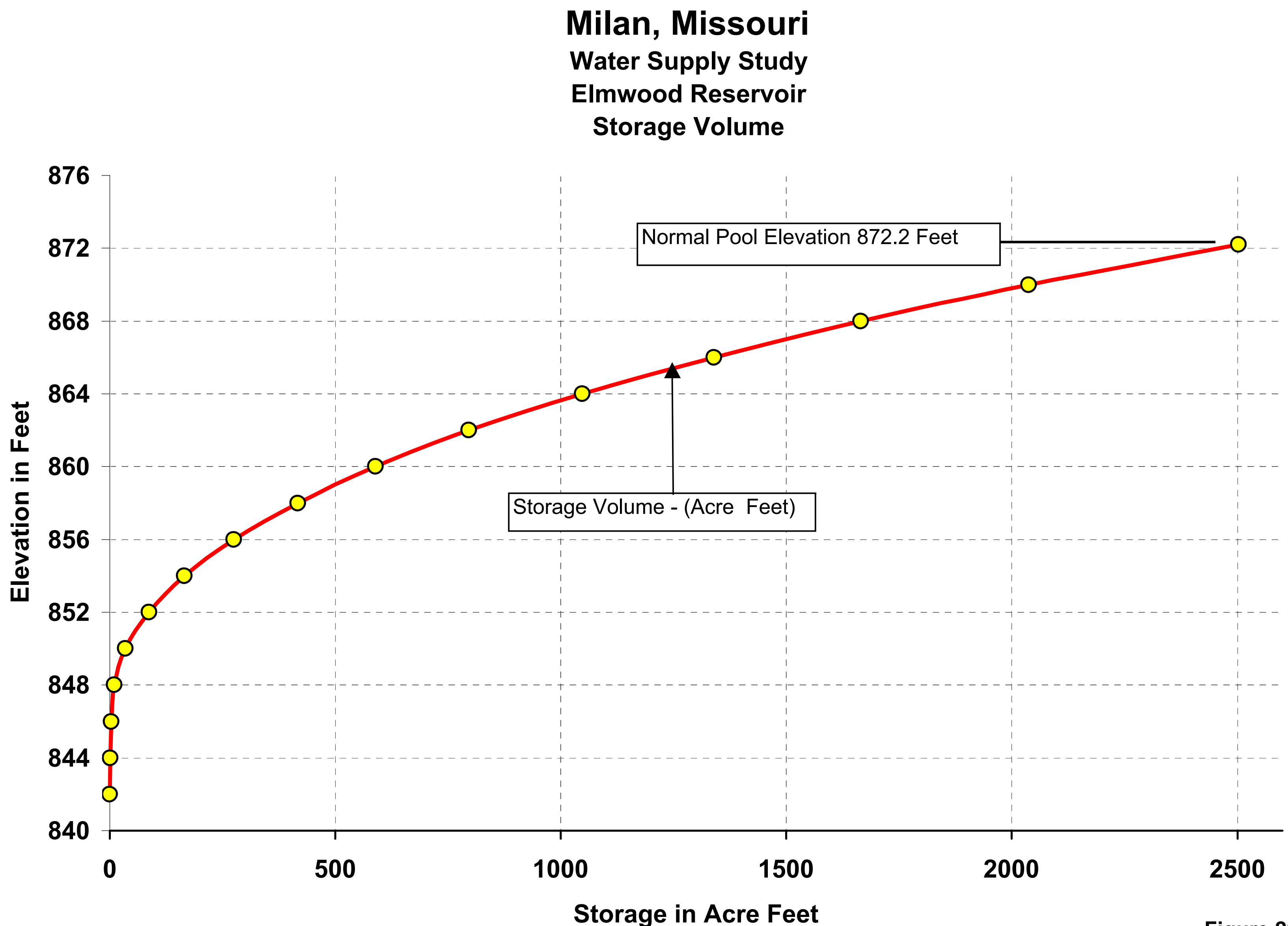
RAINFALL — Rainfall data came from the Milan, Missouri rain gage.

RUNOFF — This is the runoff into the lake from its drainage area. Monthly runoff volumes in watershed inches was determined at the Linneus gage on Locust Creek. When runoff did not appear reasonable compared to rainfall it was necessary to examine daily rainfall values for that month. Antecedent moisture was estimated for each rainfall event and adjustments to NRCS runoff curve number was made to arrive at runoff for each storm.

EVAP. — Pan evaporation at the Lakeside gaging station was used as a base because it has data for year around evaporation. This data was updated with gage data from stations at Spickard, New Franklin, and Columbia. Depending on the latest data for the station nearest to Milan.

DEMAND — This control word was only used to establish a monthly distribution because the purpose of this analysis was to determine the optimum yield.

OTHER — This control word was not used because no other inflows were considered.



Milan, Missouri
Water Supply Study
Elmwood Reservoir
Storage Volume
Elevation in Feet
876
872
868
864
860
856
852
848
844
840
Normal Pool Elevation 872.2 Feet
Storage Volume - (Acre Feet)
0
500
1000
1500
2000
2500
Storage in Acre Feet

Figure 22.1.a

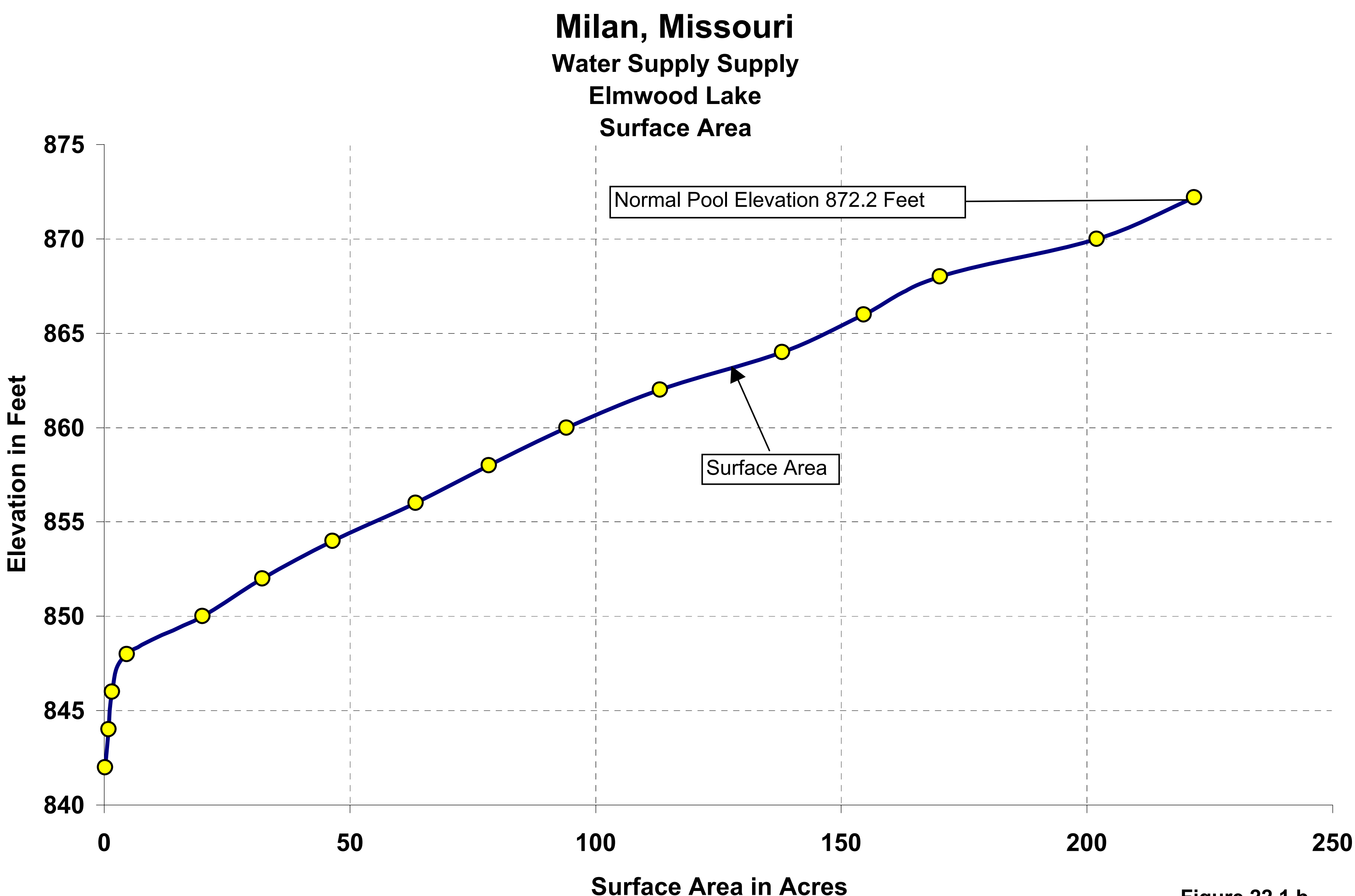

Milan, Missouri
Water Supply Supply
Elmwood Lake
Surface Area
Elevation in Feet
875
870
865
860
855
850
845
840
0
50
100
150
200
250
Surface Area in Acres
Normal Pool Elevation 872.2 Feet
Surface Area

Figure 22.1.b

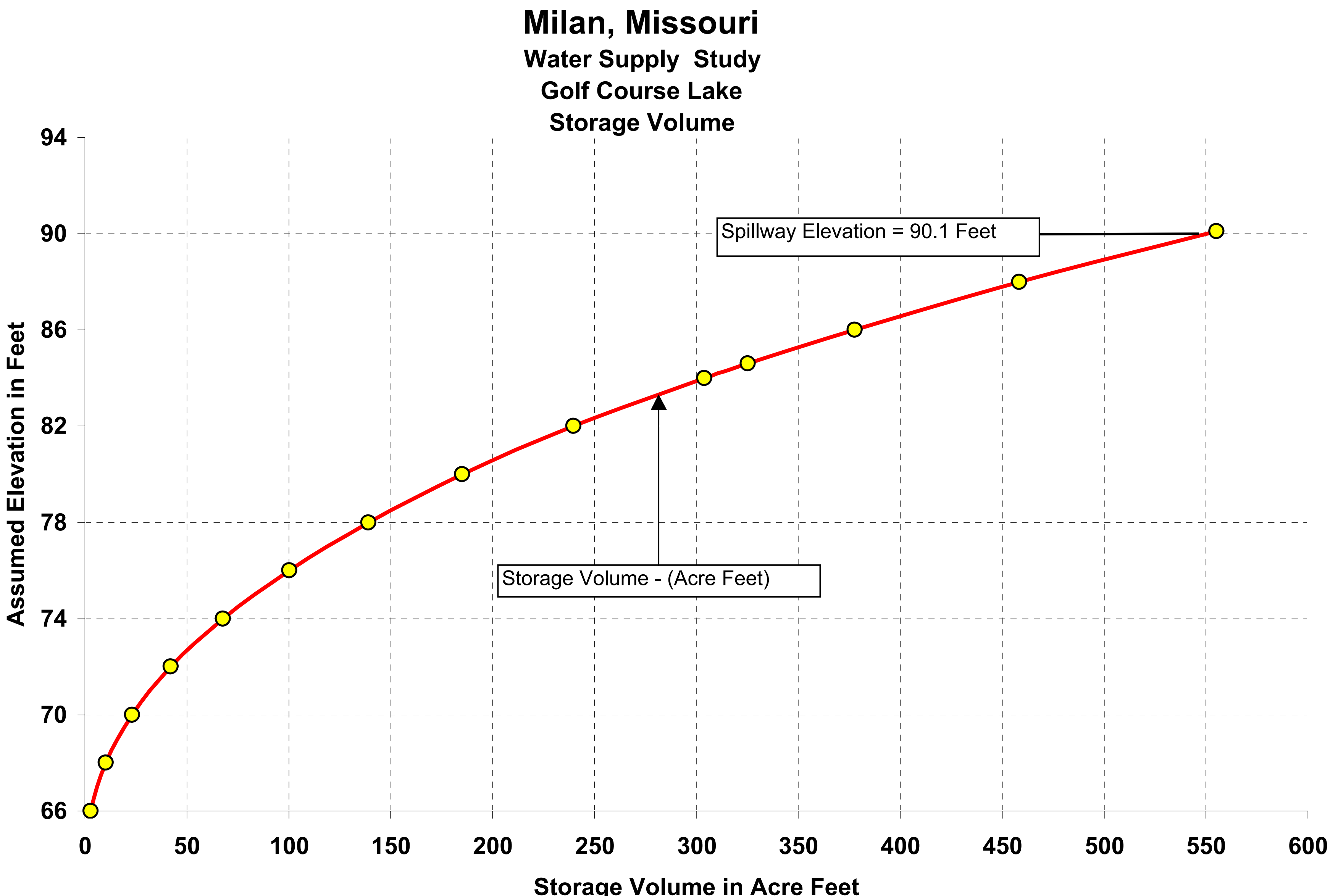

Milan, Missouri
Water Supply Study
Golf Course Lake
Storage Volume
Spillway Elevation = 90.1 Feet
Storage Volume - (Acre Feet)
Assumed Elevation in Feet
94
90
86
82
78
74
70
66
0
50
100
150
200
250
300
350
400
450
500
550
600
Storage Volume in Acre Feet

Figure 22.1.c

Milan, Missouri
Water Supply Study
Golf Course Lake
Surface Area

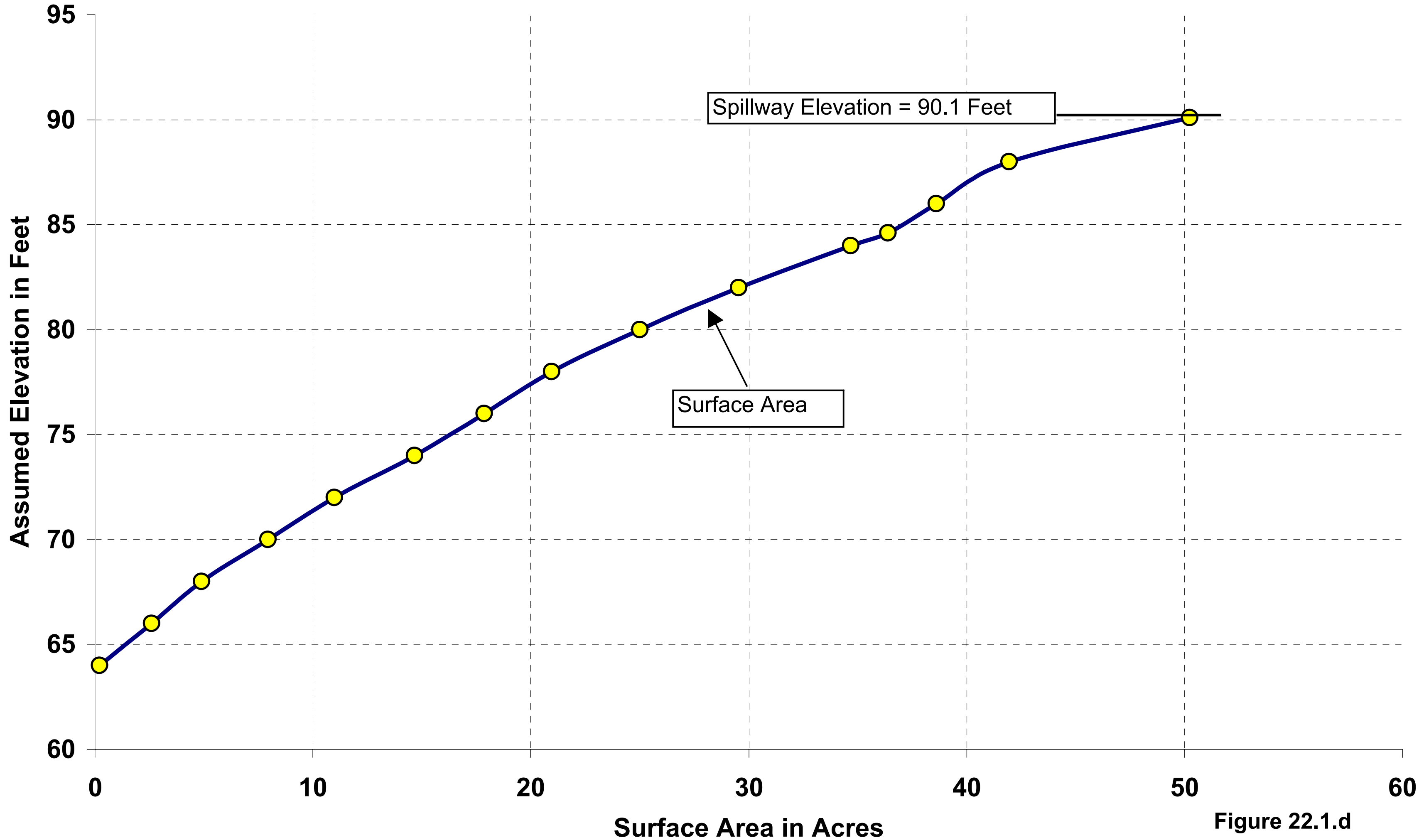
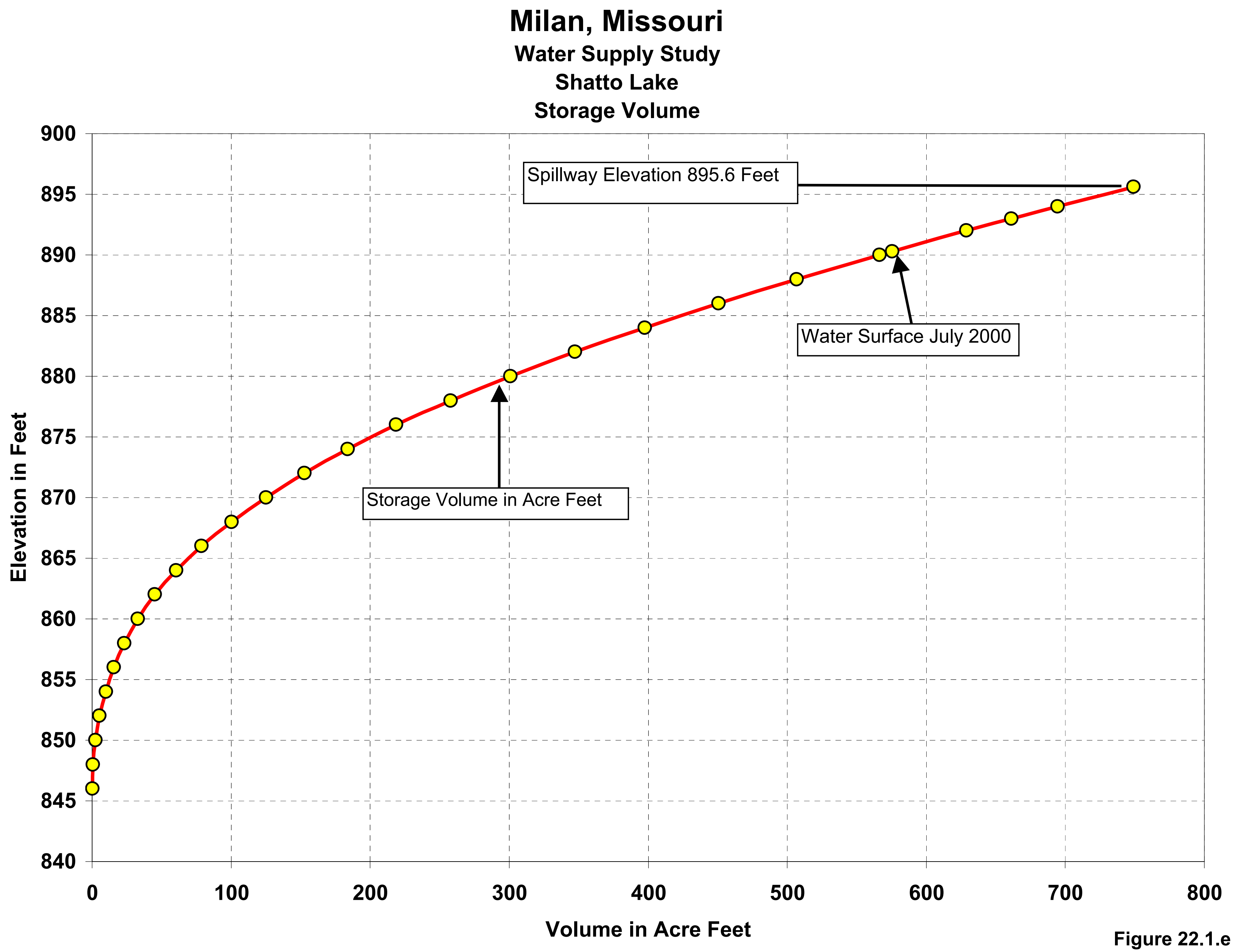
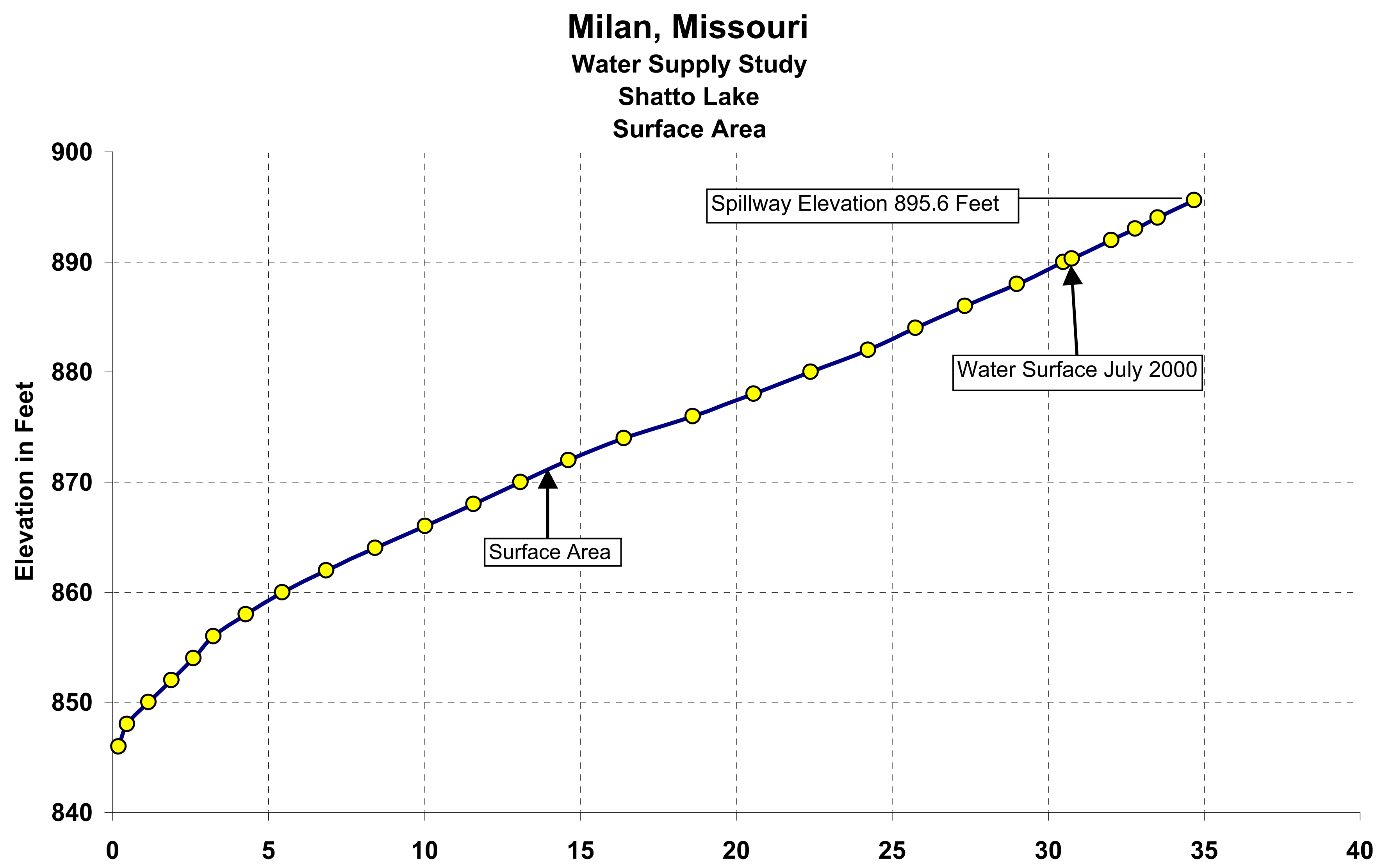


Figure 22.1.d



Milan, Missouri
Water Supply Study
Shatto Lake
Storage Volume
Spillway Elevation 895.6 Feet
Water Surface July 2000
Storage Volume in Acre Feet
Elevation in Feet
Volume in Acre Feet
900
895
890
885
880
875
870
865
860
855
850
845
840
0
100
200
300
400
500
600
700
800

Figure 22.1.e



Milan, Missouri
Water Supply Study
Shatto Lake
Surface Area
Spillway Elevation 895.6 Feet
Water Surface July 2000
Surface Area
Elevation in Feet
900
890
880
870
860
850
840
0
5
10
15
20
25
30
35
40
Area in Acres

Figure 22.1.f

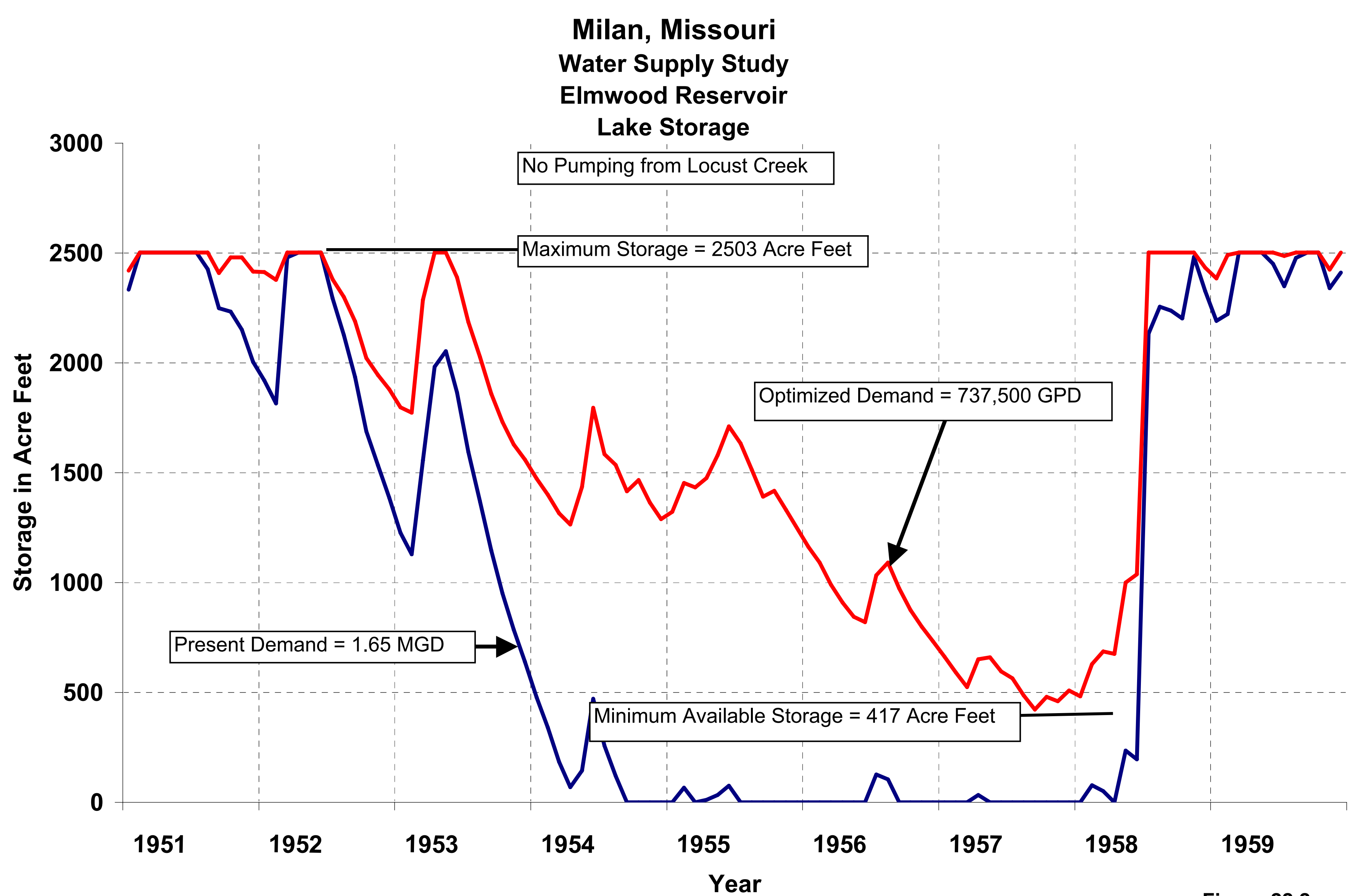

Milan, Missouri
Water Supply Study
Elmwood Reservoir
Lake Storage
No Pumping from Locust Creek
Maximum Storage = 2503 Acre Feet
Optimized Demand = 737,500 GPD
Present Demand = 1.65 MGD
Minimum Available Storage = 417 Acre Feet
Storage in Acre Feet
3000
2500
2000
1500
1000
500
0
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year

Figure 22.2.a

Milan, Missouri
Water Supply Study
Elmwood Lake
Lake Storage

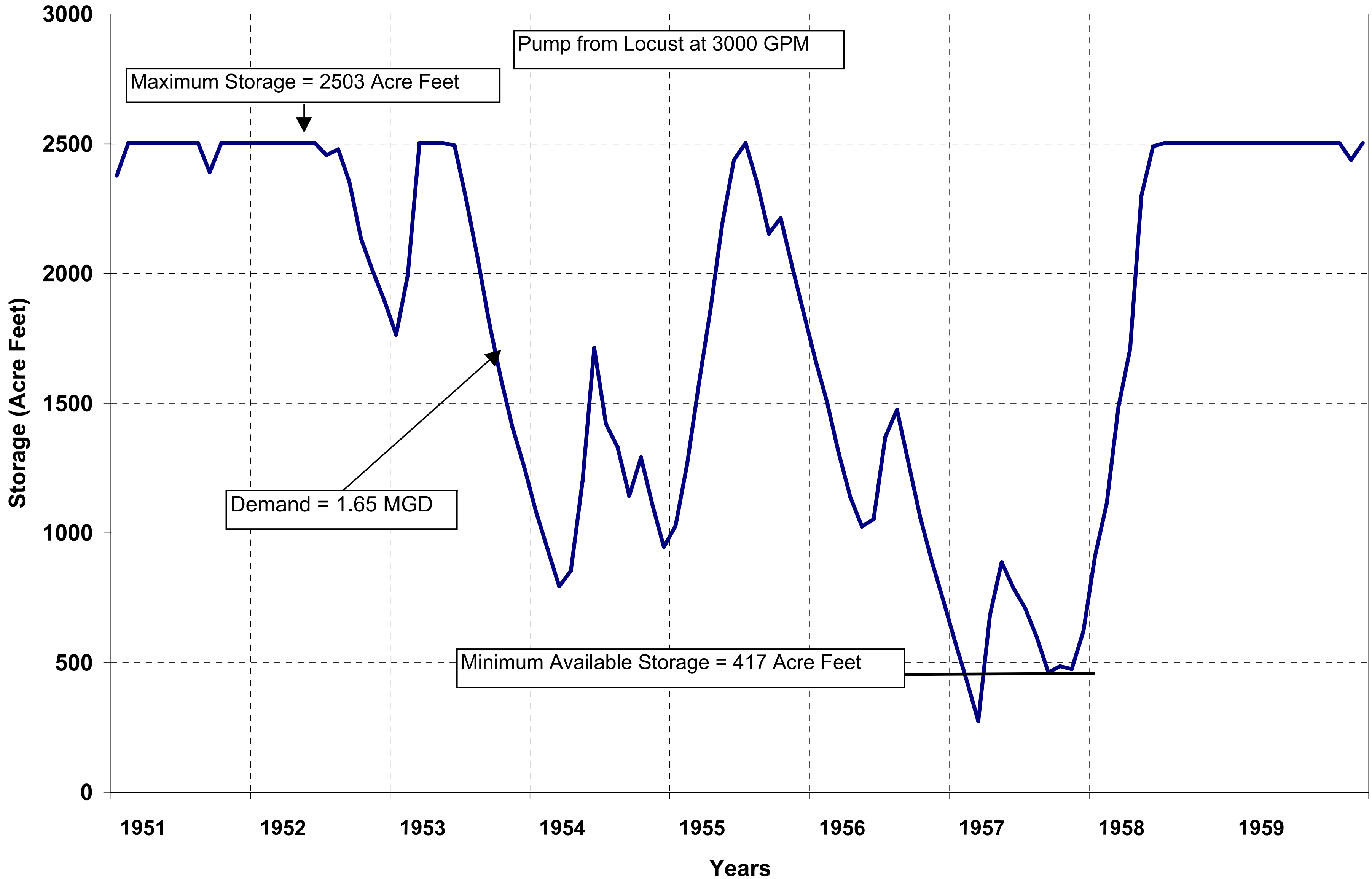


Figure 22.2.b

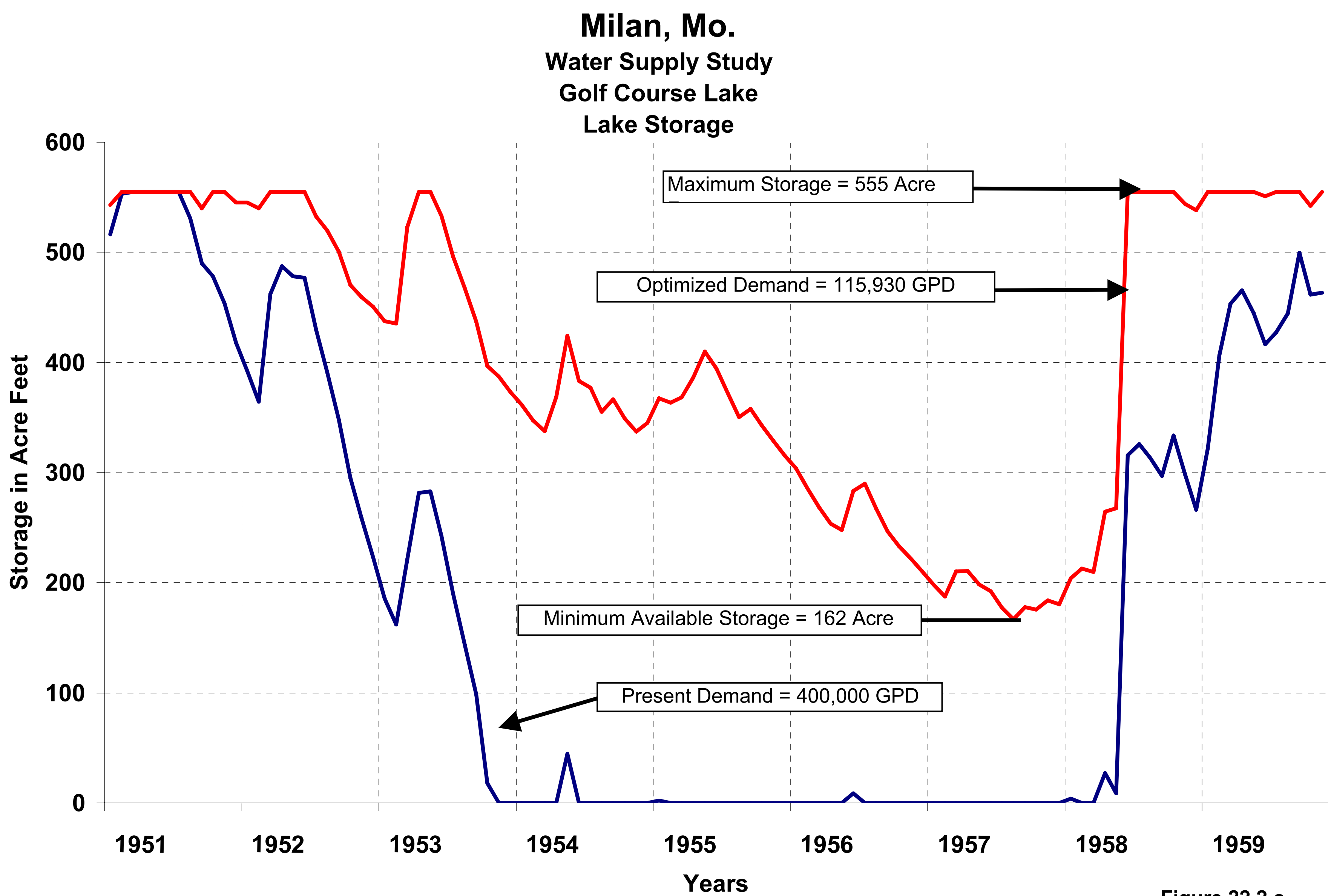

Milan, Mo.
Water Supply Study
Golf Course Lake
Lake Storage
Storage in Acre Feet
600
500
400
300
200
100
0
1951
1952
1953
1954
1955
1956
1957
1958
1959
Years
Maximum Storage = 555 Acre
Optimized Demand = 115,930 GPD
Minimum Available Storage = 162 Acre
Present Demand = 400,000 GPD

Figure 22.2.c

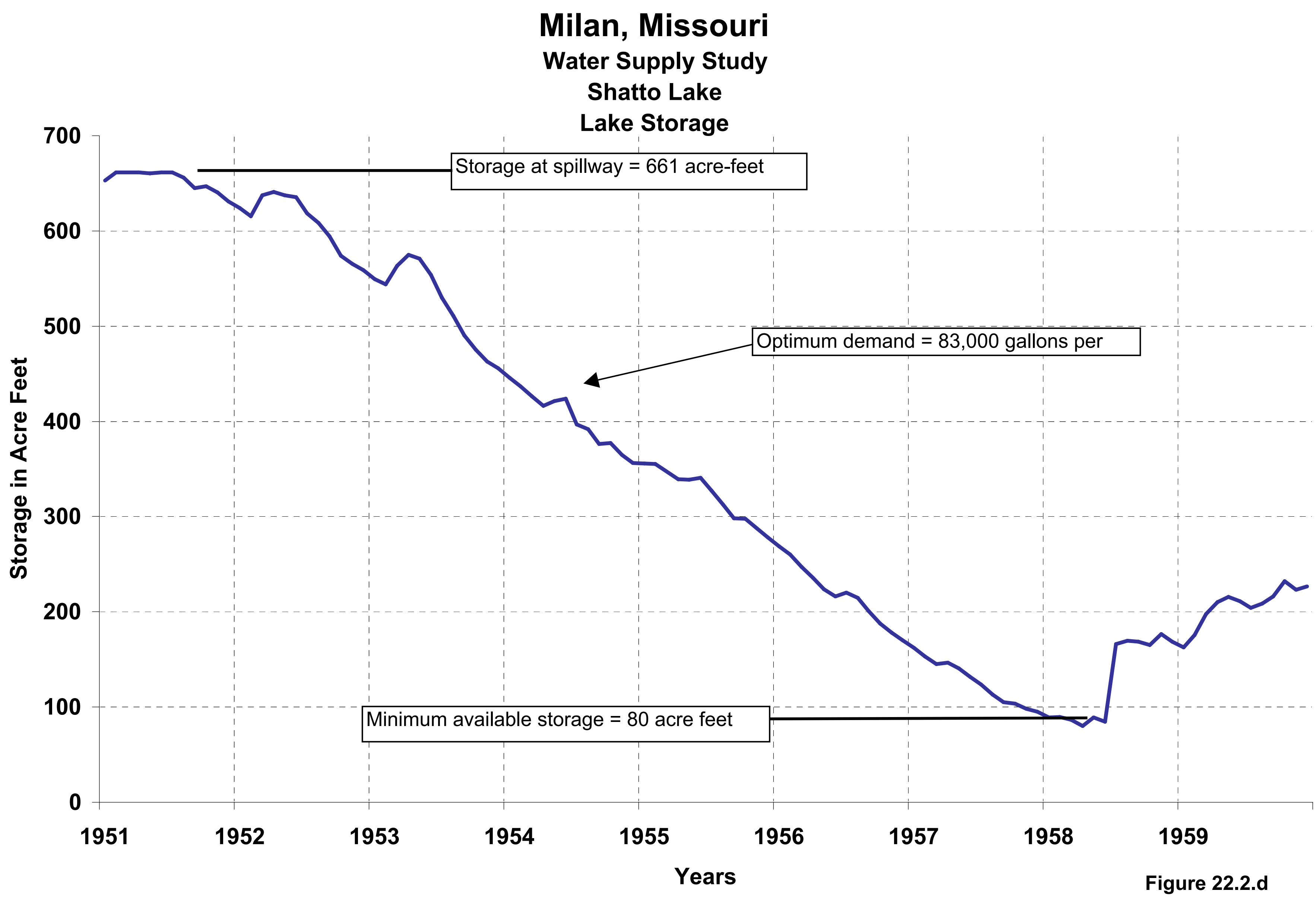

Milan, Missouri
Water Supply Study
Shatto Lake
Lake Storage
Storage in Acre Feet
700
600
500
400
300
200
100
0
Storage at spillway = 661 acre-feet
Optimum demand = 83,000 gallons per
Minimum available storage = 80 acre feet
1951
1952
1953
1954
1955
1956
1957
1958
1959
Years

Figure 22.2.d

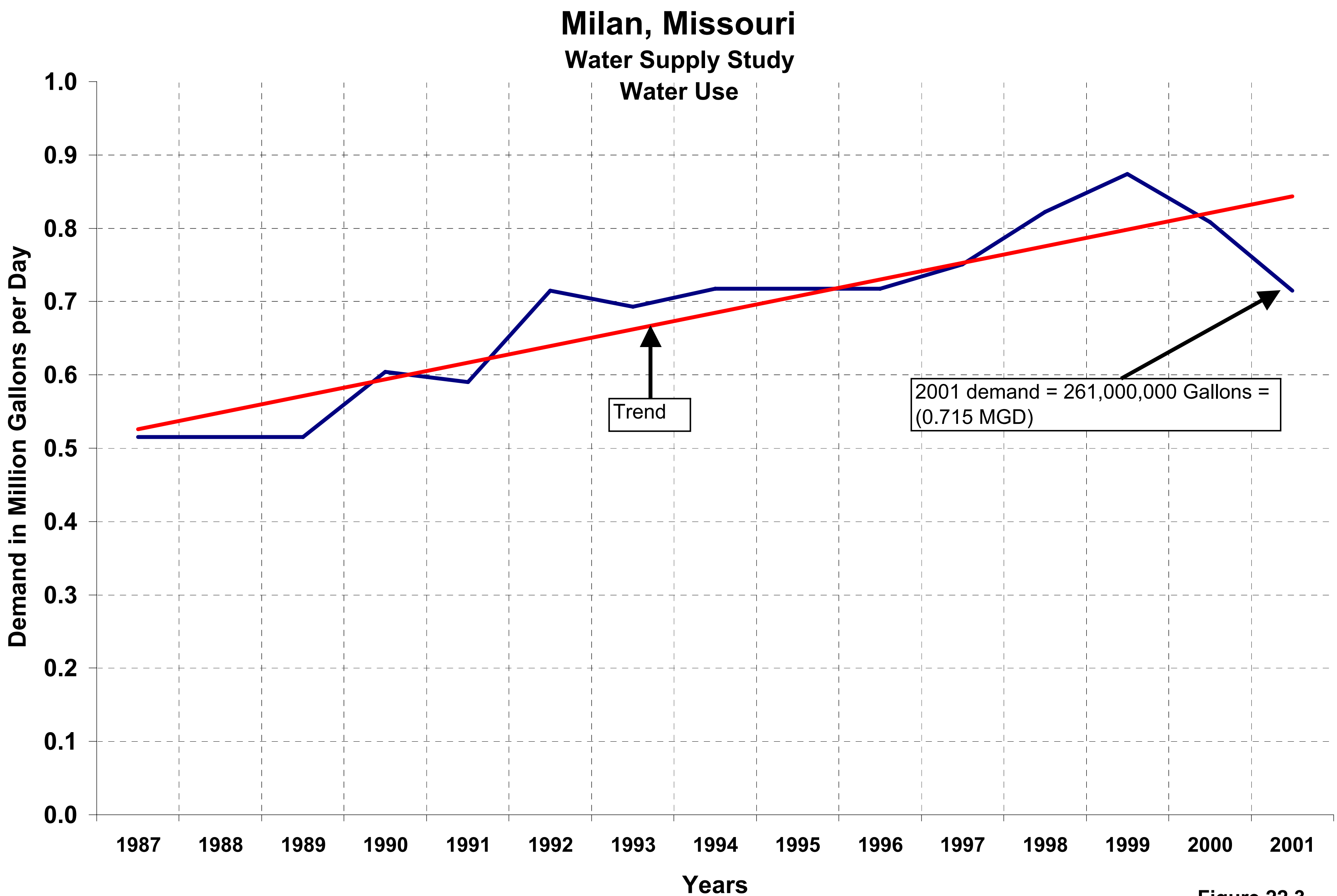
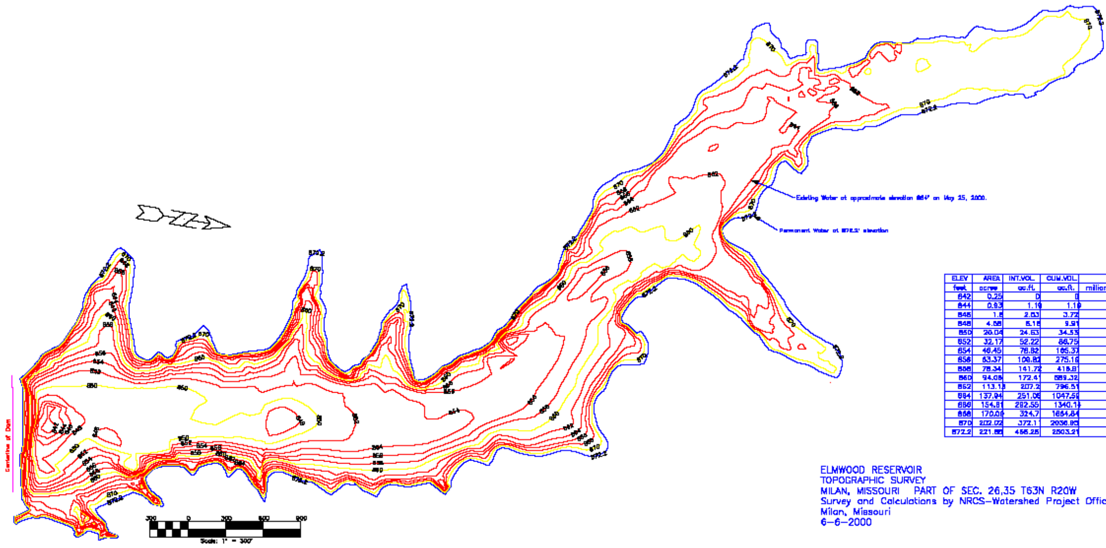

Milan, Missouri
Water Supply Study
Water Use
Demand in Million Gallons per Day
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Trend
2001 demand = 261,000,000 Gallons = (0.715 MGD)
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
Years

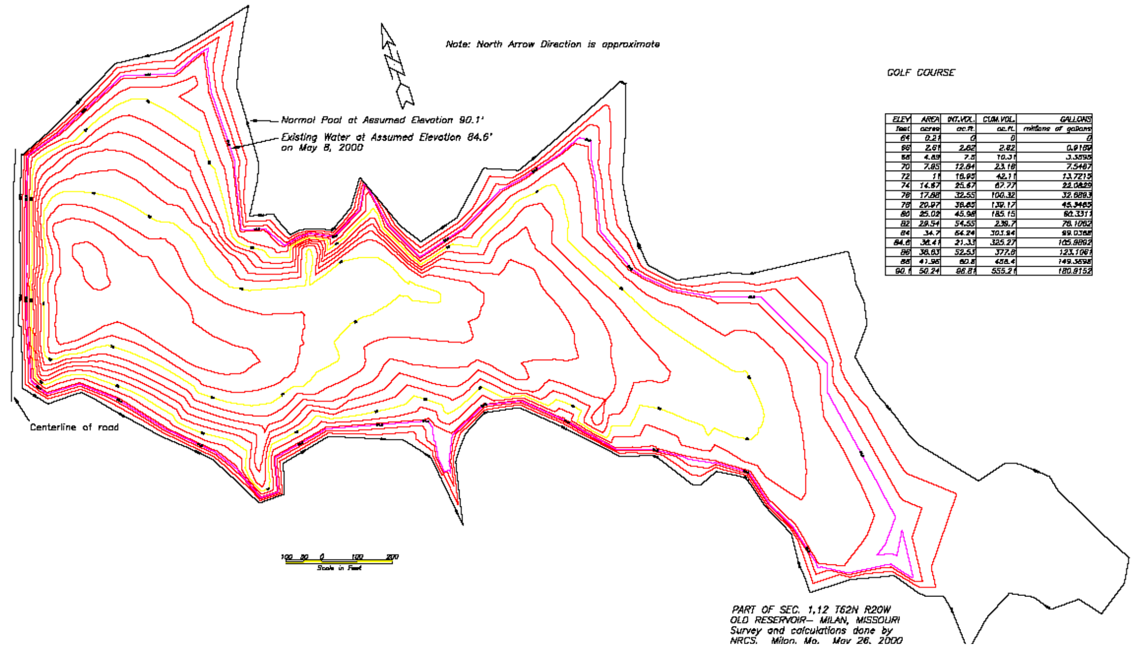
Figure 22.3



ELEV	AREA	INT.VOL.	CUM.VOL.	GALLONS
feet	acres	ac.ft.	ac.ft.	millions of gallons
842	0.25	0	0	0
844	0.83	1.19	1.19	0.3878
846	1.8	2.63	3.72	1.2122
848	4.58	6.18	9.91	3.2292
850	20.04	24.63	34.53	11.251
852	32.17	52.22	86.75	28.2675
854	46.45	78.62	165.37	53.8858
856	63.37	109.82	275.16	89.6707
858	78.34	141.72	416.87	135.860
860	94.08	172.41	589.32	192.0295
862	113.13	207.2	796.51	259.5428
864	137.94	251.08	1047.59	341.3572
866	154.81	282.55	1340.14	436.8848
868	170.06	324.7	1664.84	542.4881
870	202.02	372.11	2036.95	663.7402
872.2	221.88	466.25	2503.21	815.671

ELMWOOD RESERVOIR
TOPOGRAPHIC SURVEY
MILAN, MISSOURI PART OF SEC. 26,35 T63N R20W
Survey and Calculations by NRCS-Watershed Project Office
Milan, Missouri
6-6-2000

Figure 23.4.a Bathymetric map and area/volume table of Elmwood Reservoir, Milan, Missouri.



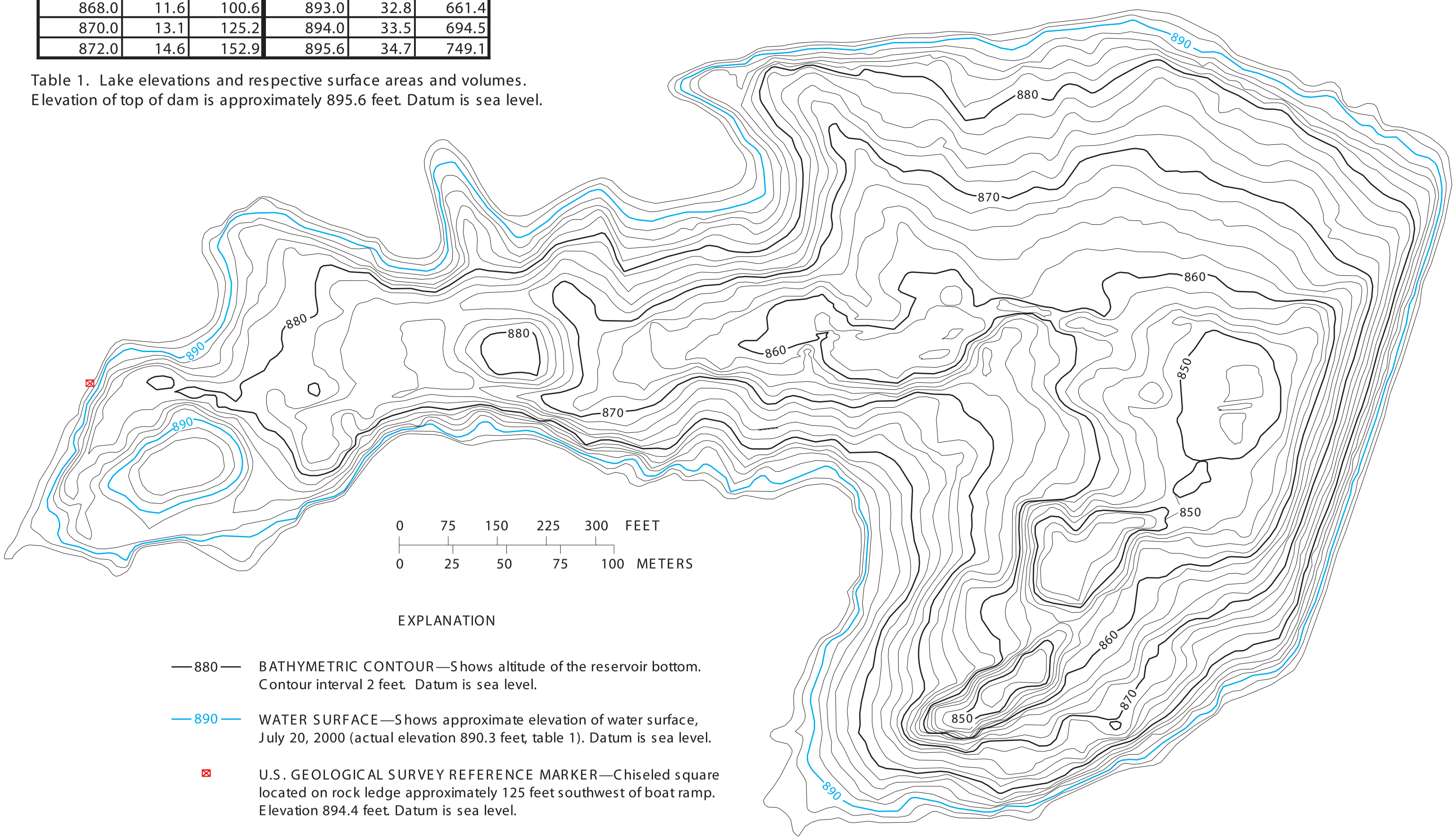
ELEV	AREA	INT.VOL.	CUM.VOL.	GALLONS
feet	acres	ac.ft.	ac.ft.	millions of gallons
64	0.21	0	0	0
66	2.61	2.82	2.82	0.9189
68	4.89	7.5	10.31	3.3595
70	7.85	12.84	23.16	7.5467
72	11	18.95	42.11	13.7215
74	14.67	25.67	67.77	22.0829
76	17.88	32.55	100.32	32.6883
78	20.97	38.85	139.17	45.3465
80	25.02	45.98	185.15	60.3311
82	29.54	54.55	239.7	78.1062
84	34.7	64.24	303.94	99.0368
84.6	36.41	21.33	325.27	105.9892
86	38.63	52.53	377.8	123.1061
88	41.96	80.6	458.4	149.3598
90.1	50.24	96.81	555.21	180.9152

Figure 23.4.b Bathymetric map and area /volume table of Golf Course Reservoir, Milan, Missouri

SHATTO LAKE

Elevation (feet)	Area (acres)	Volume (acre-ft)	Elevation (feet)	Area (acres)	Volume (acre-ft)
846.0	0.2	0.2	874.0	16.4	183.8
848.0	0.5	0.7	876.0	18.6	218.8
850.0	1.2	2.4	878.0	20.6	258.0
852.0	1.9	5.5	880.0	22.4	300.9
854.0	2.6	10.0	882.0	24.2	347.5
856.0	3.2	15.8	884.0	25.8	397.5
858.0	4.3	23.3	886.0	27.3	450.6
860.0	5.4	33.0	888.0	29.0	506.9
862.0	6.9	45.3	890.0	30.5	566.4
864.0	8.4	60.5	890.3	30.8	575.6
866.0	10.0	78.9	892.0	32.0	629.0
868.0	11.6	100.6	893.0	32.8	661.4
870.0	13.1	125.2	894.0	33.5	694.5
872.0	14.6	152.9	895.6	34.7	749.1

Table 1. Lake elevations and respective surface areas and volumes. Elevation of top of dam is approximately 895.6 feet. Datum is sea level.

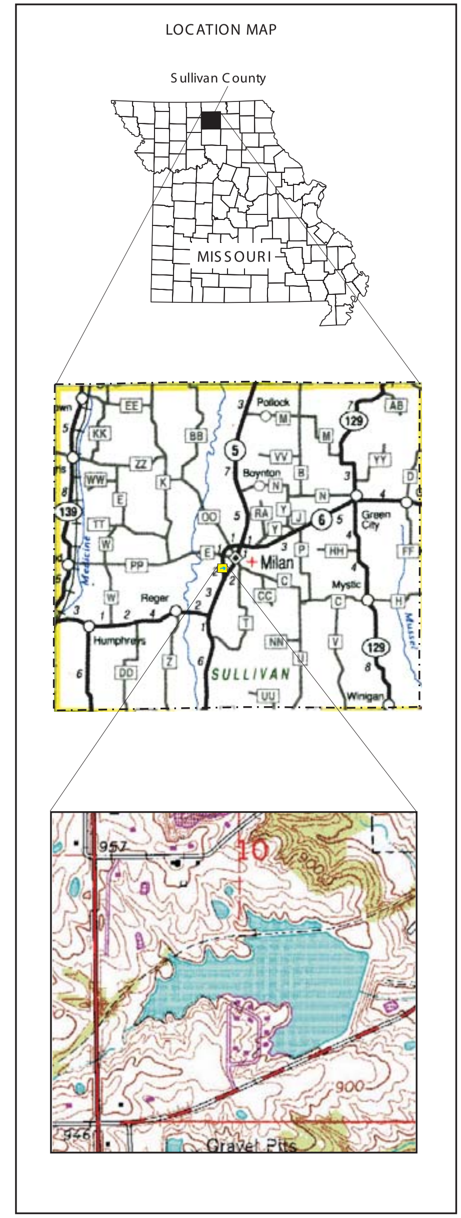


EXPLANATION

—880— BATHYMETRIC CONTOUR—Shows altitude of the reservoir bottom. Contour interval 2 feet. Datum is sea level.

—890— WATER SURFACE—Shows approximate elevation of water surface, July 20, 2000 (actual elevation 890.3 feet, table 1). Datum is sea level.

⊠ U.S. GEOLOGICAL SURVEY REFERENCE MARKER—Chiseled square located on rock ledge approximately 125 feet southwest of boat ramp. Elevation 894.4 feet. Datum is sea level.



USGS science for a changing world

Figure 1. Bathymetric map and area/volume table for Shatto Lake near Milan, Missouri.

Moberly, Missouri
Water Supply Study
Sugar Creek Lake

Sugar Creek Lake is located about 2 miles North of Moberly in Randolph County. Its drainage area is 11.05 square miles. The lake is in the East Fork Chariton River watershed.

Average annual rainfall for the period 1951 through 2002 is 37.8 inches. Annual rainfall for 1953 through 1957 is 24.9, 34.8, 37.7, 27.9, and 34.0 inches.

Three analysis were made:

1. First run was with the 2001 demand.
2. The lake was analyzed for the optimum daily use without emptying the lake during the evaluation period. The optimum yield from the lake with no additional water added to the system was 1.20 million gallons per day.
3. Additional water that was needed to meet Moberly's needs during the drought of record in the 1950's.

For this analysis actual runoff data from local stream gages was used. Comparisons were made for the Elk Fork Salt River gage, Drainage area is 262 square miles near Paris, and Moniteau Creek gage near Fayette, drainage area 81 square miles. The Elk Creek drainage area shares a common boundary with the Sugar Creek Lake drainage area. Moniteau Creek rises a few miles South of Moberly. Both of these gages yielded similar results. The monthly runoff results were less for these two gages than the USGS regional data. Because proximity of the watersheds and the topography, soils, vegetation and land use in the drainage area of Sugar Creek Lake is similar to the Elk and Moniteau Creeks drainage areas it was elected to use Moniteau Creek for runoff values because the records are the most complete.

Sugar Creek Lake analysis consisted of using the NRCS's computer program "RESOP". This program analyses remaining stored water at the end of each month by summing gains and losses.

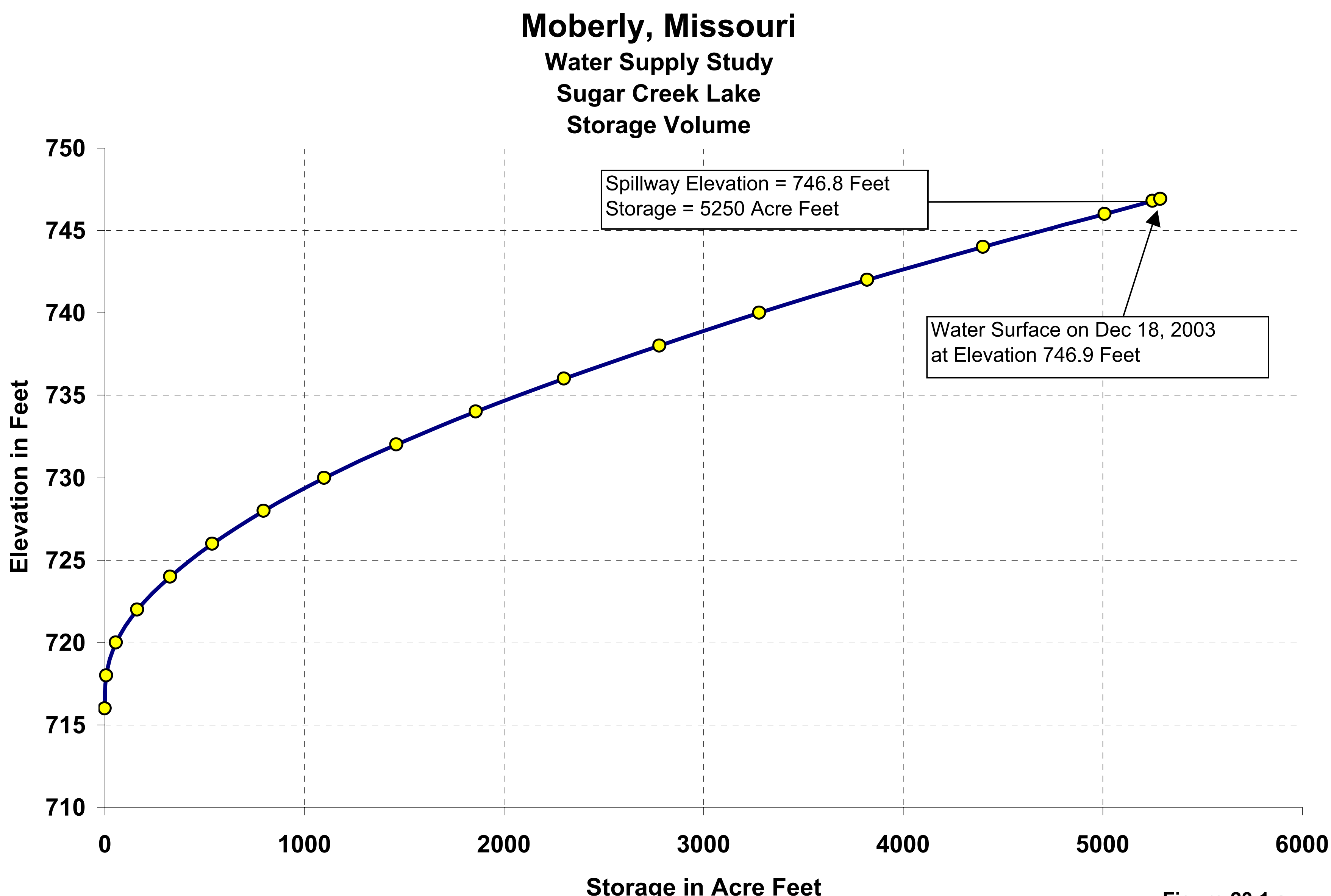
Following is the data and procedures for input to the "RESOP" program.

STO-AREA Elevation-Storage and Elevation-Area data were determined from April 6, 2004 survey made by USGS.

Sugar Creek Lake

Elevation (feet)	Area (acres)	Volume (acre-ft)	
716.0	0.1	0.01	
718.0	11.9	8.1	
720.0	39.1	55.4	
722.0	68.7	163	
724.0	93.8	328	
726.0	117	539	
728.0	141	797	
730.0	164	1,100	
732.0	188	1,460	
734.0	214	1,860	
736.0	230	2,300	
738.0	245	2,780	
740.0	259	3,280	
742.0	279	3,820	
744.0	297	4,400	
746.0	314	5,010	
746.8	320	5,250	Spillway Elevation
746.9	332	5,290	Water Surface in Dec. 2003

LIMITS	Full Pool storage 5250 Ac.Ft. Minimum pool storage 330 Ac.Ft. Starting storage was considered at full pool elevation. The drainage area of the lake is 11.05 square miles.
GENERAL	The adjustment factor of 0.76 to convert from pan evaporation to lake evaporation was applied prior to entering the data for the control word EVAP. As a result a factor of 100 is applied. The record period of drought is in the 1950's. Analysis began in January 1951 and ended December 1959.
SEEPAGE	The reservoir seepage varied from 0 seepage near empty to a maximum of 3.0 inch per month when at full pool. The material in the dam is compacted earth of clayey soils.
RAINFALL	Rainfall data came from the Moberly, Mo. rain gage for the period 1951 through 1959.
RUNOFF	The runoff into the lake from its drainage area. Monthly runoff volumes in watershed Inches were determined for the Moniteau Creek stream gage. In cases where rainfall to runoff values did not appear reasonable, adjustments were made for that month by looking at individual rains and estimating antecedent moisture and then, adjusting runoff based on NRCS's runoff curve numbers.
EVAP.	Pan evaporation at the Lakeside gaging station was used as a base because it has data for year around evaporation. All other stations only measure data between April through November. Lakeside data was updated during these months with gage data from stations at New Franklin, and Columbia. Depending on the latest data for the station nearest to Moberly.
DEMAND	This was determined by city records. The total use in 2001 was 561,159,100 gallons which amounts to 1.537 million gallons per day.



Moberly, Missouri
Water Supply Study
Sugar Creek Lake
Storage Volume
Spillway Elevation = 746.8 Feet
Storage = 5250 Acre Feet
Water Surface on Dec 18, 2003
at Elevation 746.9 Feet
Elevation in Feet
750
745
740
735
730
725
720
715
710
0
1000
2000
3000
4000
5000
6000
Storage in Acre Feet

Figure 23.1.a

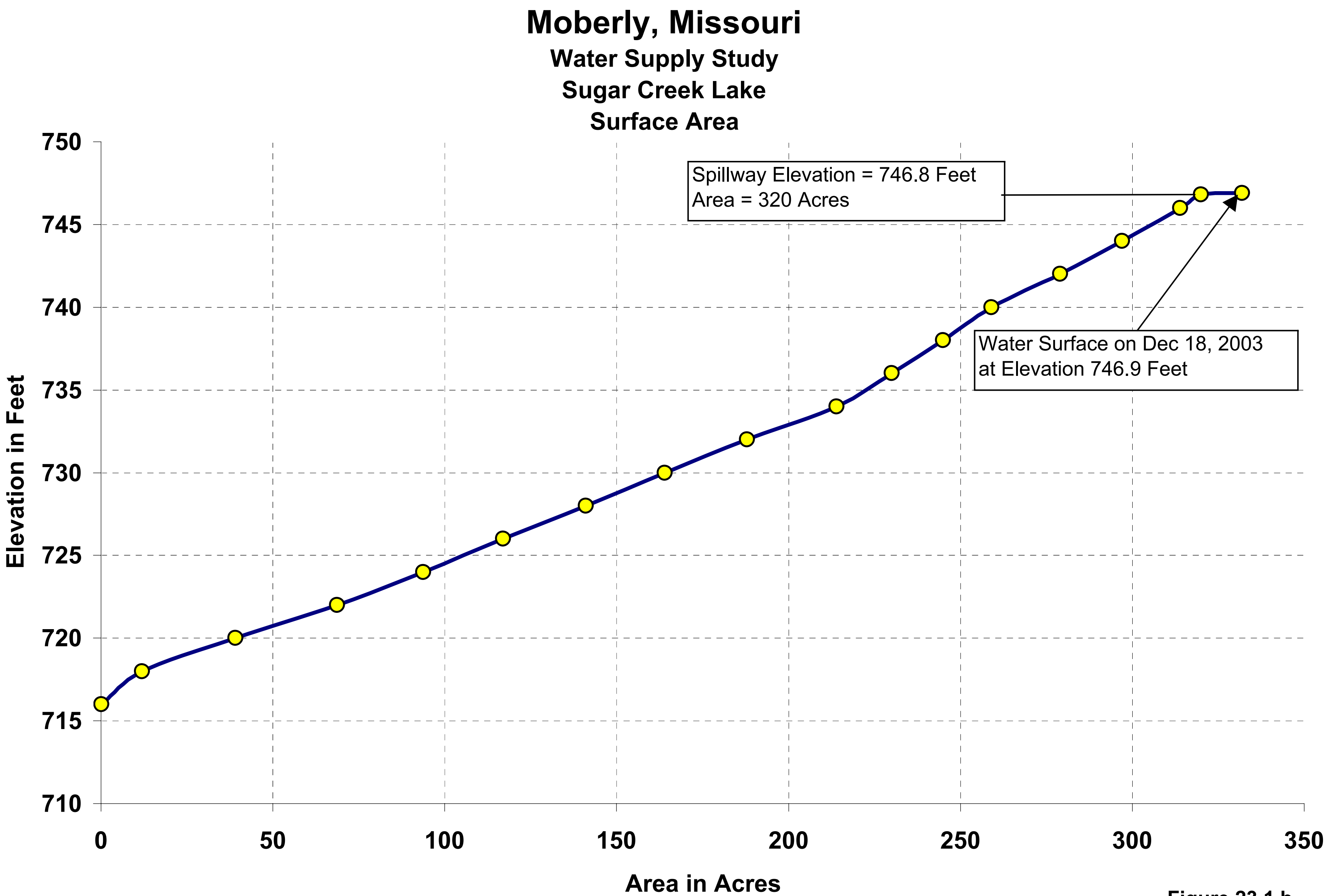
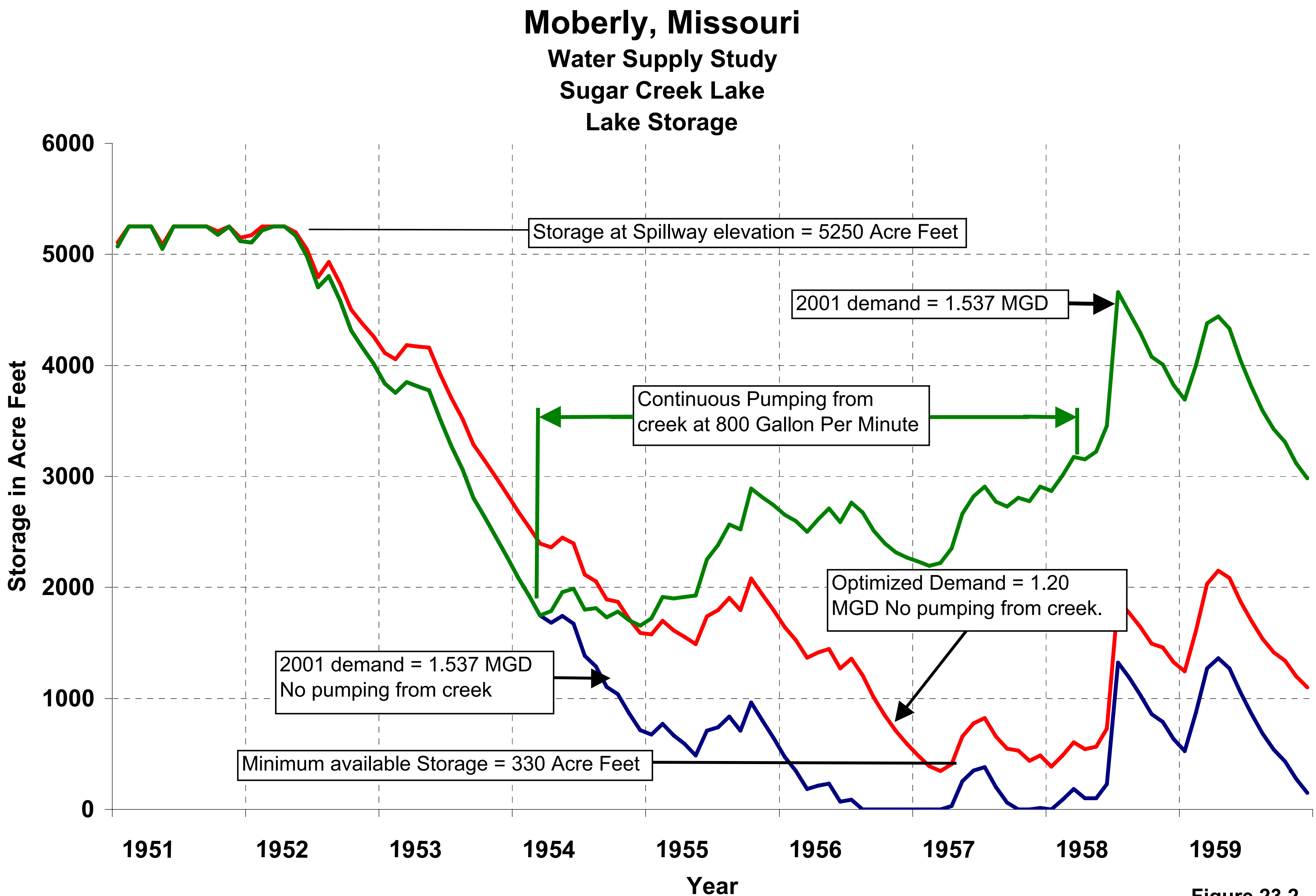

Moberly, Missouri
Water Supply Study
Sugar Creek Lake
Surface Area
Spillway Elevation = 746.8 Feet
Area = 320 Acres
Water Surface on Dec 18, 2003
at Elevation 746.9 Feet
Elevation in Feet
750
745
740
735
730
725
720
715
710
0
50
100
150
200
250
300
350
Area in Acres

Figure 23.1.b



Moberly, Missouri
Water Supply Study
Sugar Creek Lake
Lake Storage
Storage in Acre Feet
6000
5000
4000
3000
2000
1000
0
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year
Storage at Spillway elevation = 5250 Acre Feet
2001 demand = 1.537 MGD
Continuous Pumping from creek at 800 Gallon Per Minute
Optimized Demand = 1.20 MGD No pumping from creek.
2001 demand = 1.537 MGD No pumping from creek
Minimum available Storage = 330 Acre Feet

Figure 23.2

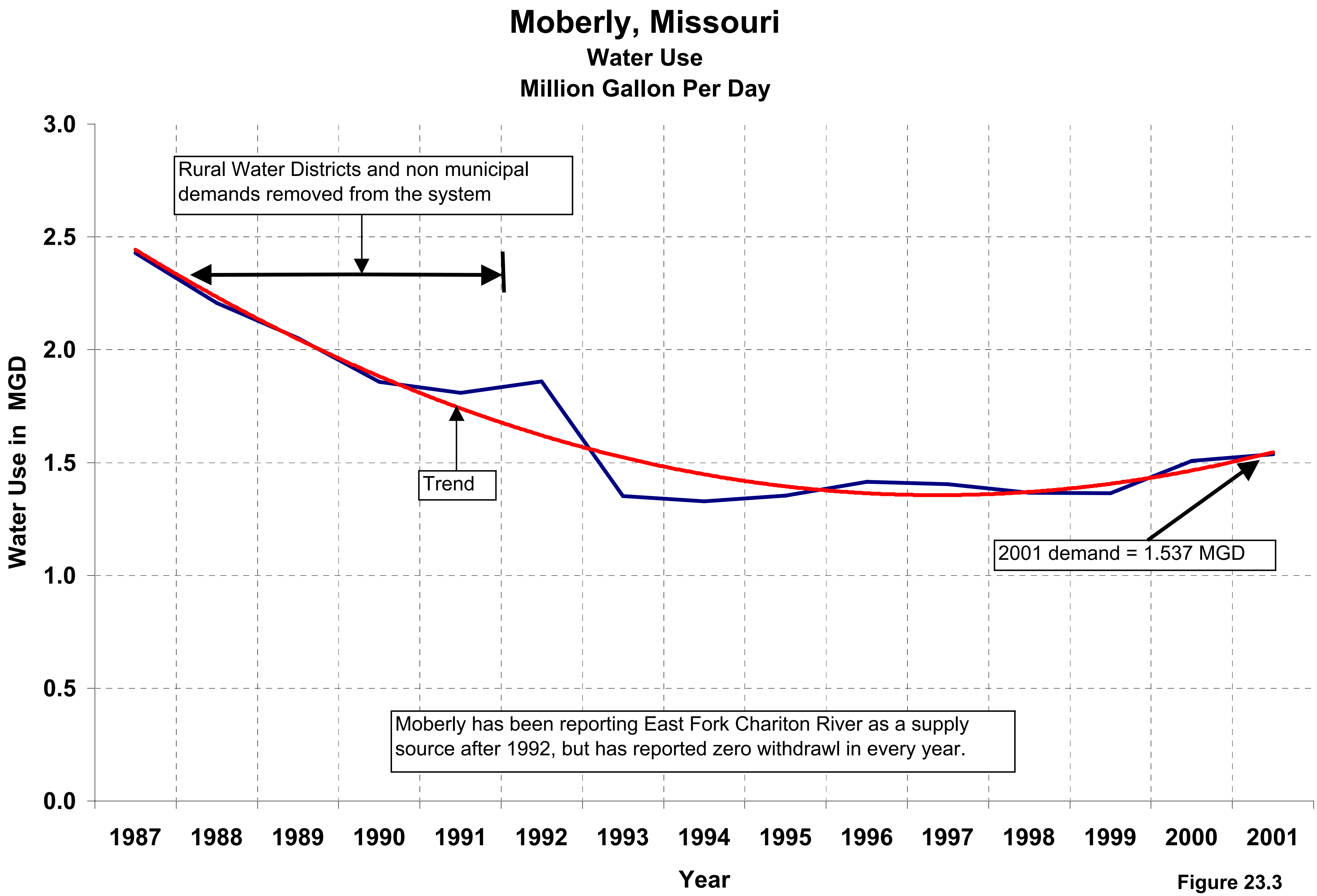
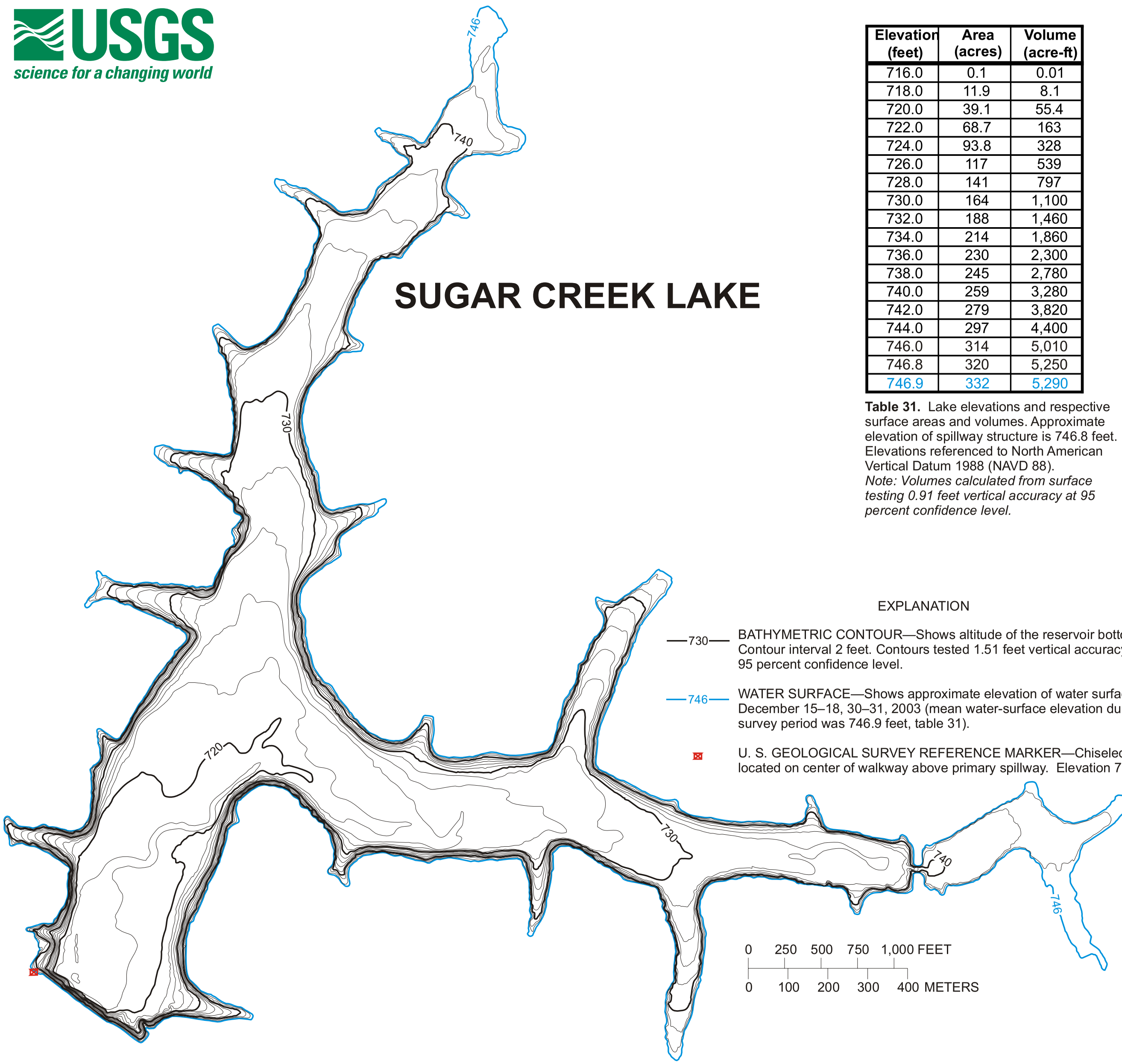

Moberly, Missouri
Water Use
Million Gallon Per Day
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Water Use in MGD
Rural Water Districts and non municipal demands removed from the system
Trend
2001 demand = 1.537 MGD
Moberly has been reporting East Fork Chariton River as a supply source after 1992, but has reported zero withdrawl in every year.
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
Year

Figure 23.3

SUGAR CREEK LAKE



Elevation (feet)	Area (acres)	Volume (acre-ft)
716.0	0.1	0.01
718.0	11.9	8.1
720.0	39.1	55.4
722.0	68.7	163
724.0	93.8	328
726.0	117	539
728.0	141	797
730.0	164	1,100
732.0	188	1,460
734.0	214	1,860
736.0	230	2,300
738.0	245	2,780
740.0	259	3,280
742.0	279	3,820
744.0	297	4,400
746.0	314	5,010
746.8	320	5,250
746.9	332	5,290

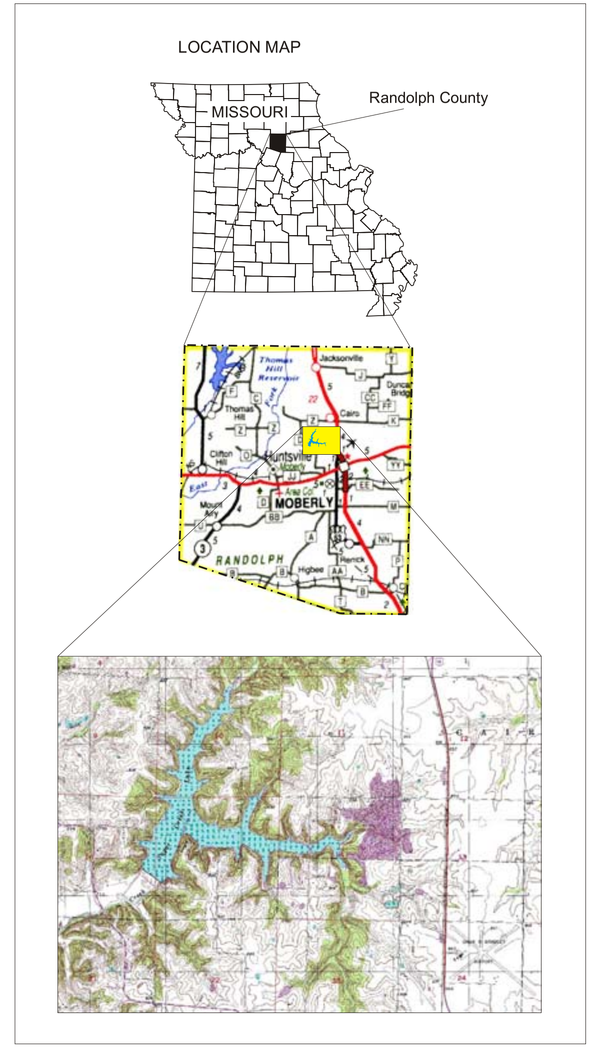
Table 31. Lake elevations and respective surface areas and volumes. Approximate elevation of spillway structure is 746.8 feet. Elevations referenced to North American Vertical Datum 1988 (NAVD 88).
Note: Volumes calculated from surface testing 0.91 feet vertical accuracy at 95 percent confidence level.

EXPLANATION

—730— BATHYMETRIC CONTOUR—Shows altitude of the reservoir bottom. Contour interval 2 feet. Contours tested 1.51 feet vertical accuracy at 95 percent confidence level.

—746— WATER SURFACE—Shows approximate elevation of water surface, December 15–18, 30–31, 2003 (mean water-surface elevation during survey period was 746.9 feet, table 31).

⊠ U. S. GEOLOGICAL SURVEY REFERENCE MARKER—Chiseled arrow located on center of walkway above primary spillway. Elevation 755.1 feet.



In cooperation with Missouri Department of Natural Resources

Figure 31. Bathymetric map and table of areas/volumes of the Sugar Creek Lake near Moberly, Missouri.

Monroe City, Missouri
Water Supply Study
Route "J" Lake

Monroe City is located in the extreme northeast corner of Monroe County, Missouri.

Monroe City water supply comes from the city owned lake on Route "J" and may be supplemented by a smaller city lake, South Lake, which was not surveyed. This analysis show that the Route "J" lake would be able to supply approximately three times the current demand.

This 95 acre lake is located southeast of Monroe City in Ralls County and has a drainage area of 8.20 square miles.

Average annual rainfall at the Monroe City rain gage for the latest 30 years of record is 40.49 inches. Annual rainfall for 1953 through 1957 is 28.38, 34.63, 38.45, 27.23, and 45.13 inches.

Monroe City Lake analysis consisted of using the NRCS's computer program called "RESOP". This program analyses remaining stored water at the end of each month by summing gains and losses.

Two analysis were made:

1. First run was the year 2001 demand taken from Route “J” Lake.
2. Both lakes was analyzed for the optimum daily use without emptying the lakes during the evaluation period.

STO-AREA Elevation-Storage and Elevation-Area data were determined from June 5, 2002 survey made by USGS.

Route “J” Lake

Elevation (feet)	Area (acres)	Volume (acre-ft)	
638.0	0.10	0.05	
640.0	1.00	1.04	
642.0	4.04	5.47	
644.0	9.01	18.43	
646.0	14.40	41.84	
648.0	19.31	75.44	
650.0	25.18	119.85	
652.0	30.99	175.79	
654.0	37.13	243.87	
656.0	43.46	324.36	
658.0	50.13	417.99	
660.0	56.71	524.80	
662.0	63.70	645.33	
664.0	70.71	779.52	
666.0	79.82	929.37	
668.0	88.37	1097.86	
669.3	94.90	1216.31	W.S. Elevation on 6/5/02
669.6	99.45	1245.65	Spillway Elevation

Starting storage was considered at maximum pool.

The drainage area of the lake is 8.20 square miles.

GENERAL — The adjustment factor of 0.76 to convert from pan evaporation to lake evaporation was applied prior to entering the data for the control word EVAP. As a result a factor of 100.

The record period of drought is in the 1950's.
Analysis began in January 1951 and ended December. 1959

SEEPAGE — The reservoir seepage varied from 0 seepage near empty to a maximum of 2.50 inches per month at full pool. The seepage rate is a best estimate based on history of the reservoir, soil type, material of the core of the dam and compaction of the earth fill. The material in the dam is compacted earth of clayey soils.

RAINFALL — Rainfall data came from the Monroe City, Missouri rain gage.

RUNOFF — This is the runoff into the lake from its drainage area. Monthly runoff volumes in watershed inches from the North Fork of Salt River stream gage near Shelbina, Missouri was used. Salt River runoff was compared to North River stream gage runoff at Bethel Missouri. Comparisons were favorable. It was also compared to Monroe City rainfall and if the rainfall results did not appear reasonable, adjustments were made for that month by looking at individual rains and estimating antecedent moisture, then adjusting runoff based on NRCS's runoff curve numbers.

EVAP. — Pan evaporation at the Lakeside gaging station was used as a base because it has data for year around evaporation. All other stations only measure data between April through November. Lakeside data was updated during these months with gage data from stations at New Franklin, and Columbia. Depending on the latest data for the station nearest to Monroe City.

DEMAND — This was determined by city records. Monroe City has a daily use of 418,360 gallons per day. Based on Year 2001 use of 152,701,000 gallons.

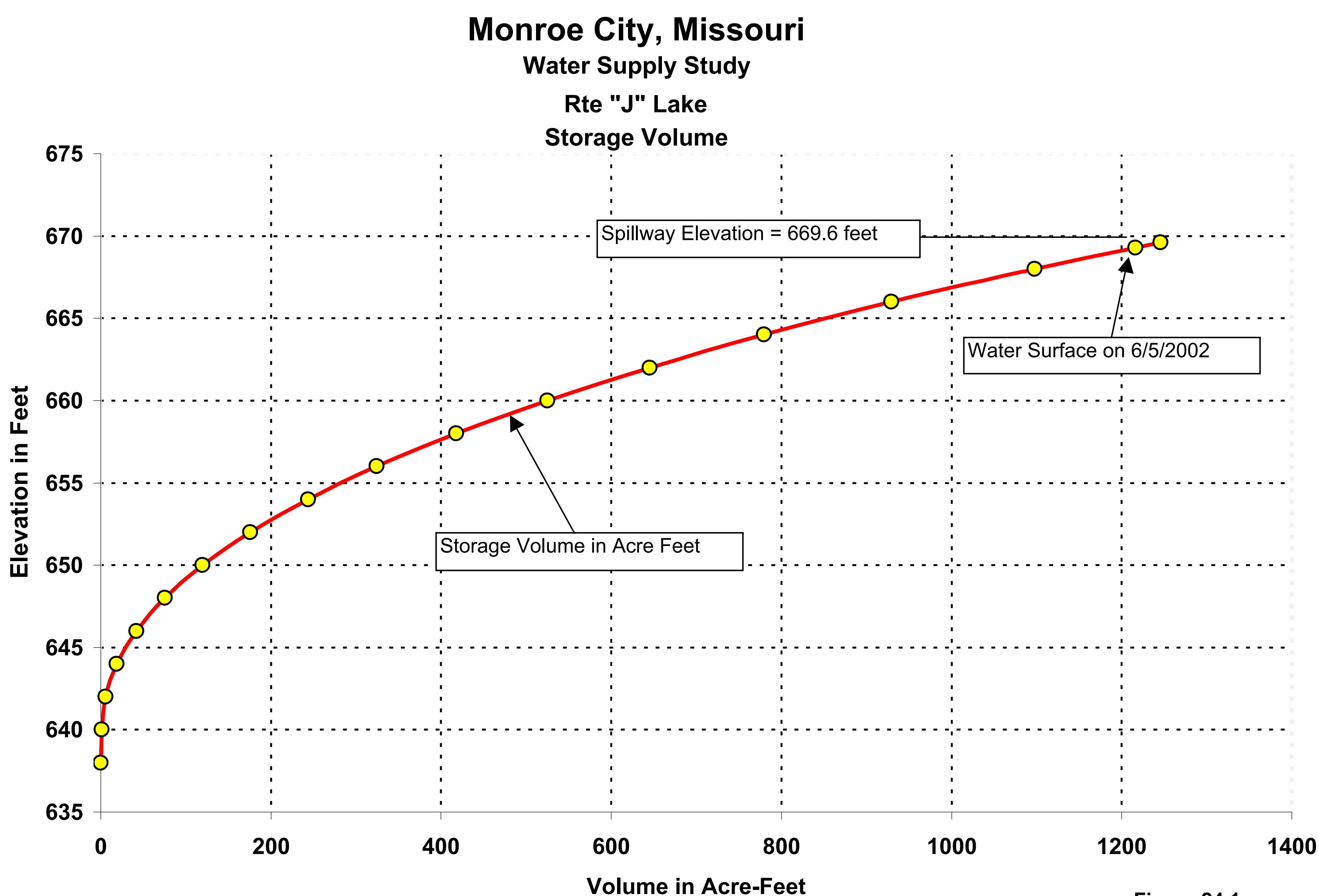

Monroe City, Missouri
Water Supply Study
Rte "J" Lake
Storage Volume
Elevation in Feet
675
670
665
660
655
650
645
640
635
0
200
400
600
800
1000
1200
1400
Volume in Acre-Feet
Spillway Elevation = 669.6 feet
Water Surface on 6/5/2002
Storage Volume in Acre Feet

Figure 24.1.a

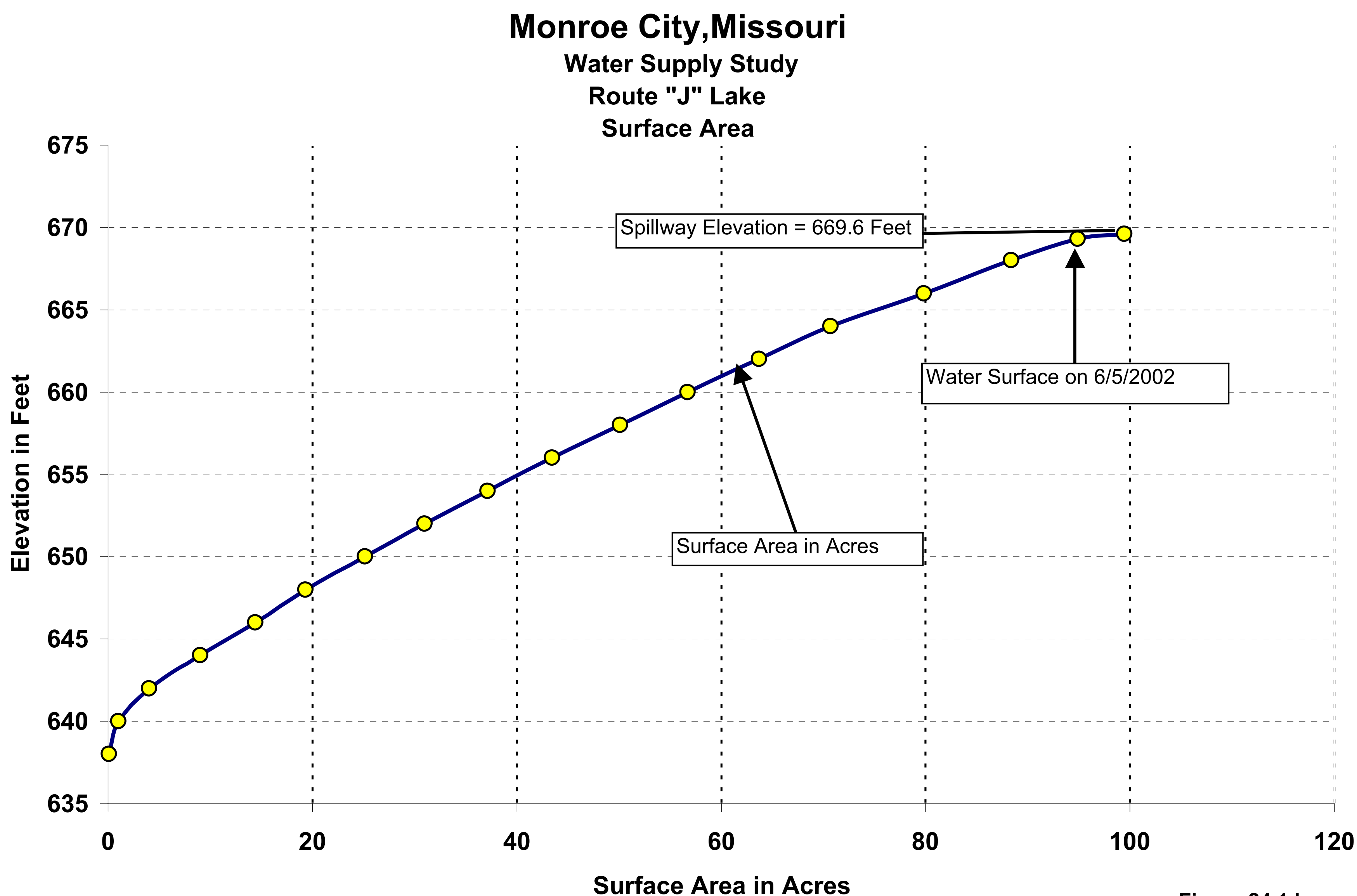
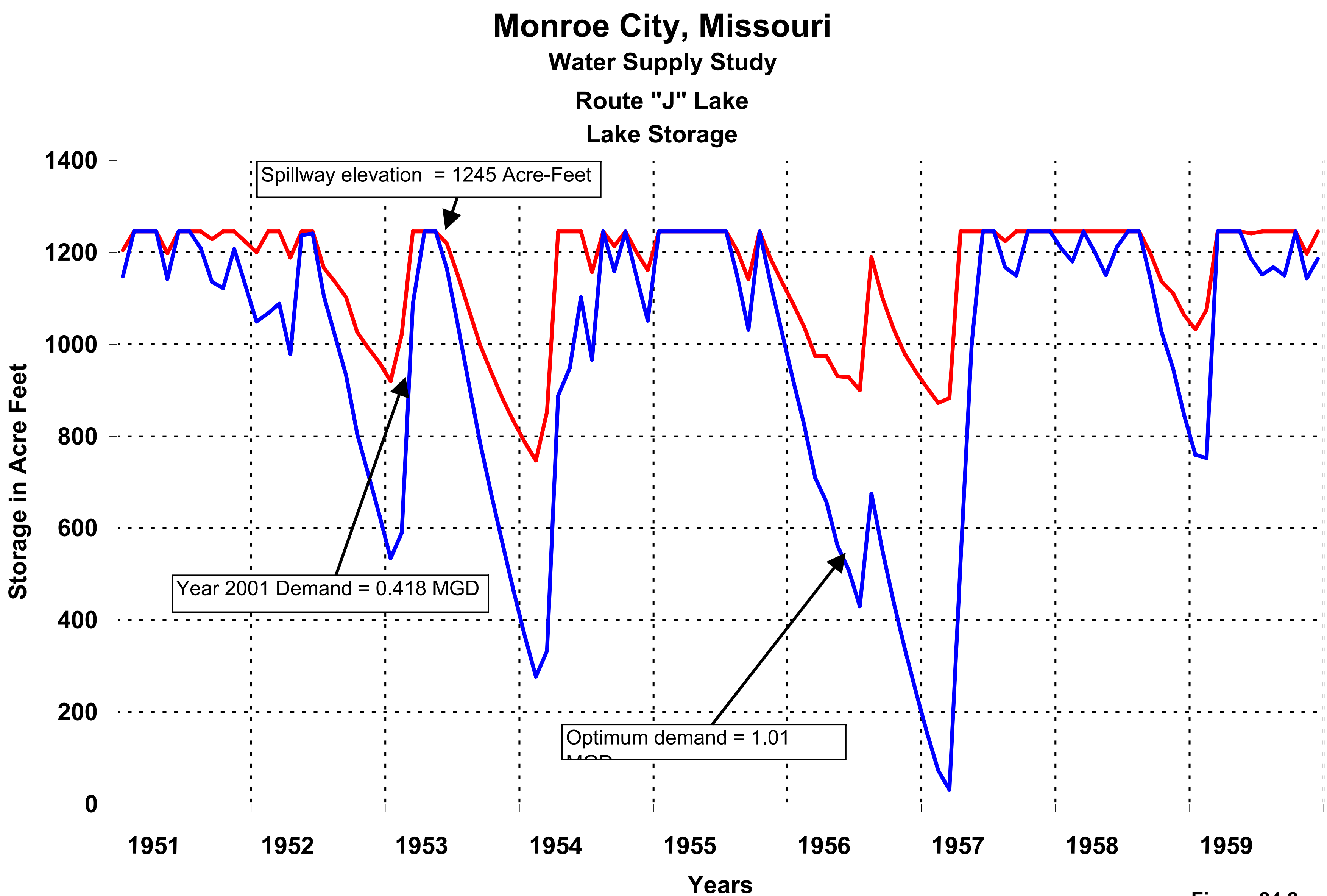

Monroe City,Missouri
Water Supply Study
Route "J" Lake
Surface Area
Spillway Elevation = 669.6 Feet
Water Surface on 6/5/2002
Surface Area in Acres
Elevation in Feet
675
670
665
660
655
650
645
640
635
0
20
40
60
80
100
120
Surface Area in Acres

Figure 24.1.b



Monroe City, Missouri
Water Supply Study
Route "J" Lake
Lake Storage
Storage in Acre Feet
1400
1200
1000
800
600
400
200
0
Spillway elevation = 1245 Acre-Feet
Year 2001 Demand = 0.418 MGD
Optimum demand = 1.01
1951
1952
1953
1954
1955
1956
1957
1958
1959
Years

Figure 24.2

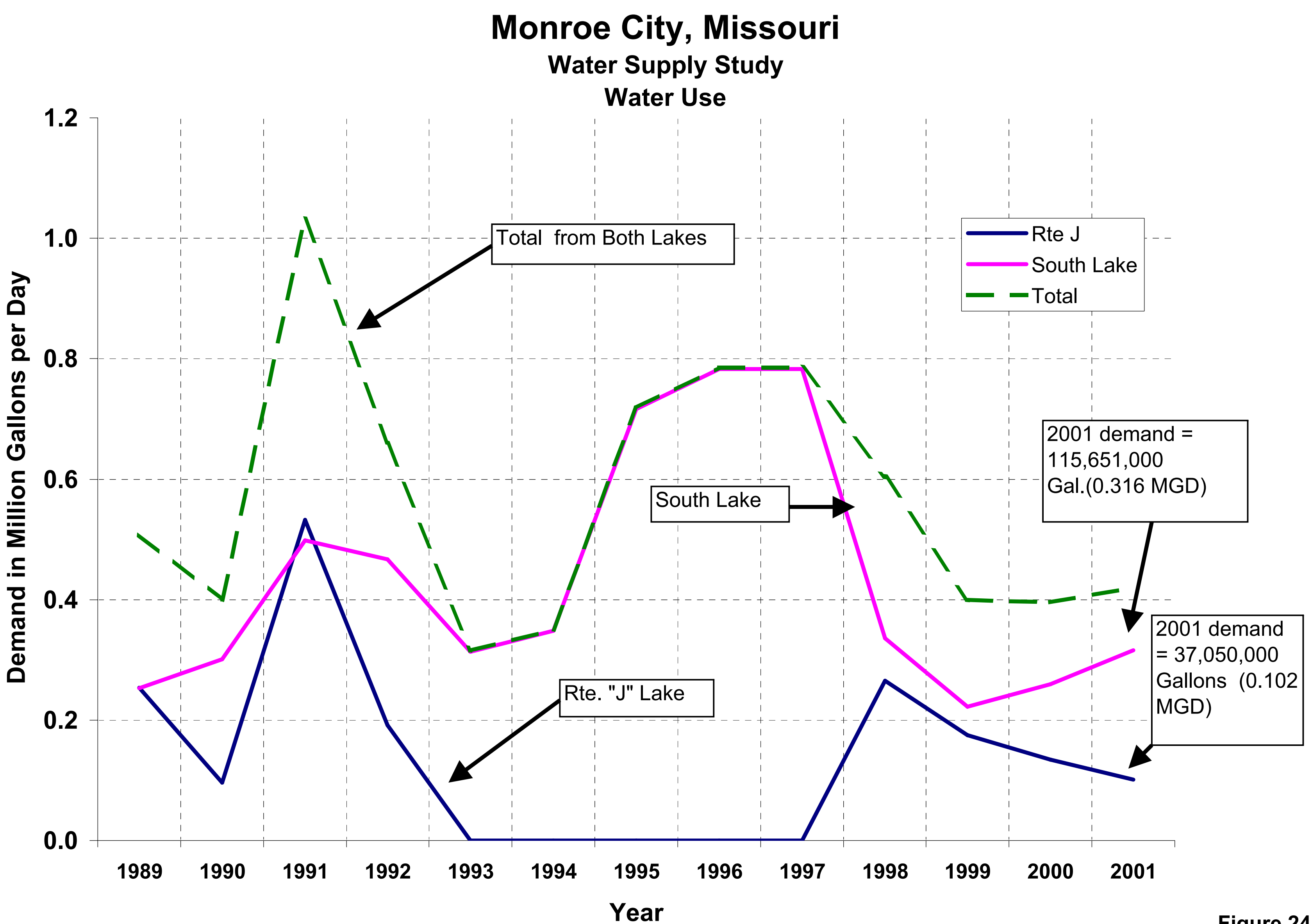
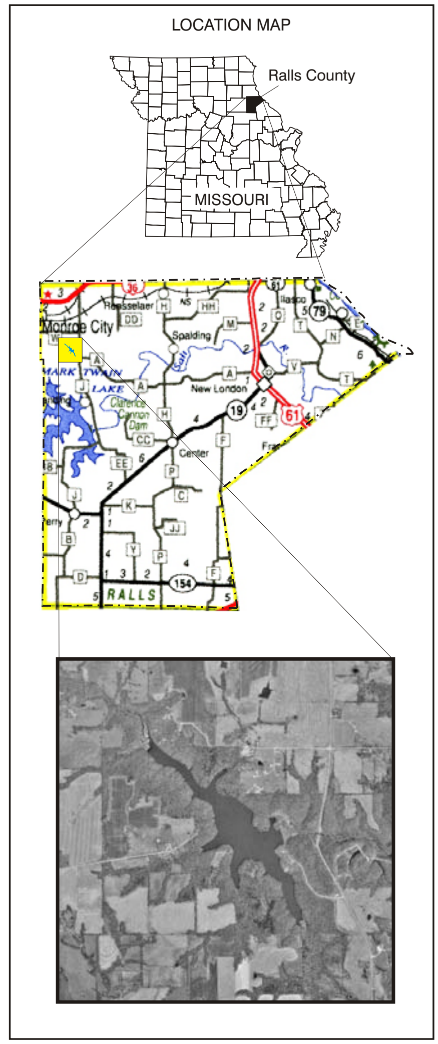

Monroe City, Missouri
Water Supply Study
Water Use
Demand in Million Gallons per Day
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
Year
Total from Both Lakes
Rte J
South Lake
Total
South Lake
Rte. "J" Lake
2001 demand = 115,651,000 Gal.(0.316 MGD)
2001 demand = 37,050,000 Gallons (0.102 MGD)

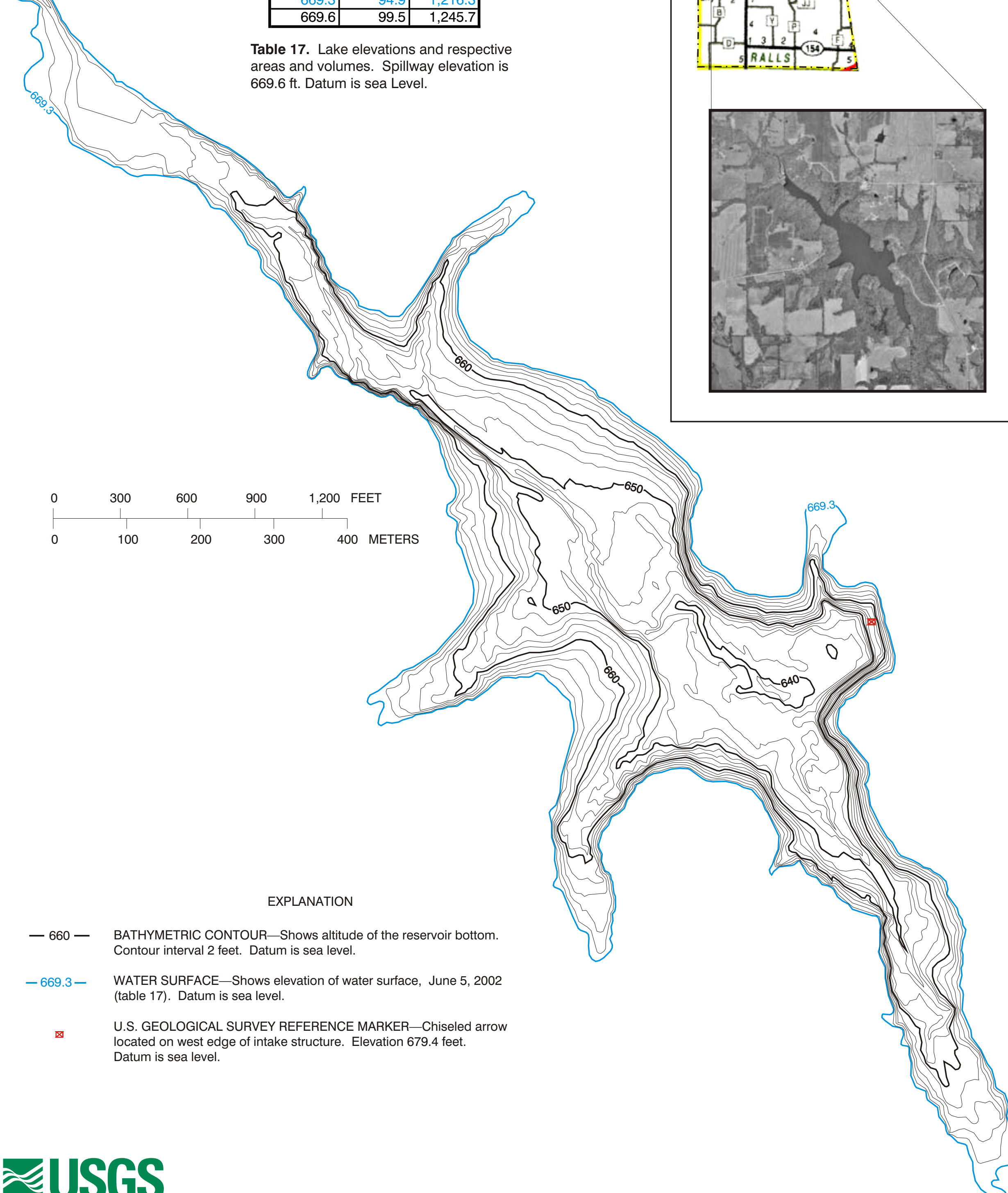
Figure 24.3

MONROE CITY LAKE



Elevation (feet)	Area (acres)	Volume (acre-ft)
638.0	0.1	0.0
640.0	1.0	1.0
642.0	4.0	5.5
644.0	9.0	18.4
646.0	14.4	41.8
648.0	19.3	75.4
650.0	25.2	119.9
652.0	31.0	175.8
654.0	37.1	243.9
656.0	43.5	324.4
658.0	50.1	418.0
660.0	56.7	524.8
662.0	63.7	645.3
664.0	70.7	779.5
666.0	79.8	929.4
668.0	88.4	1,097.9
669.3	94.9	1,216.3
669.6	99.5	1,245.7

Table 17. Lake elevations and respective areas and volumes. Spillway elevation is 669.6 ft. Datum is sea Level.



EXPLANATION

— 660 — BATHYMETRIC CONTOUR—Shows altitude of the reservoir bottom. Contour interval 2 feet. Datum is sea level.

— 669.3 — WATER SURFACE—Shows elevation of water surface, June 5, 2002 (table 17). Datum is sea level.

⊠ U.S. GEOLOGICAL SURVEY REFERENCE MARKER—Chiseled arrow located on west edge of intake structure. Elevation 679.4 feet. Datum is sea level.

USGS science for a changing world

Figure 17. Bathymetric map and table of areas/volumes of the Monroe City Lake near Monroe City, Missouri.

Ridgeway, Missouri
Harrison County
Water Supply Study
Rock House Lake

Prior to 2004, Ridgeway water supply comes from Rockhouse Lake. Rockhouse Lake was built as one of the Natural Resource Conservation Service's (NRCS) Panther Creek PL-566 watershed project lakes.

The record period of drought was used to estimate if Ridgeway's water supply was adequate to provide ample water during extreme drought. The 1950's were determined to be that period.

The 30-year average annual rainfall is 37.24 inches at Bethany. For the Period 1953 through 1957, annual rainfall was 24.09, 32.05, 27.00, 24.31, and 32.27 inches.

Ridgeway has a storage lake located one mile West of the city of Ridgeway, in sections 32 and 33 in Mission Township. Water is pumped from Rockhouse Lake to the storage lake prior to treatment. Plans are being made to connect the city of Ridgeway to Harrison County rural water supply district Number 3.

Ridgeway used 13,991,000 gallons of water in 1999 (0.038 million gallons per day).

Ridgeway Lake analysis consisted of using the NRCS's computer program called "RESOP". Following is the data and procedures for input to the program.

STO-AREA Elevation-Storage and Elevation-Area data were determined from July 11, 2000 survey made by USGS.

Ridgeway Water Supply
Rock House Lake

Elevation (feet)	Area (acres)	Storage (ac-ft)	
888.0	0.1	0.01	
890.0	0.6	0.7	
892.0	2.1	2.9	
894.0	9.8	14.2	
896.0	20.6	43.3	
898.0	28.3	93.0	
900.0	38.0	159.0	
902.0	43.3	240.0	
904.0	51.6	334.0	
906.0	58.2	443.0	
906.3	60.8	461.0	Full and Spillway Elevation. on 5/28/2003

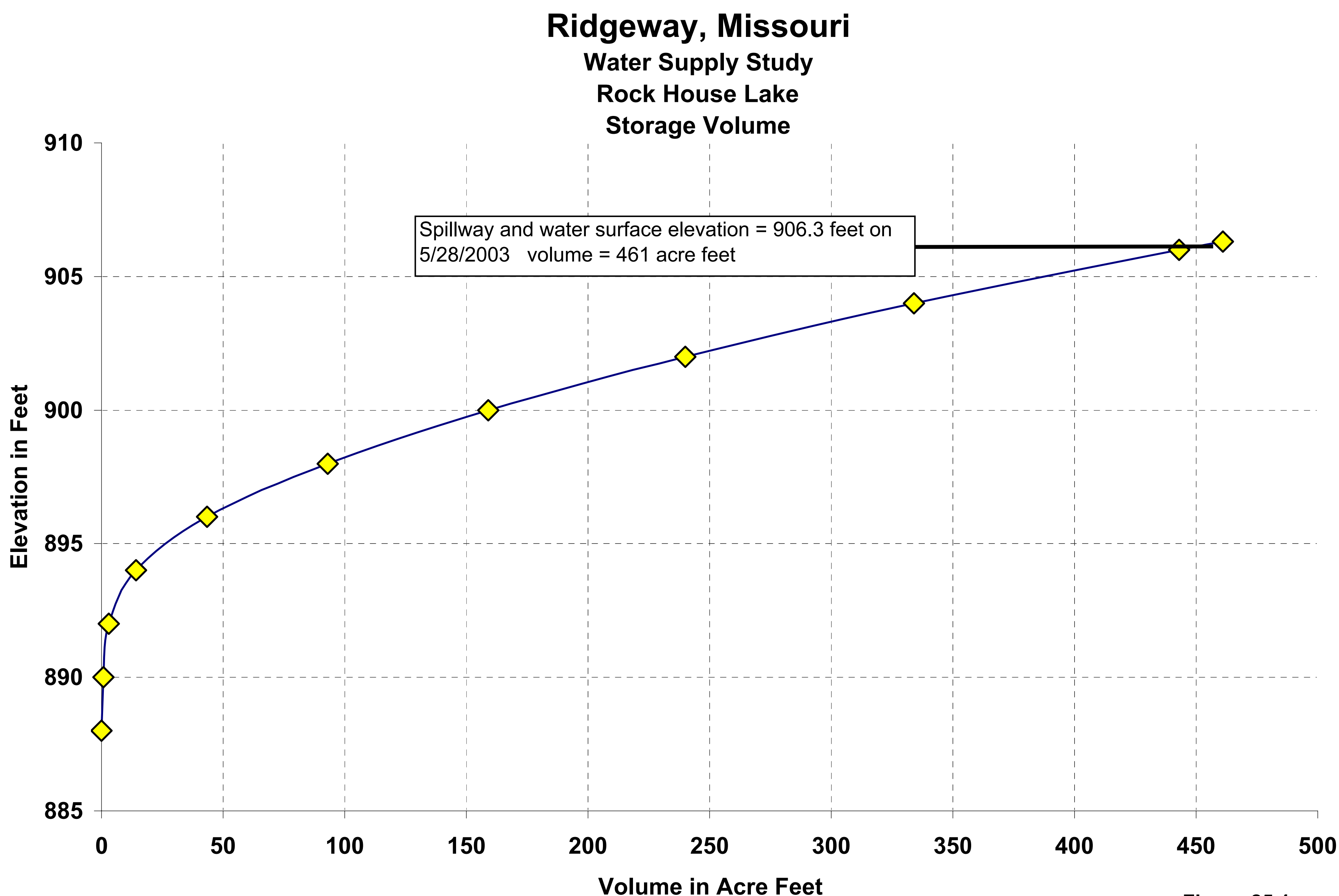
Spillway Elev. = 906.3 Feet mean sea level.
Minimum Elev. = 21 Acres

LIMITS Maximum Pool storage 461 Ac.Ft.
Minimum Pool storage 50 Ac.Ft.

Starting storage was considered at maximum pool.

The drainage area of the lake is 5723 acres (8.94 square miles).

GENERAL	The adjustment factor of 0.76 to convert from pan evaporation to lake evaporation was applied prior to entering the data for the control word EVAP. As a result a factor of 100 is applied. The record period of drought is in the 1950's. Analysis began in January 1951 and ended December 1959.
SEEPAGE	The reservoir seepage varied from 0 seepage near empty to a maximum of 1.5 inch per month when at full pool. The material in the dam is compacted earth of clayey soils. The lake is shallow so that static pressure is low. As a result seepage is small.
RAINFALL	Rainfall data came from the Bethany, Missouri rain gage.
RUNOFF	This is the runoff into the lake from its drainage area. Monthly runoff volumes in watershed inches. East Fork Big Creek at Bethany having a drainage area of 95 square miles. Ridgeway is in the East Fork Big Creek watershed. Monthly runoff was compared to the rainfall and if the results did not appear reasonable, adjustments were made for that month by looking at individual rains and estimating anticedent moisture then adjusting runoff based on NRCS's runoff curve numbers.
EVAP.	Pan evaporation at the Lakeside gaging station was used as a base because it has data for year around evaporation. This data was updated with gage data from stations at Spickard, New Franklin, and Columbia. Depending on the latest data for the station nearest to Ridgeway. The adjustment factor of 0.76 to convert from pan to lake evaporation was applied at this step.
DEMAND	Determined from by city records. Ridgeway reported using 13,991,000 gallons in 1999 for an average daily use of 0.038 million gallons per day in 1999.



Ridgeway, Missouri
Water Supply Study
Rock House Lake
Storage Volume
Spillway and water surface elevation = 906.3 feet on
5/28/2003 volume = 461 acre feet
Elevation in Feet
910
905
900
895
890
885
0
50
100
150
200
250
300
350
400
450
500
Volume in Acre Feet

Figure 25.1.a

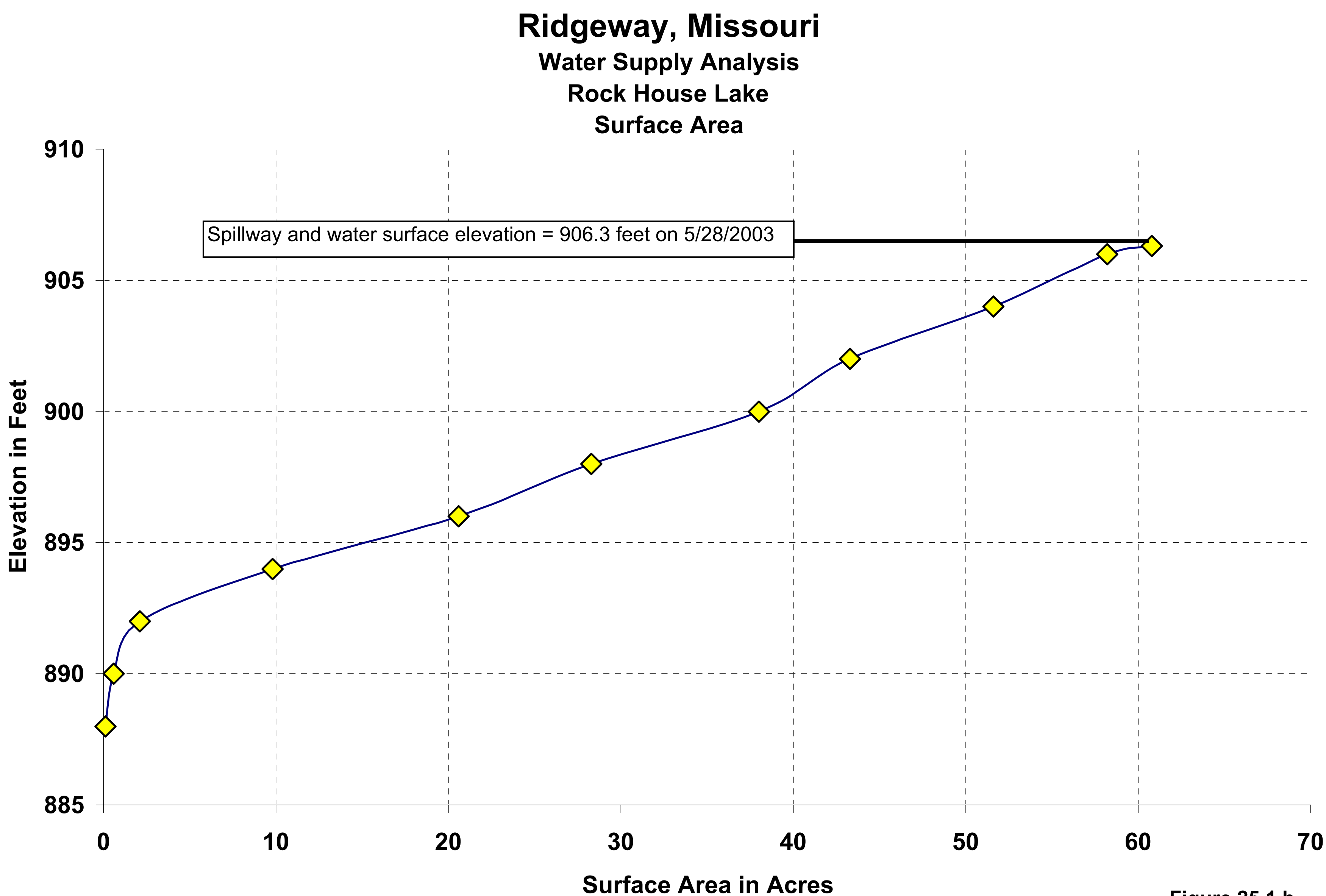
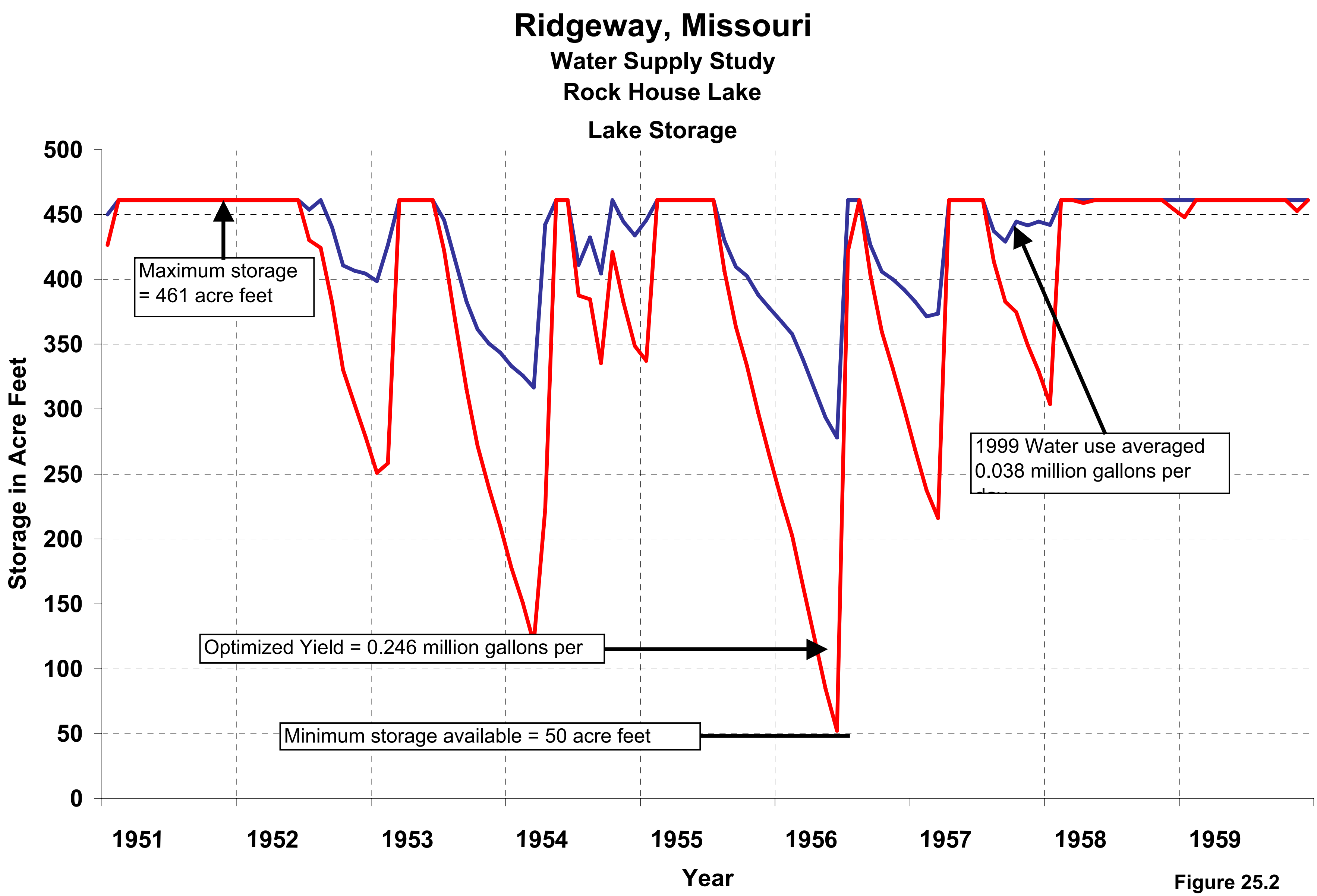

Ridgeway, Missouri
Water Supply Analysis
Rock House Lake
Surface Area
Spillway and water surface elevation = 906.3 feet on 5/28/2003
910
905
900
895
890
885
Elevation in Feet
0
10
20
30
40
50
60
70
Surface Area in Acres

Figure 25.1.b



Ridgeway, Missouri
Water Supply Study
Rock House Lake
Lake Storage
Storage in Acre Feet
500
450
400
350
300
250
200
150
100
50
0
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year
Maximum storage = 461 acre feet
Optimized Yield = 0.246 million gallons per
Minimum storage available = 50 acre feet
1999 Water use averaged 0.038 million gallons per

Figure 25.2

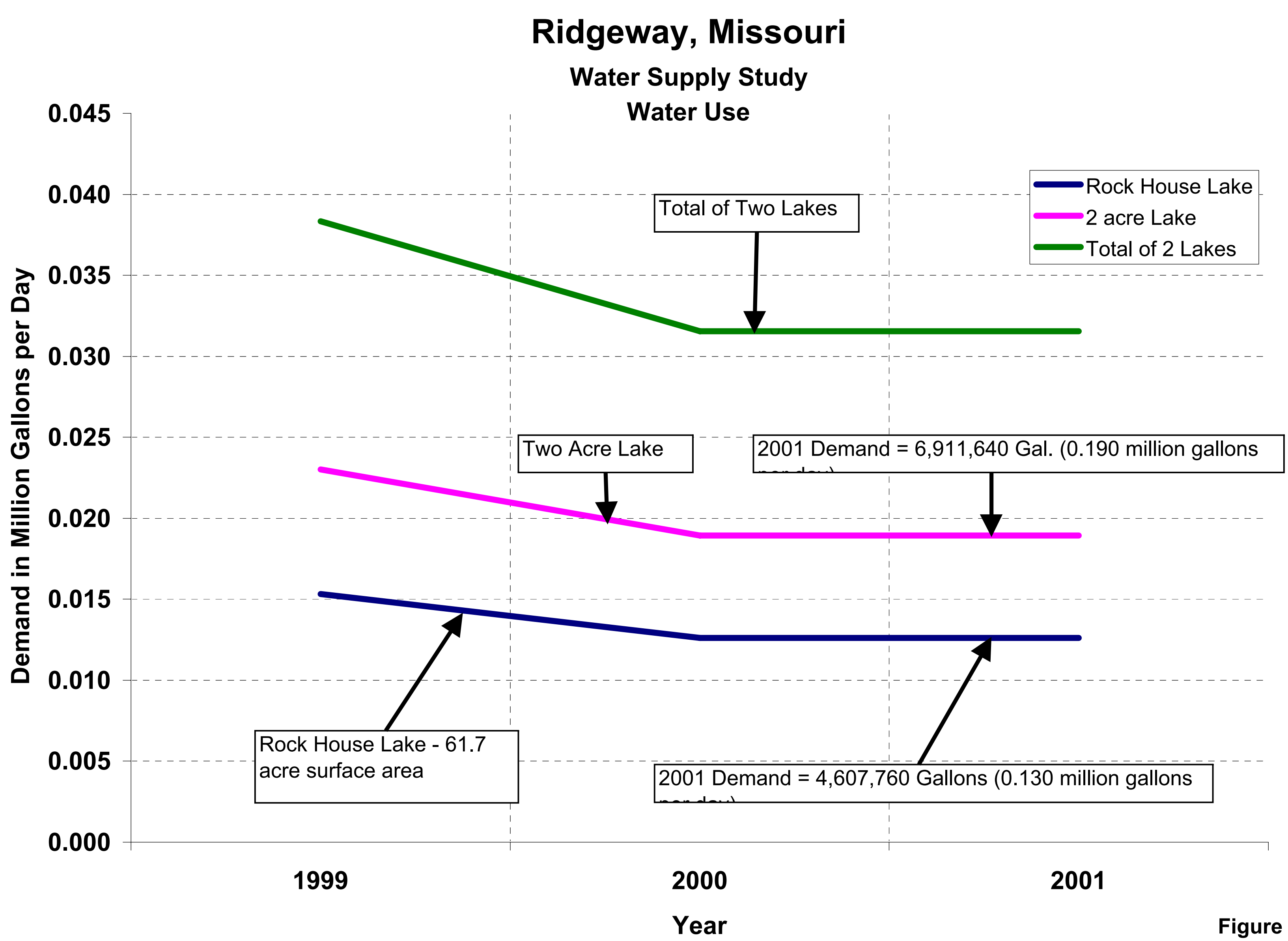
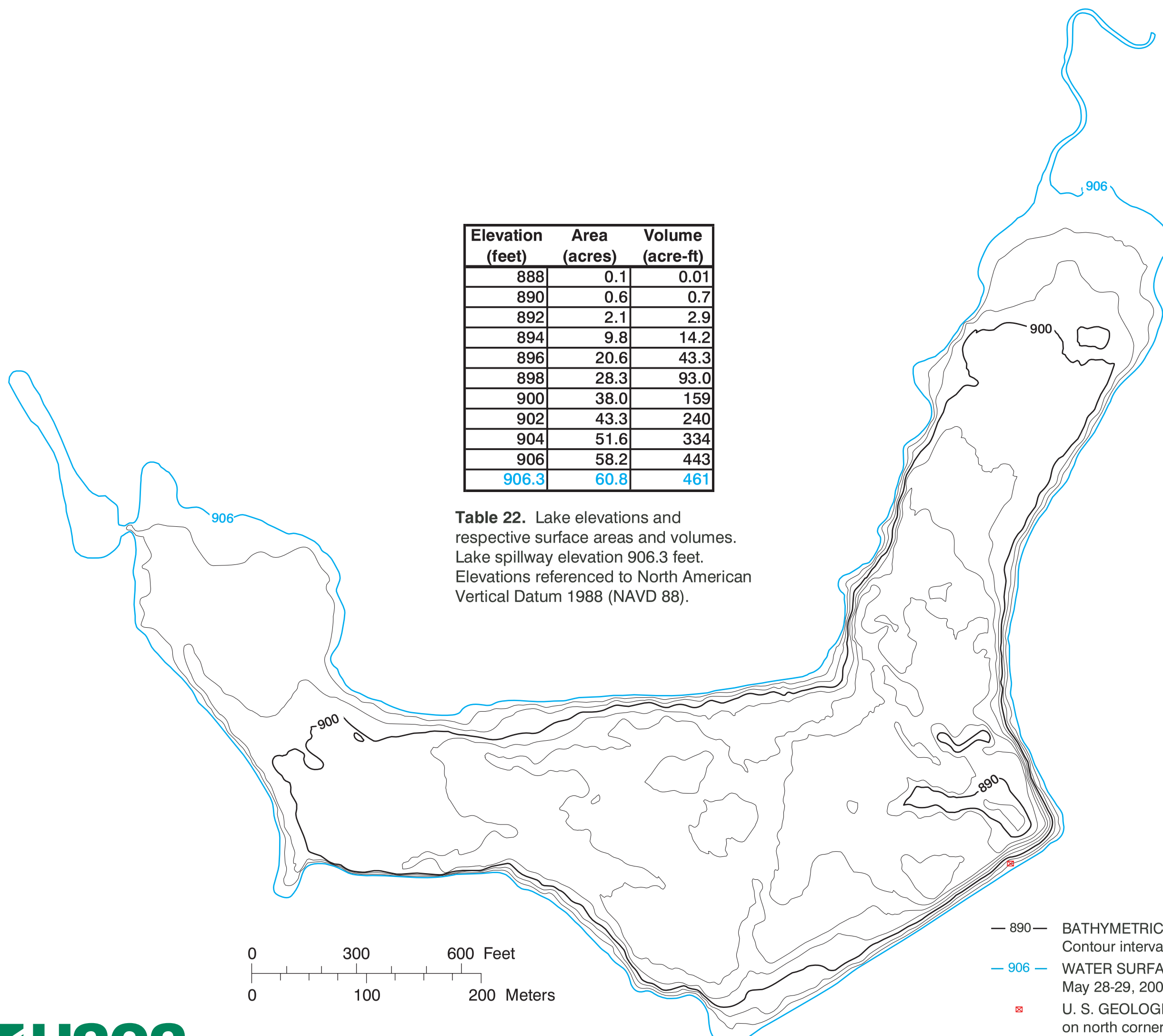

Ridgeway, Missouri
Water Supply Study
Water Use
Demand in Million Gallons per Day
0.045
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
1999
2000
2001
Year
Rock House Lake
2 acre Lake
Total of 2 Lakes
Total of Two Lakes
Two Acre Lake
2001 Demand = 6,911,640 Gal. (0.190 million gallons
Rock House Lake - 61.7 acre surface area
2001 Demand = 4,607,760 Gallons (0.130 million gallons

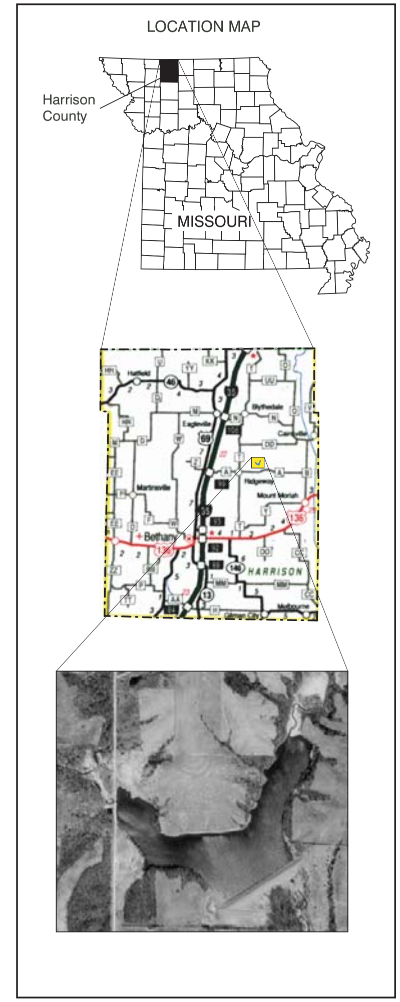
Figure 25.3

ROCK HOUSE LAKE



Elevation (feet)	Area (acres)	Volume (acre-ft)
888	0.1	0.01
890	0.6	0.7
892	2.1	2.9
894	9.8	14.2
896	20.6	43.3
898	28.3	93.0
900	38.0	159
902	43.3	240
904	51.6	334
906	58.2	443
906.3	60.8	461

Table 22. Lake elevations and respective surface areas and volumes. Lake spillway elevation 906.3 feet. Elevations referenced to North American Vertical Datum 1988 (NAVD 88).



EXPLANATION

— 890 — BATHYMETRIC CONTOUR—Shows altitude of the reservoir bottom. Contour interval 2 feet.

— 906 — WATER SURFACE—Shows approximate elevation of water surface, May 28-29, 2003 (table 22) actual elevation 906.3.

⊠ U. S. GEOLOGICAL SURVEY REFERENCE MARKER—Chiseled arrow on north corner of concrete drop-box spillway. Elevation 910.3 feet.

USGS science for a changing world

In cooperation with Missouri Department of Natural Resources

Figure 22. Bathymetric map and area/volume table for Rock House Lake near Ridgeway, Missouri.

Sedalia, Missouri
Water Supply Study
Spring Fork Lake

Sedalia is located in Pettis County Missouri. The lake is approximately 5 miles South of Sedalia on Spring Fork Creek.

Sedalia gets their water from two sources. In year 2001, Sedalia used 990,657,900 gallon of water, 64% came from the lake and the rest from their nine wells.

Spring Fork Lake analysis consisted of using the NRCS's computer program "RESOP". This program analyzes remaining stored water at the end of each month by summing gains and losses.

Two analysis were made:

1. First run was the 2001 demand from the lake for the evaluation period.
2. The lake was analyzed for the optimum daily use without emptying the lake during the evaluation period.

STO-AREA Elevation-Storage and Elevation-Area data were determined from June 26, 2002 survey made by USGS.

Spring Fork Lake

Elevation (feet)	Area (acres)	Storage (ac-ft)	
870.0	0.73	0.54	
872.0	5.09	5.72	
874.0	13.04	23.50	
876.0	22.05	57.51	
878.0	32.46	111.79	
880.0	43.07	186.96	
882.0	53.29	283.20	
884.0	65.92	401.93	
886.0	80.43	548.43	
888.1	97.18	725.32	
890.0	112.43	934.35	
891.6	122.74	1122.21	Water Surface on 4/17/2002
892.0	126.95	1171.26	
892.6	131.24	1249.74	Spillway Elevation

LIMITS Maximum Pool storage 1249 Ac.Ft.
Minimum Pool storage 60 Ac.Ft.

Starting storage was considered full pool.

The drainage area of the lake is 10.98 Square Miles.

GENERAL The adjustment factor of 0.76 to convert from pan evaporation to lake evaporation was applied prior to entering the data for the control word EVAP. As a result a factor of 100.0 was used.

The record period of drought is in the 1950's.
Analysis began in January 1951 and ended December 1959.

SEEPAGE The reservoir seepage varied from 0 seepage near empty to a maximum of 2.25 inches per month at full pool. The seepage rate is a best estimate based on history of the reservoir, soil type, material of the core of the dam and compaction. The material in the dam is compacted earth of clayey soils.

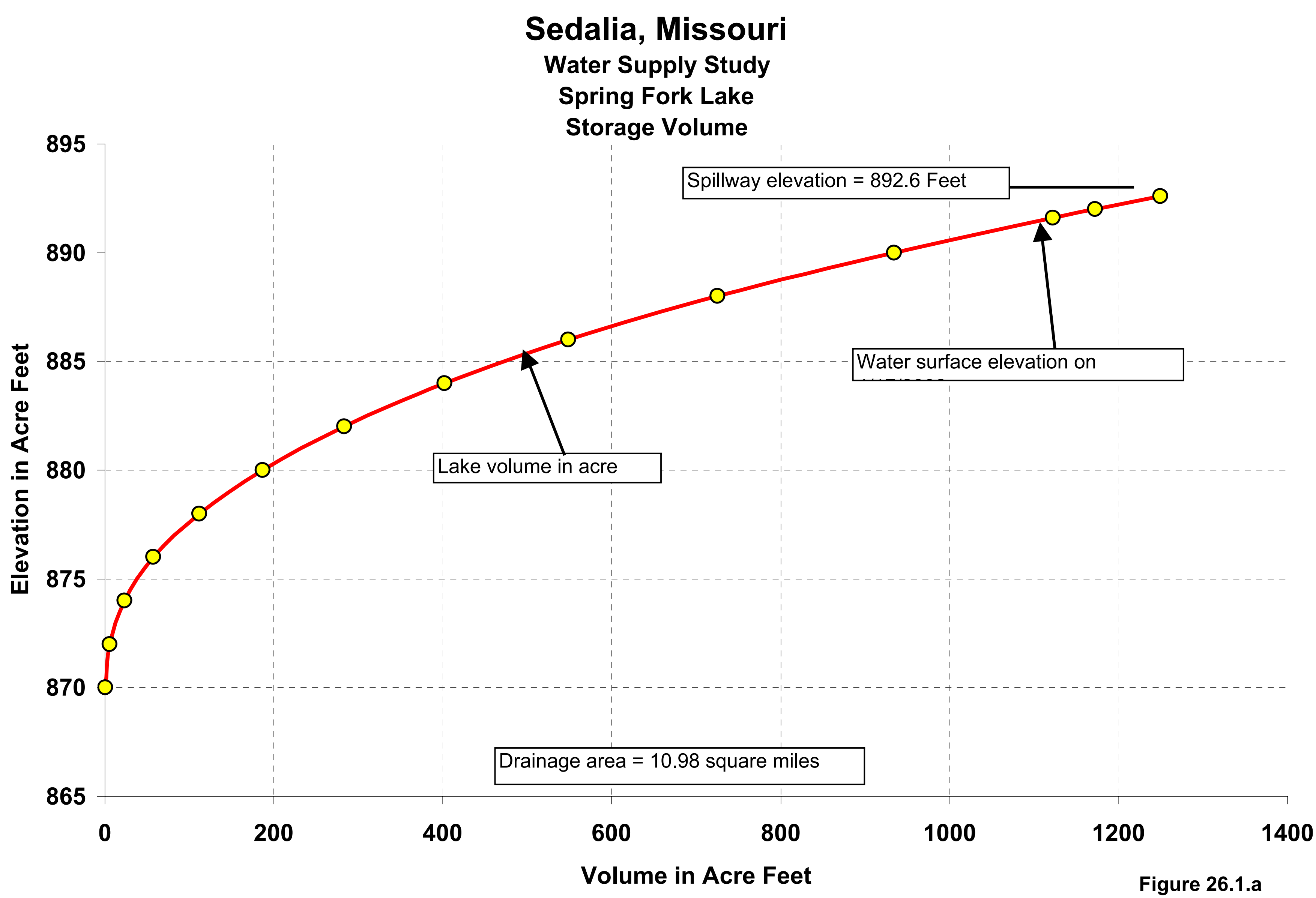
RAINFALL Rainfall data came from the Sedalia, Missouri rain gage for the period 1951 through 1959.

RUNOFF This is the runoff into the lake from its drainage area. Monthly runoff volumes in watershed inches were determined for the Lamine River Gage. Flat Creek Gage is upstream of the Lamine River gage and only has records for the 1960's. These two gages were compared for that time period. The Flat creek gage had 8% more runoff, on an annual basis, than the Lamine River gage. Flat creek drainage has more cropland and the soils have a higher clay content than Spring Fork Creek. As a result the Lamine Gage records seemed to fit the Springfork Lake drainage area runoff. The Lamine River gage runoff was used for this analysis.

In cases where rainfall to runoff values did not appear reasonable, adjustments were made for that month by looking at individual rains and estimating anticedent moisture then, adjusting runoff based on NRCS's runoff curve numbers.

EVAP. Pan evaporation at the Lakeside gaging station was used as a base because it has data for year around evaporation. All other stations only measure data between April through November. Lakeside data was updated during these months with gage data from stations at New Franklin, and Columbia. Depending on the latest data for the station nearest to Sedalia.

DEMAND This was determined by city records. Sedalia used a total of 990,657,900 gallons during 2001. Of this 633,275,000 gallons came from Spring Fork Lake and the rest came from their 9 wells. The volume of water used for this lake analysis was 1.735 million gallons per day.



Sedalia, Missouri
Water Supply Study
Spring Fork Lake
Storage Volume
Elevation in Acre Feet
895
890
885
880
875
870
865
0
200
400
600
800
1000
1200
1400
Volume in Acre Feet
Spillway elevation = 892.6 Feet
Water surface elevation on
Lake volume in acre
Drainage area = 10.98 square miles

Figure 26.1.a

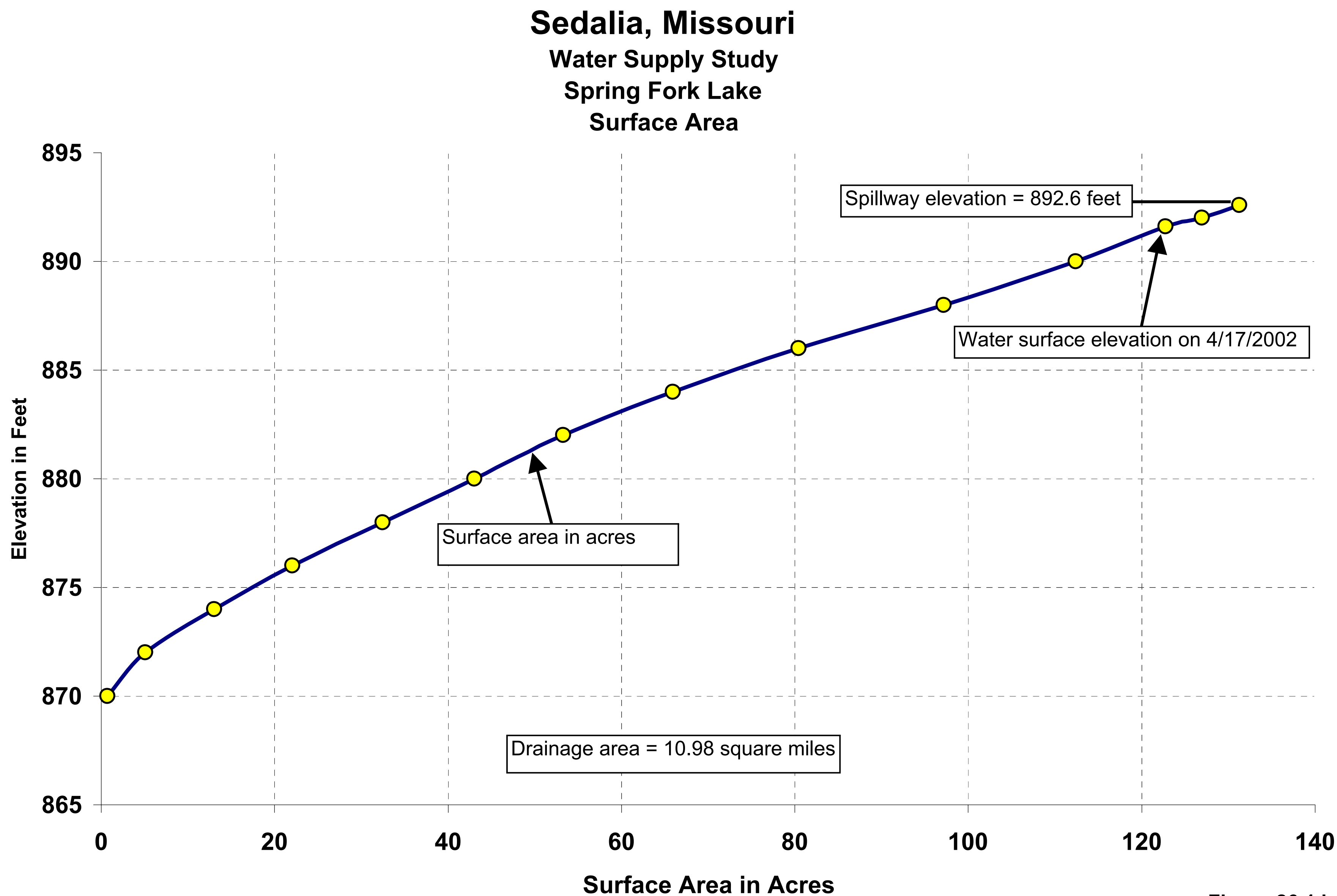
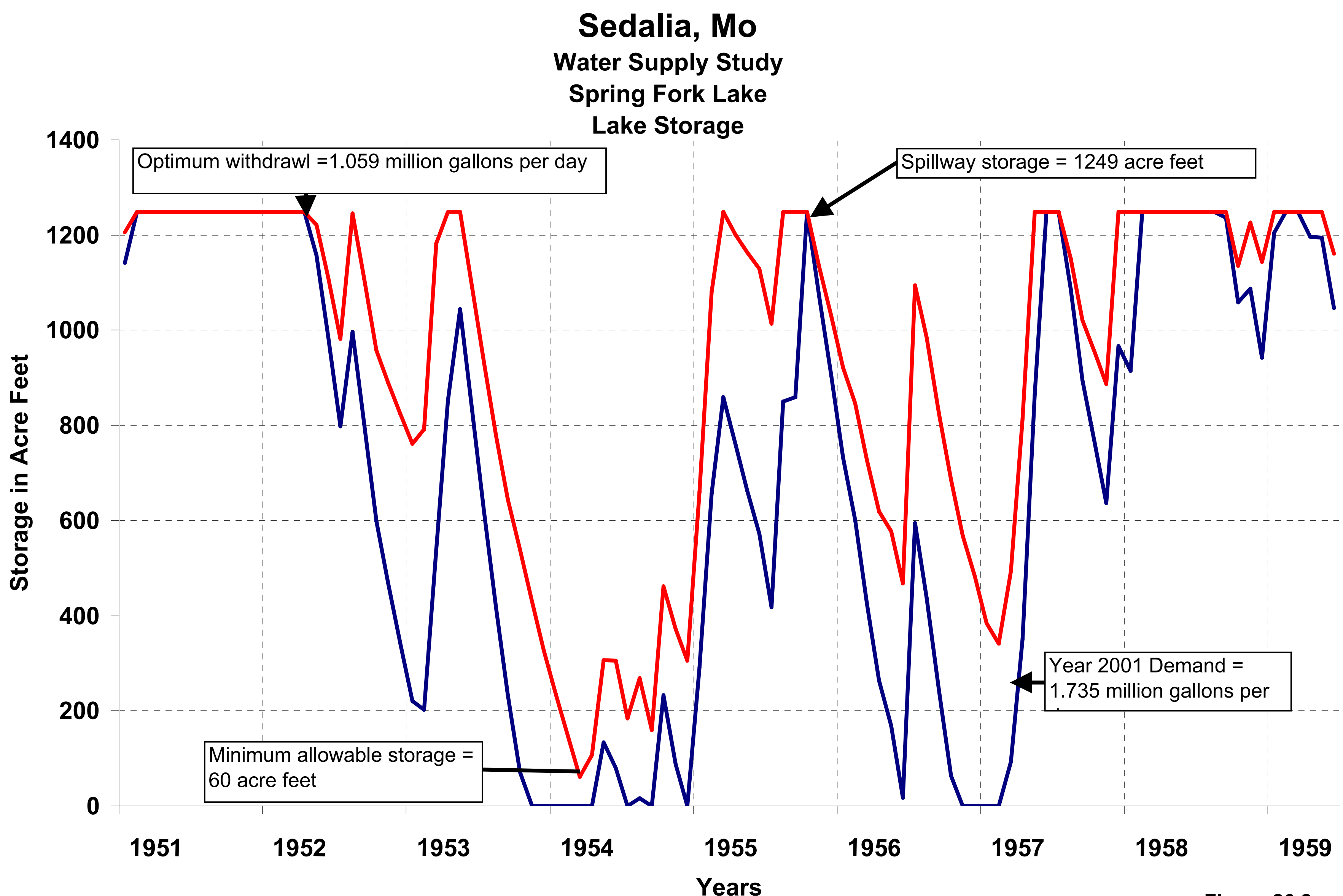
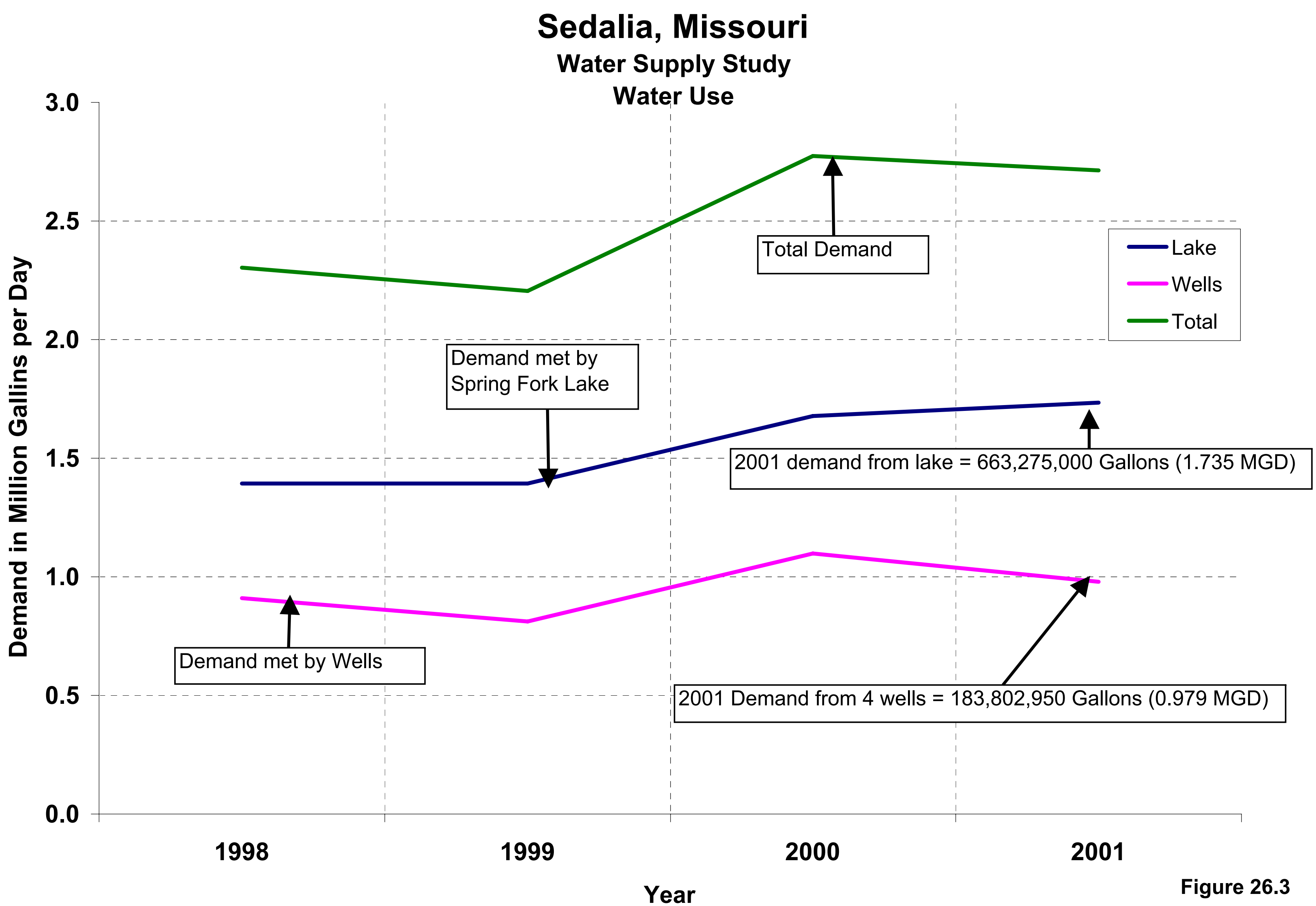

Sedalia, Missouri
Water Supply Study
Spring Fork Lake
Surface Area
Elevation in Feet
895
890
885
880
875
870
865
0
20
40
60
80
100
120
140
Surface Area in Acres
Spillway elevation = 892.6 feet
Water surface elevation on 4/17/2002
Surface area in acres
Drainage area = 10.98 square miles

Figure 26.1.b



Sedalia, Mo
Water Supply Study
Spring Fork Lake
Lake Storage
Storage in Acre Feet
1400
1200
1000
800
600
400
200
0
1951
1952
1953
1954
1955
1956
1957
1958
1959
Years
Optimum withdrawl =1.059 million gallons per day
Spillway storage = 1249 acre feet
Minimum allowable storage = 60 acre feet
Year 2001 Demand = 1.735 million gallons per

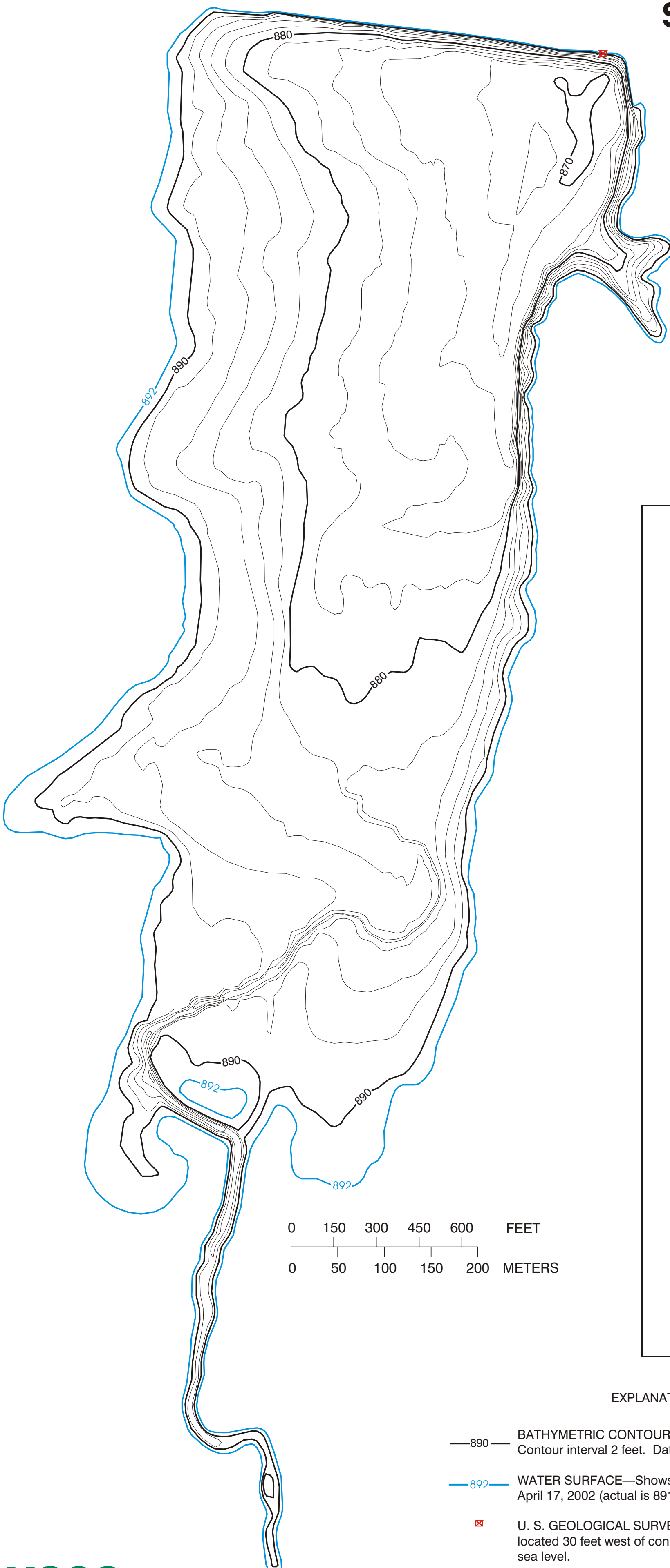
Figure 26.2



Sedalia, Missouri
Water Supply Study
Water Use
Demand in Million Gallins per Day
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1998
1999
2000
2001
Year
Lake
Wells
Total
Total Demand
Demand met by Spring Fork Lake
2001 demand from lake = 663,275,000 Gallons (1.735 MGD)
Demand met by Wells
2001 Demand from 4 wells = 183,802,950 Gallons (0.979 MGD)

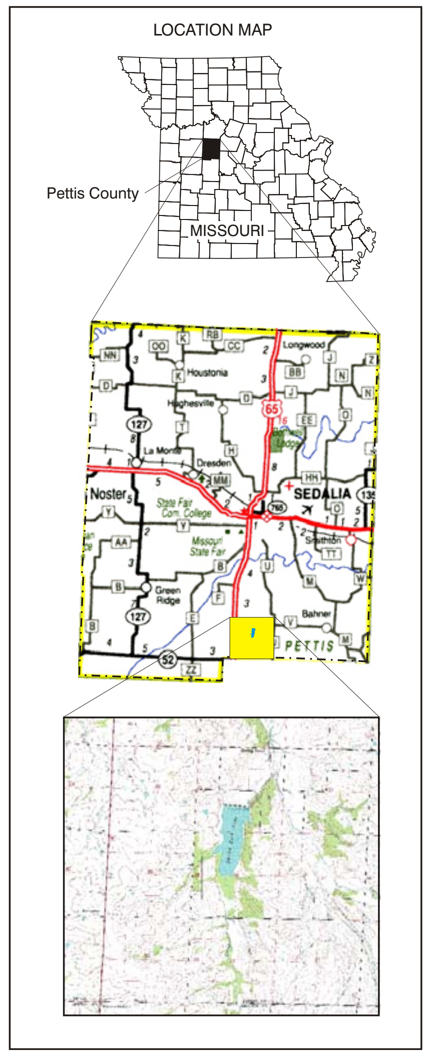
Figure 26.3

SPRINGFORK LAKE



Elevation (feet)	Area (acres)	Volume (acre-ft)
870.0	0.7	0.5
872.0	5.1	5.7
874.0	13.0	23.5
876.0	22.0	57.5
878.0	32.5	111.8
880.0	43.1	187.0
882.0	53.3	283.2
884.0	65.9	401.9
886.0	80.4	548.4
888.0	97.2	725.3
890.0	112.4	934.3
891.6	122.7	1,122.2
892.0	126.9	1,172.3
892.6	131.2	1,249.7

Table 15. Lake elevations and respective surface areas and volumes. Spillway elevation is 892.6 feet.



EXPLANATION

—890— BATHYMETRIC CONTOUR—Shows altitude of the reservoir bottom. Contour interval 2 feet. Datum is sea level

—892— WATER SURFACE—Shows approximate elevation of water surface, April 17, 2002 (actual is 891.6 feet, table 15). Datum is sea level.

⊠ U. S. GEOLOGICAL SURVEY REFERENCE MARKER—Chiseled Square located 30 feet west of concrete spillway. Elevation 892.6 feet. Datum is sea level.

USGS
science for a changing world

Figure 15. Bathymetric map and area/volume table of Springfork Lake near Sedalia, Missouri.

Shelbina, Missouri
Water Supply Study
City Lake

Shelbina is located in Shelby County, Missouri.

Shelbina water supply comes from a city owned lake located about one mile North of the city. The water supply is supplemented by pumping into the lake from nearby Salt River when supplies in the lake become low. They attempt to keep the lake level within a few feet of the spillway. This analysis shows that only in dry periods would it be necessary to obtain water from the river.

Irrigation water for the golf course is taken from this lake and was not analyzed as part of this study. It was assumed that irrigation water would be replaced by pumping from the river and that the result of this would be no effect. The city operating plan is to keep the lake near full by pumping from the river.

In year 2000, the city used 127,249,000 gallon of water for municipal needs.

Average annual rainfall is 37.2 inches. Annual rainfall for 1953 through 1957 is 24.1, 33.6, 39.4, 25.59, and 47.1 inches.

Shelbina Lake analysis consisted of using the NRCS's computer program called "RESOP". This program analyses remaining stored water at the end of each month by summing gains and losses.

The following discussion is for input to the computer program by control word.

STO-AREA Elevation-Storage and Elevation-Area data were determined from July 11, 2000 survey made by USGS.

Shelbina Lake

Elevation (feet)	Area (acres)	Storage (ac-ft)	
700	4.09	4.27	
702	9.93	18.04	
704	15.35	42.73	
706	22.75	80.69	
708	27.97	131.64	
710	36.73	194.48	
712	41.50	273.75	
714	44.97	360.17	
714.3	45.68	373.75	Water Surface on 6/20/2001
715	47.06	406.25	Spillway Elevation (Fool Pool)
716	53.66	457.67	
718	63.75	575.31	
720	81.92	717.84	Top of Dam

LIMITS Full Pool storage 406 Acre Feet
Minimum Pool storage 10 Acre Feet

Starting storage was considered at Full pool.

The drainage area of the lake is 1542 acres (2.41 square miles).

GENERAL The adjustment factor of 0.76 to convert from pan evaporation to lake evaporation was applied prior to entering the data for the control word EVAP. As a result, a factor of 100 is used.

The record period of drought is in the 1950's.
Analysis began in January 1951 and ended December 1959.

SEEPAGE The reservoir seepage varied from 0 seepage near empty to a maximum of 2.50 inches per month at full pool. The seepage rate is a best estimate based on history of the reservoir, soil type, material of the core of the dam and compaction of the earth fill. The material in the dam is compacted earth of clayey soils.

RAINFALL Rainfall data came from the Shelbina, Missouri rain gage. For periods of missing data, the Shelbyville gage was used.

RUNOFF This is the runoff into the lake from its drainage area. Monthly runoff volumes in watershed inches were determined at the North River stream gage at Bethel Missouri. The drainage area is 58 square miles. The runoff was compared to the rainfall and if the results did not appear reasonable, adjustments were made for that month by looking at individual rains and estimating antecedent moisture then, adjusting runoff based on NRCS's runoff curve numbers.

EVAP. Pan evaporation at the Lakeside gaging station was used as a base because it has data for year around evaporation. This data was updated with gage data from stations at Spickard, New Franklin, and Columbia. Depending on the latest data for the station nearest to Shelbina. The adjustment factor of 0.76 to convert from pan to lake evaporation was applied at this step.

DEMAND This was determined by city records. Shelbina has a daily use of 348,627 gallons per day. Based on Year 2000 use of 127,249,000 gallons.

OTHER This refers to other inflows to the reservoir, such as pumping from Salt River into the lake. There is an 8 inch pipe line with a 30 horsepower pump that is about 0.75 miles long to pump water to the lake when the water level gets more than a few feet below the spillway. For this analysis, water was allowed to drop 6 feet below the spillway before pumping to present an extreme condition.

To assure adequate downstream flow in Salt River, two sets of data were examined. The 7-day Q-10 low flow for the period 1989 through 1999 was studied for in-stream flow requirements and this value was determined to be 2 cubic feet second. It was decided to factor the value used on Locust Creek to the drainage area on Salt River. This value was determined to be 23 cubic feet per second. Twenty three-cubic feet second was allowed to pass downstream before pumping, only on days that flow exceeded 23 cubic feet per second was pumping evaluated. The pump is rated at 600 gallons per minute.

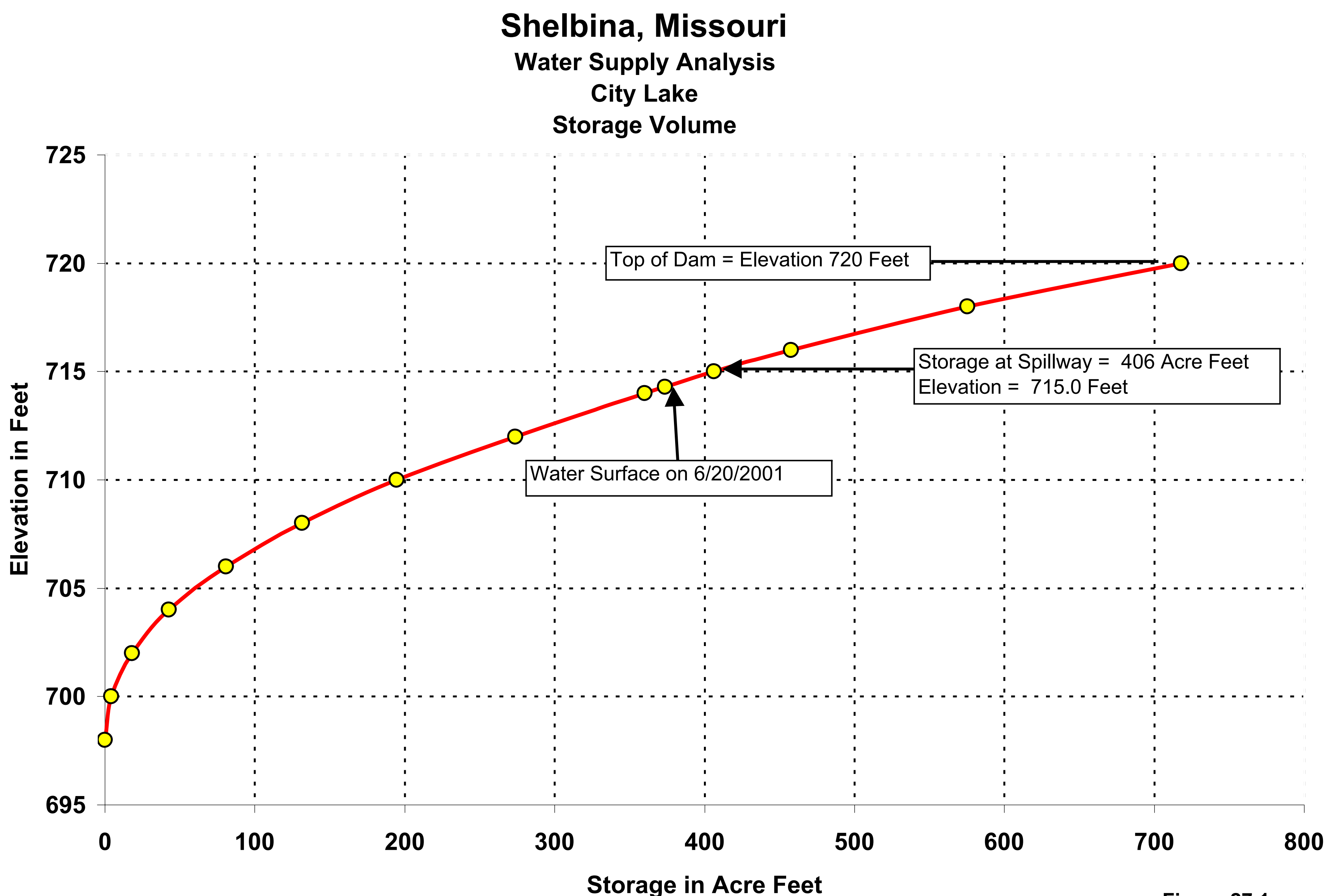

Shelbina, Missouri
Water Supply Analysis
City Lake
Storage Volume
Top of Dam = Elevation 720 Feet
Storage at Spillway = 406 Acre Feet
Elevation = 715.0 Feet
Water Surface on 6/20/2001
Elevation in Feet
Storage in Acre Feet
725
720
715
710
705
700
695
0
100
200
300
400
500
600
700
800

Figure 27.1.a

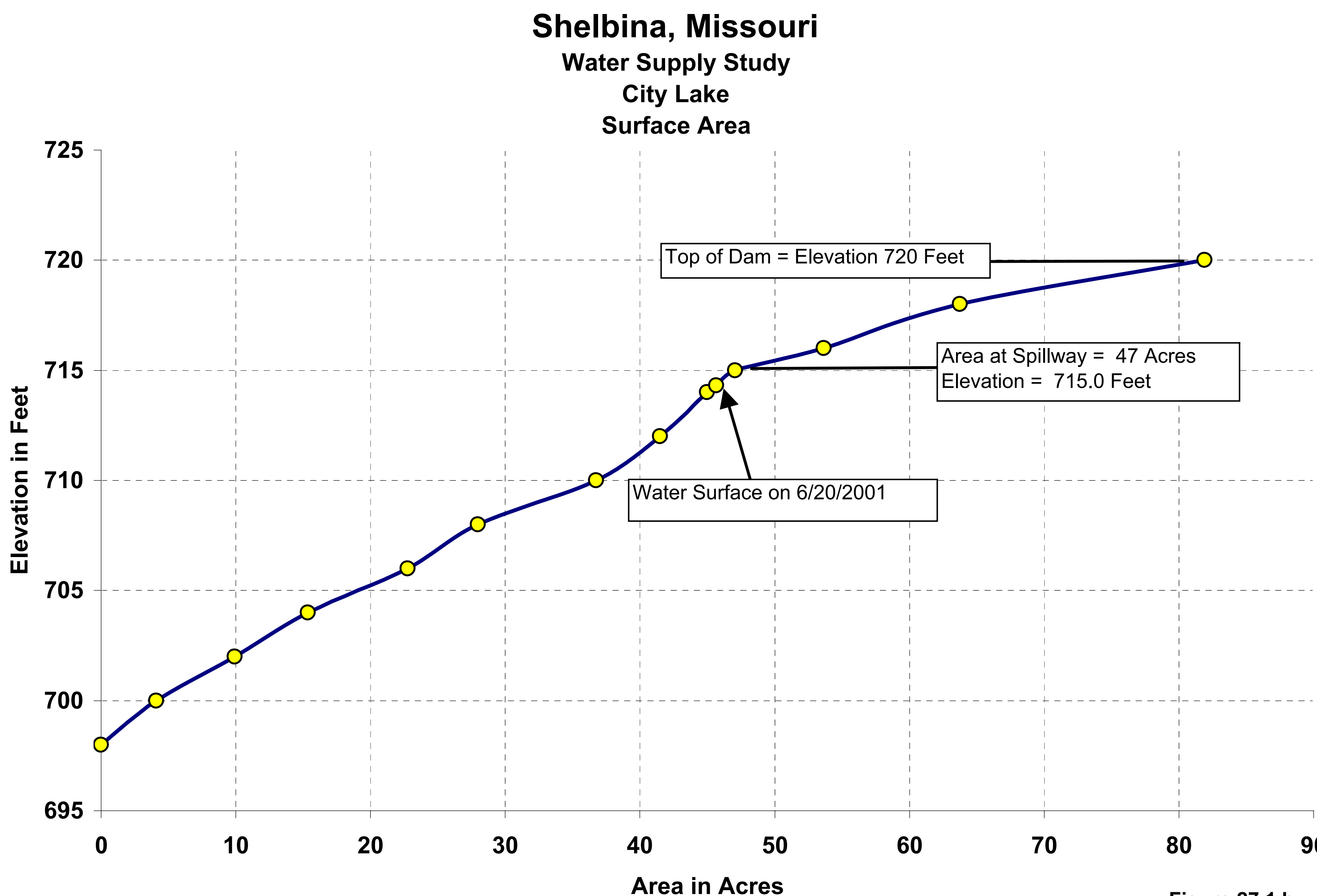

Shelbina, Missouri
Water Supply Study
City Lake
Surface Area
Elevation in Feet
Area in Acres
725
720
715
710
705
700
695
0
10
20
30
40
50
60
70
80
90
Top of Dam = Elevation 720 Feet
Area at Spillway = 47 Acres
Elevation = 715.0 Feet
Water Surface on 6/20/2001

Figure 27.1.b

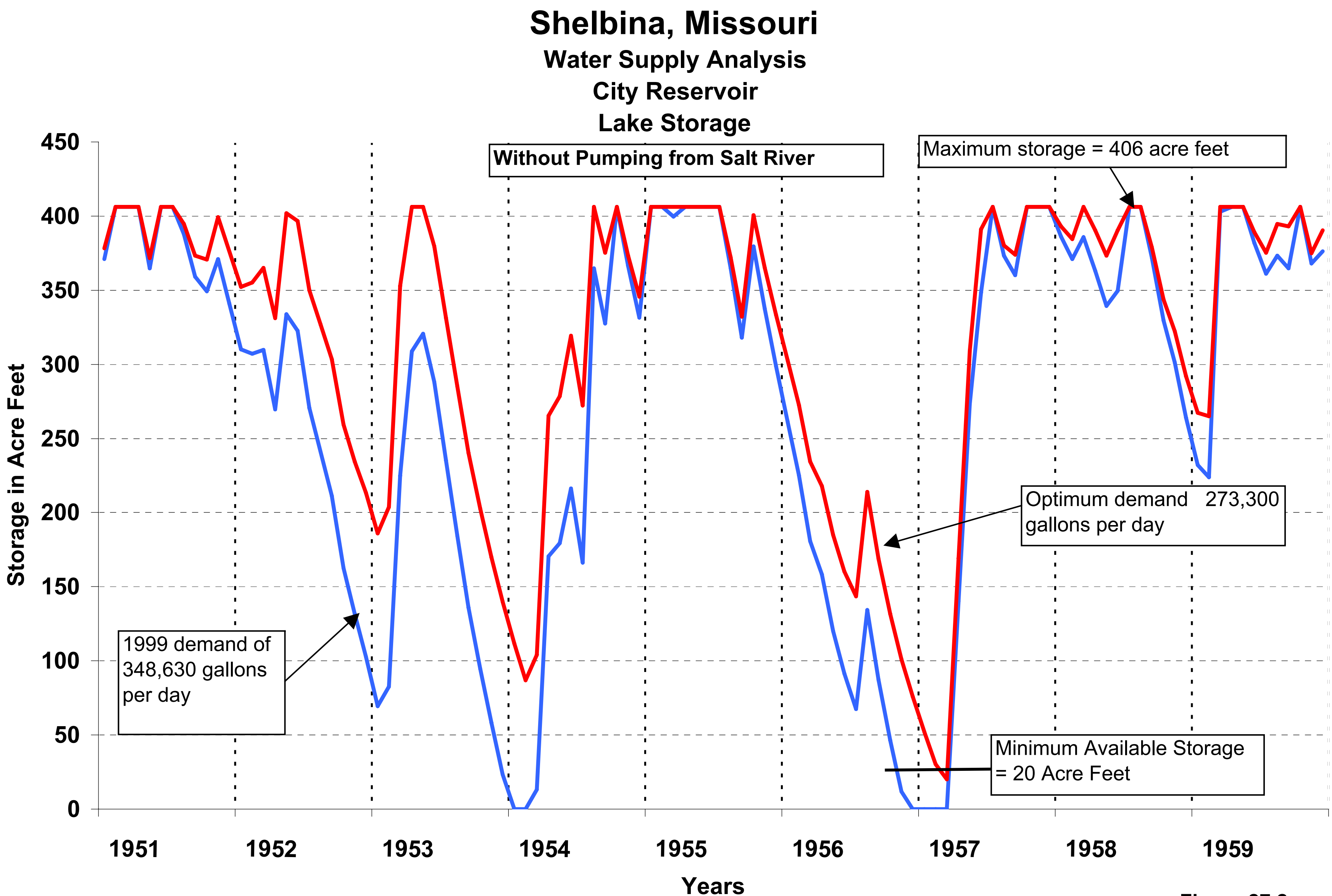
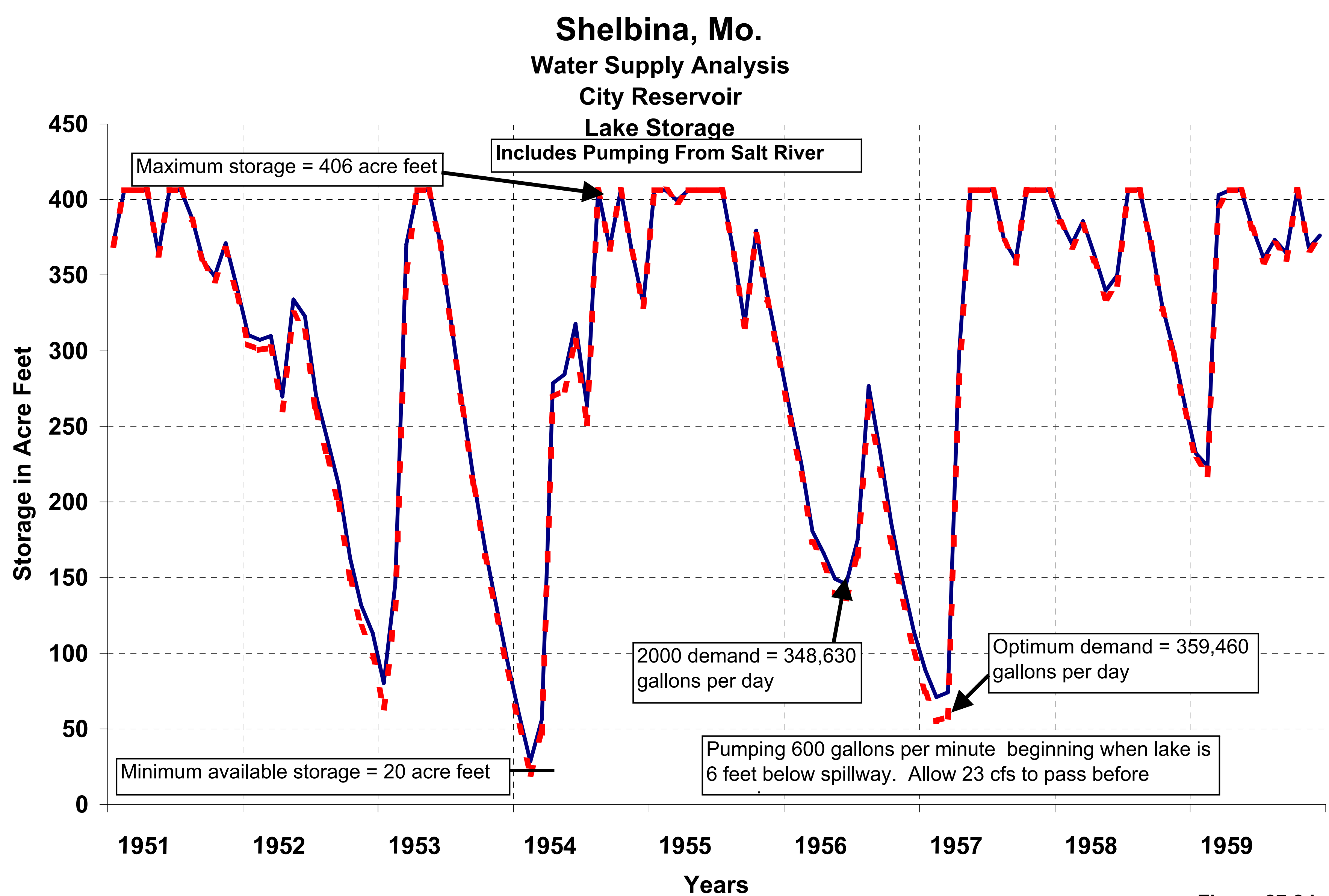
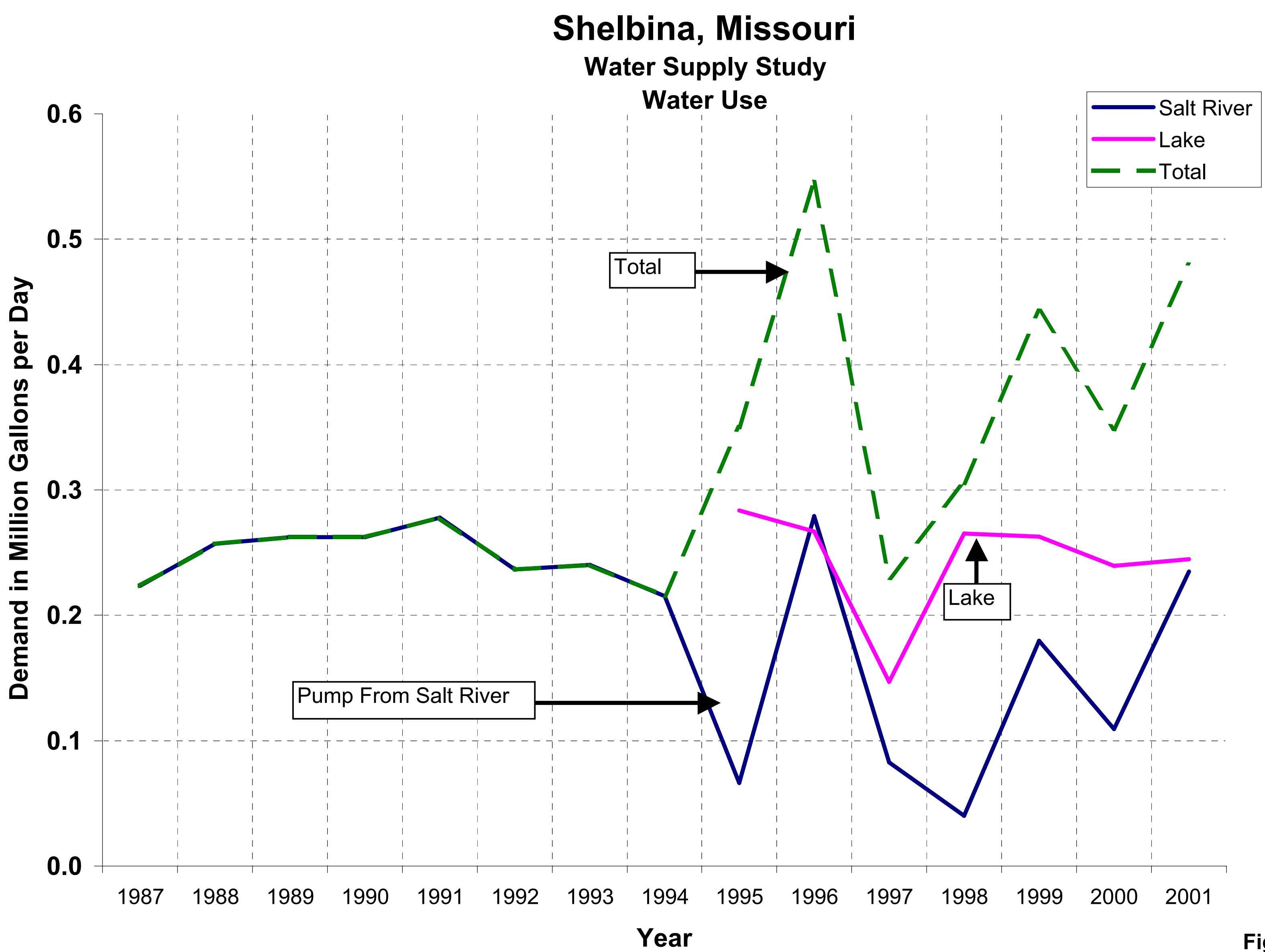

Shelbina, Missouri
Water Supply Analysis
City Reservoir
Lake Storage
Without Pumping from Salt River
Maximum storage = 406 acre feet
Optimum demand 273,300 gallons per day
1999 demand of 348,630 gallons per day
Minimum Available Storage = 20 Acre Feet
Storage in Acre Feet
450
400
350
300
250
200
150
100
50
0
1951
1952
1953
1954
1955
1956
1957
1958
1959
Years

Figure 27.2.a



Shelbina, Mo.
Water Supply Analysis
City Reservoir
Lake Storage
Includes Pumping From Salt River
Maximum storage = 406 acre feet
2000 demand = 348,630
gallons per day
Optimum demand = 359,460
gallons per day
Pumping 600 gallons per minute beginning when lake is
6 feet below spillway. Allow 23 cfs to pass before
Minimum available storage = 20 acre feet
Storage in Acre Feet
0
50
100
150
200
250
300
350
400
450
1951
1952
1953
1954
1955
1956
1957
1958
1959
Years

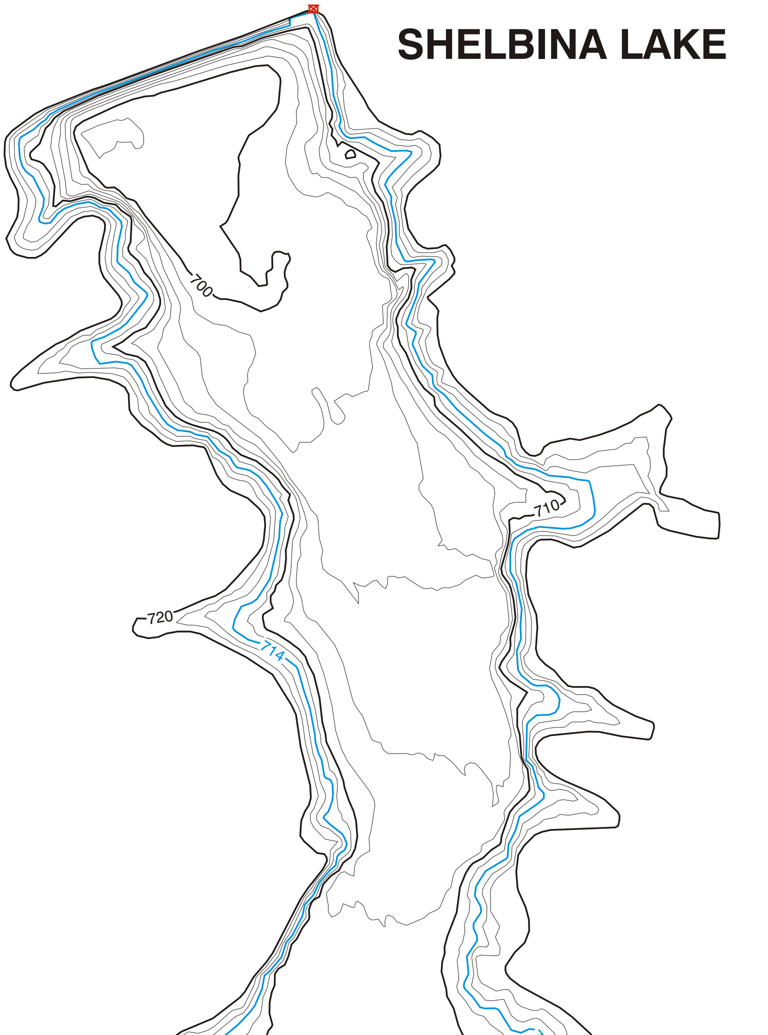
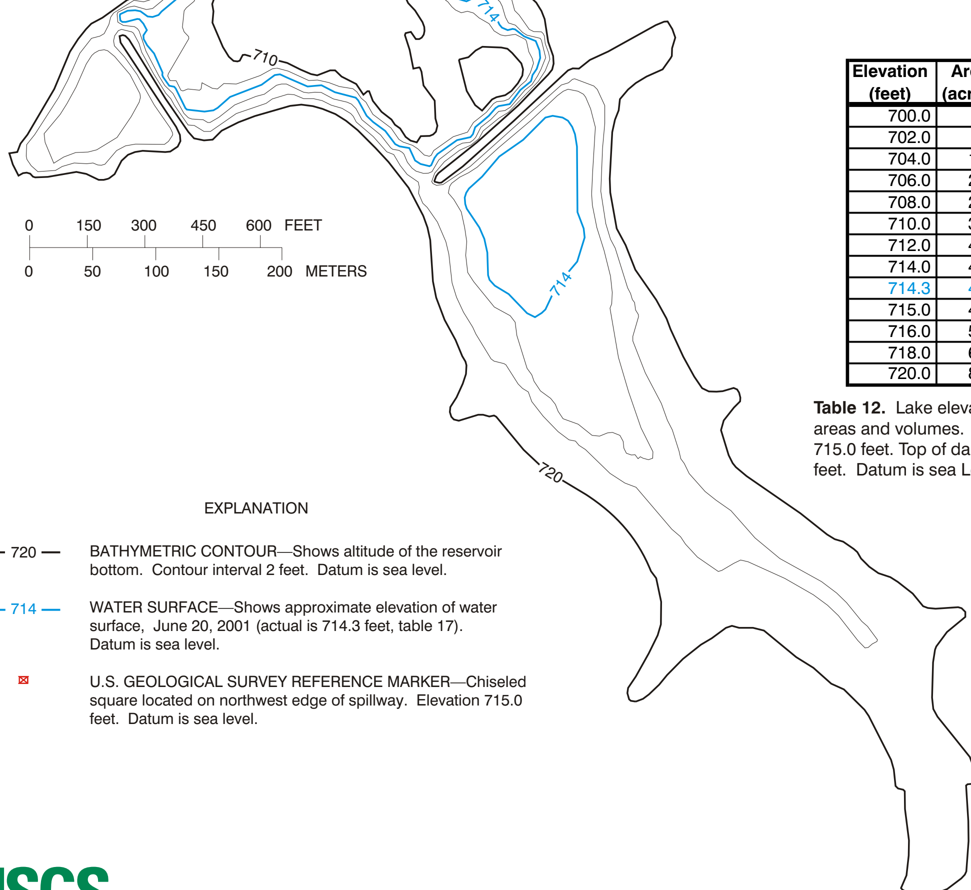
Figure 27.2.b

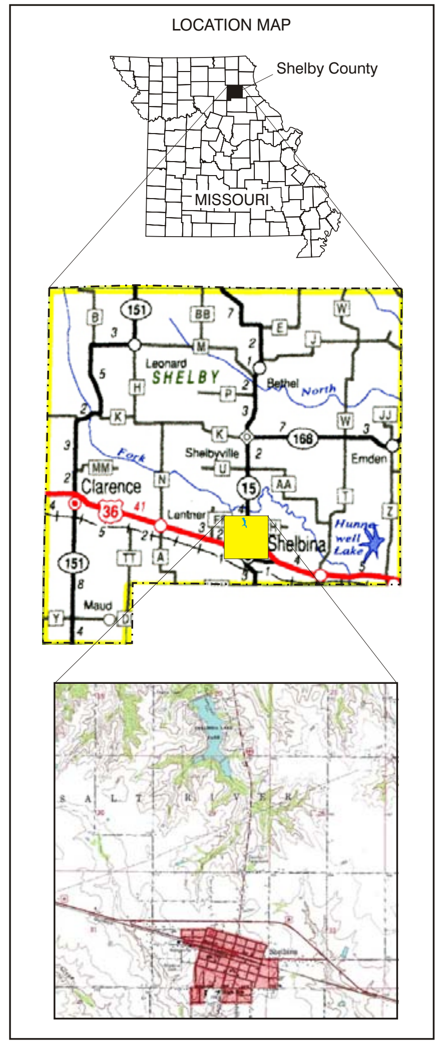


Shelbina, Missouri
Water Supply Study
Water Use
Salt River
Lake
Total
Total
Pump From Salt River
Lake
Demand in Million Gallons per Day
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
Year

Figure 27.3

SHELBINA LAKE



Elevation (feet)	Area (acres)	Volume (acre-ft)
700.0	4.1	4.3
702.0	9.9	18.0
704.0	15.3	42.7
706.0	22.7	80.7
708.0	28.0	131.6
710.0	36.7	194.5
712.0	41.5	273.8
714.0	45.0	360.2
714.3	45.7	373.7
715.0	47.1	406.3
716.0	53.7	457.7
718.0	63.8	575.3
720.0	81.9	717.8

Table 12. Lake elevations and respective areas and volumes. Spillway elevation is 715.0 feet. Top of dam is approximately 720 feet. Datum is sea Level.

EXPLANATION

— 720 — BATHYMETRIC CONTOUR—Shows altitude of the reservoir bottom. Contour interval 2 feet. Datum is sea level.

— 714 — WATER SURFACE—Shows approximate elevation of water surface, June 20, 2001 (actual is 714.3 feet, table 17). Datum is sea level.

⊠ U.S. GEOLOGICAL SURVEY REFERENCE MARKER—Chiseled square located on northwest edge of spillway. Elevation 715.0 feet. Datum is sea level.

USGS science for a changing world

Figure 12. Bathymetric map and table of areas/volumes of Shelbina Lake near Shelbina, Missouri.

Unionville, Missouri
Water Supply Study
Lake Mahoney

Lake Mahoney is located 2 miles North of Unionville in central Putnam County. Its drainage area is part of Thunderhead Reservoir drainage area and Lake Mahoney has a drainage area of 2.97 Square Miles. The lake is in the Blackbird Wildcat Creek Watershed.

Average annual rainfall is 37.2 inches. Annual rainfall for 1953 through 1957 is 24.1, 33.6, 39.4, 25.59, and 47.1 inches.

Two analysis were made:

1. First run was with the 2000 demand of 0.382 million gallons per day.
2. The lake was analyzed for the optimum daily use without emptying the lake during the evaluation period. Optimum demand is 0.283 million gallons per day.

Lake Mahoney analysis consisted of using the NRCS's computer program "RESOP". This program analyses remaining stored water at the end of each month by summing gains and losses.

Following is the data and procedures for input to the "RESOP" program.

STO-AREA Elevation-Storage and Elevation-Area data were determined from April 6, 2004 survey made by USGS.

Lake Mahoney

Unionville Water Supply

Elevation Feet	Area Acres	Volume Ac. Ft.	
959	1.1	0.3	
961	7.4	8.5	
963	14.4	30.2	
965	21.8	66.2	
967	31.1	120	
969	39.1	190	
971	45.9	270	
973	52.5	370	
975	60.1	490	
977	72.3	620	Top of Spillway Structure
977.3	75.5	640	Water surface on April 6, 2004
979	98.0	790	
981	129.0	1020	
985	154.0	1580	
987	168.0	1900	
989	183.0	2250	
989.5	187.0	2360	Top of Dam

LIMITS	Full pool storage	620 Ac.Ft.
	Minimum pool storage	120 Ac.Ft.

Starting storage was considered at full pool elevation.

The Drainage area of the lake is 2.97 square miles.

GENERAL The adjustment factor of 0.76 to convert from pan evaporation to lake evaporation was applied prior to entering the data for the control word EVAP. As a result a factor of 100 is applied.

The record period of drought is in the 1950's.
Analysis began in January 1951 and ended December 1959.

SEEPAGE The reservoir seepage varied from 0 seepage near empty to a maximum of 1.0 inch per month when at full pool. The material in the dam is compacted earth of clayey soils.

RAINFALL Rainfall data came from the Unionville, Mo. rain gage for the period 1951 through 1959.

RUNOFF This is the runoff into the lake from its drainage area. Monthly runoff volumes in watershed inches were determined and comparisons were made for the Locust Creek River Gage at Linneus, Medicine Creek near Galt, and South Fork Chariton River near Promise, Iowa. The three gages yielded similar monthly runoff volumes. The South Fork Chariton River gage did not have enough years of data to evaluate the drought of record. After these comparisons, Locust Creek gage was chosen to represent runoff for the watershed.

In cases where rainfall to runoff values did not appear reasonable, adjustments were made for that month by looking at individual rains and estimating antecedent moisture and then, adjusting runoff based on NRCS's runoff curve numbers.

EVAP. Pan evaporation at the Lakeside gaging station was used as a base because it has data for year around evaporation. All other stations only measure data between April through November. Lakeside data was updated during these months with gage data from stations at New Franklin, and Columbia. Depending on the latest data for the station nearest to Unionville.

DEMAND Determined from city records. The total use in 2000 was 139,500,000 gallons which amounts to 0.382 million gallon per day.

Lake Thunderhead
Putnam County, Missouri
Water Supply Study

Lake Thunderhead is a privately owned lake located 5 miles North of Unionville in central Putnam County. It's total drainage area is 25.97 square miles. Unionville's Lake Mahoney makes up 2.97 square miles of the drainage area. The lake is in the Blackbird Wildcat Creek watershed.

Average annual rainfall at Unionville is 37.2 inches. Annual rainfall for 1953 through 1957 is 24.1, 33.6, 39.4, 25.59, and 47.1 inches.

Lake Thunderhead was not designed for water supply. It only serves as a supplemental supply during periods of drought. It is downstream of Lake Mahoney. Spillage from Lake Mahoney was added to the inflow to Lake Thunderhead.

Four analysis were made:

1. First run was to optimize the potential demand through the drought of record in the 1950's. Lake Thunderhead and Lake Mahoney availability of water was optimized. Lake Mahoney's optimum demand = 0.283 MGD and Lake Thunderhead demand was 3.36 MGD.
2. The second run assumes that none of Unionville demand comes from Lake Mahoney and all of the year 2000 demand of 0.382 MGD came from Lake Thunderhead. The water surface elevation in Lake Thunderhead would reach 3.5 feet below the spillway.
3. The third run assumed that optimum demand (0.283 MGD) came from Lake Mahoney and none came from Lake Thunderhead. Losses in Lake Thunderhead would be evaporation and seepage. The result would be the water surface would be expected to reach 2.9 feet below the spillway.
4. The fourth run assumed that the optimum demand of 0.283 MGD came from Lake mahoney and 0.099 MGD came from Lake Thunderhead, meeting the 2000 demand for Unionville of 0.382 MGD. The result would be the water surface would be expected to reach 3.1 feet below the spillway.

All spillage from Lake Mahoney was added to inflow for Lake Thunderhead.

Lake Thunderhead analysis consisted of using the NRCS's computer program "RESOP". This program analyses remaining stored water at the end of each month by summing gains and losses. See Unionville study for Lake Mahoney analysis and input data. Lake Thunderhead has the potential to supply an optimum yield of 3.361 million gallons per day.

Following is the data and procedures for input to the "RESOP" program.

STO-AREA Elevation-Storage and Elevation-Area data were determined from April 6, 2004 survey made by USGS.

Lake Thunderhead

Elevation (feet)	Area (acres)	Volume (acre-ft)
932.0	16.8	10.1
934.0	48.7	76.5
936.0	78.0	202
938.0	118	398
940.0	162	678
942.0	208	1,050
944.0	260	1,510
946.0	304	2,080
948.0	356	2,740

950.0	412	3,500	
952.0	476	4,390	
954.0	537	5,400	
956.0	598	6,540	
958.0	660	7,800	
960.0	721	9,180	
962.0	791	10,690	
964.0	864	12,340	
966.0	940	14,140	
967.3	989	15,400	Spillway elevation
967.8	1,010	15,900	Water surface elevation April 2004
968.0	1,040	16,100	
970.0	1,100	18,240	
971.3	1,140	19,690	Emergency spillway elevation

LIMITS Full pool storage 15,400 Ac.Ft.
Minimum pool storage 1500 Ac.Ft.

Starting storage was considered at full pool elevation.

The net drainage area, after subtracting Lake Mahoney drainage area, is 22.96 square miles.

GENERAL The adjustment factor of 0.76 to convert from pan evaporation to lake evaporation was applied prior to entering the data for the control word EVAP. As a result a factor of 100 is applied.

The record period of drought is in the 1950's.
Analysis began in January 1951 and ended December 1959

SEEPAGE The reservoir seepage varied from 0 seepage near empty to a maximum of 3.0 inch per month when at full pool. The material in the dam is compacted earth of clayey soils.

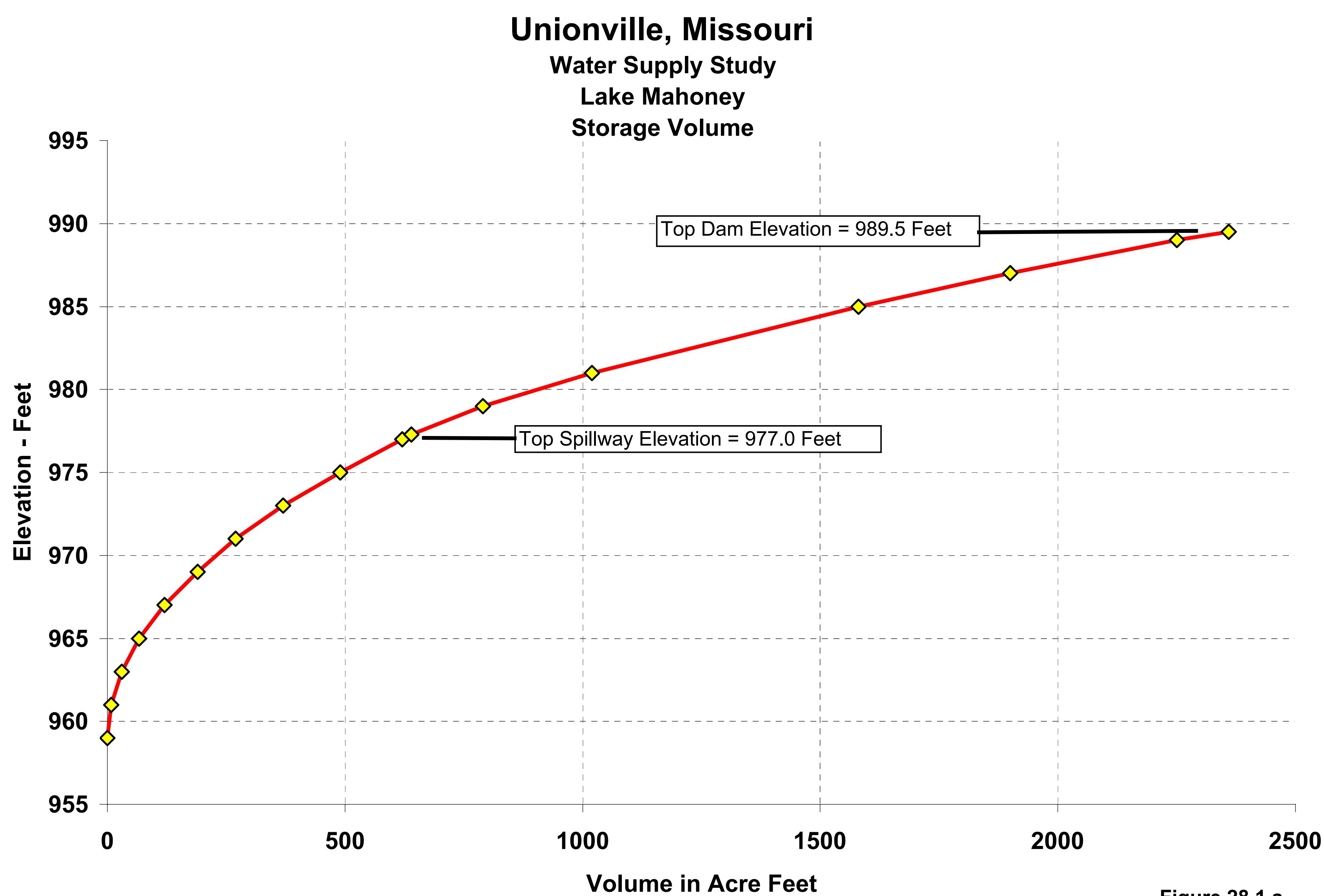
RAINFALL Rainfall data came from the Unionville, Mo. rain gage for the period 1951 through 1959.

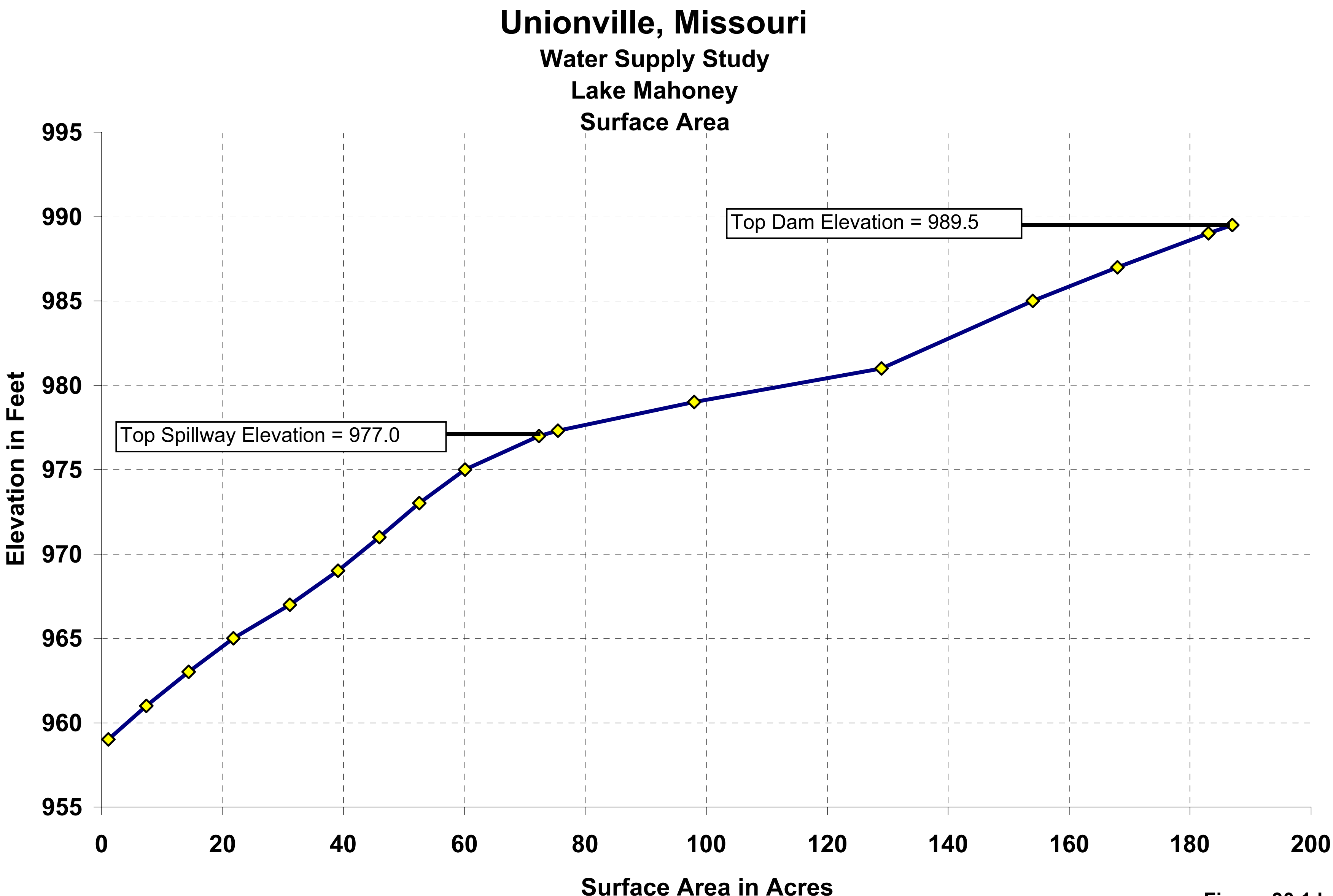
RUNOFF This is the runoff into the lake from its drainage area. Monthly runoff volumes in watershed inches were determined and comparisons were made for the Locust Creek Stream Gage at Linneus, Medicine Creek near Galt, and South Fork Chariton River near Promise, Iowa. The three gages yielded similar monthly runoff volumes. The South Fork Chariton River Gage did not have enough years of data to evaluate the drought of record. After these comparisons, Locust Creek Gage was chosen to represent runoff for the watershed.

In cases where rainfall to runoff values did not appear reasonable, adjustments were made for that month by looking at individual rains and estimating antecedent moisture and then, adjusting runoff based on NRCS's runoff curve numbers.

EVAP Pan evaporation at the Lakeside gaging station was used as a base because it has data for year around evaporation. All other stations only measure data between April through November. Lakeside data was updated during these months with gage data from stations at New Franklin, and Columbia. Depending on the latest data for the station nearest to Unionville.

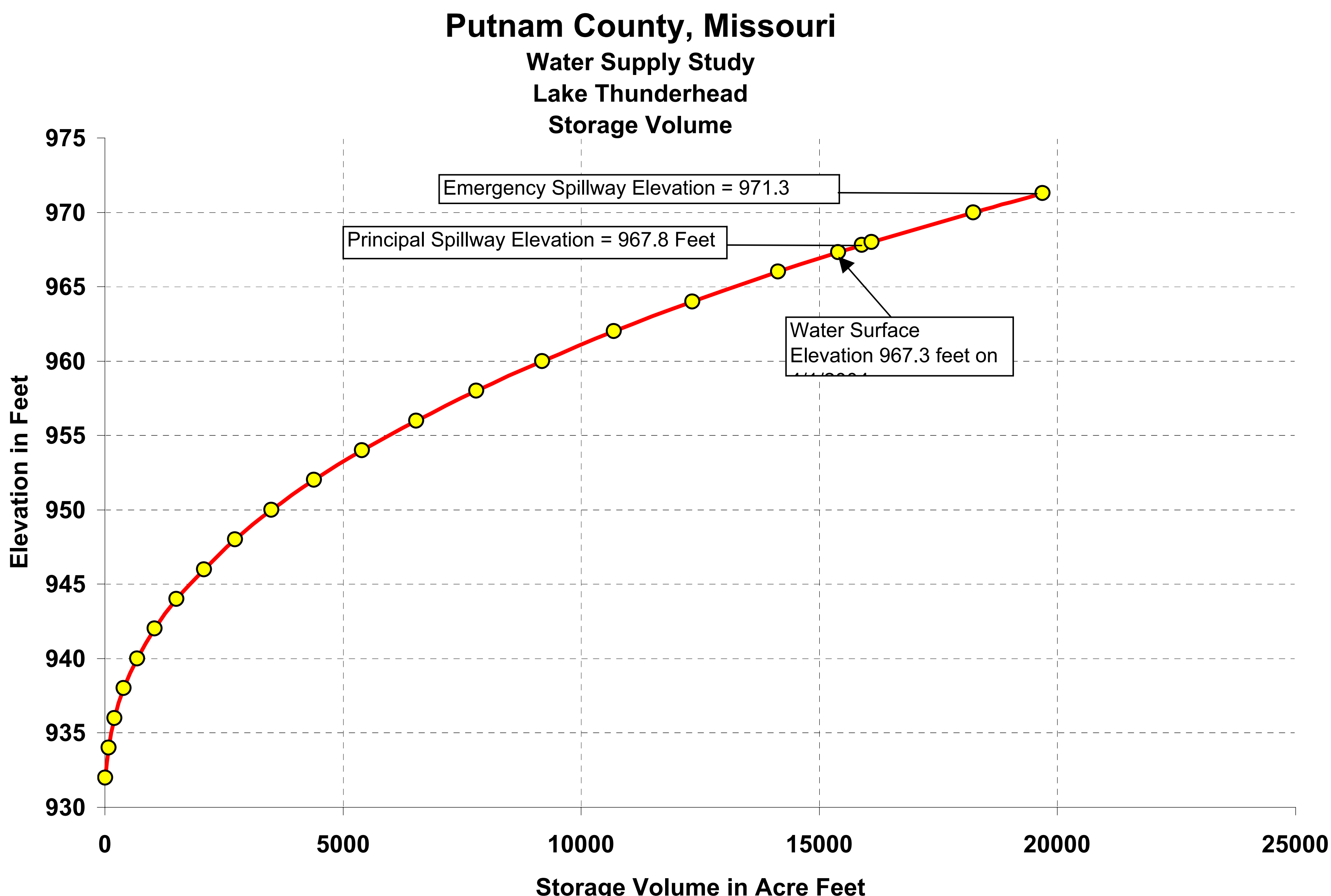
DEMAND The demand was calculated to determine the capabilities of the lake to meet local needs. Unionville demand for year 2000 was 0.382 MGD. Runs were made to determine effects of three different scenarios of combinations of withdrawal.


Unionville, Missouri
Water Supply Study
Lake Mahoney
Storage Volume
Elevation - Feet
Volume in Acre Feet
995
990
985
980
975
970
965
960
955
0
500
1000
1500
2000
2500
Top Dam Elevation = 989.5 Feet
Top Spillway Elevation = 977.0 Feet
Figure 28.1.a



Unionville, Missouri
Water Supply Study
Lake Mahoney
Surface Area
Elevation in Feet
995
990
985
980
975
970
965
960
955
0
20
40
60
80
100
120
140
160
180
200
Surface Area in Acres
Top Spillway Elevation = 977.0
Top Dam Elevation = 989.5

Figure 30.1.b



Putnam County, Missouri
Water Supply Study
Lake Thunderhead
Storage Volume
Emergency Spillway Elevation = 971.3
Principal Spillway Elevation = 967.8 Feet
Water Surface
Elevation 967.3 feet on
975
970
965
960
955
950
945
940
935
930
Elevation in Feet
0
5000
10000
15000
20000
25000
Storage Volume in Acre Feet

Figure 18.1.a

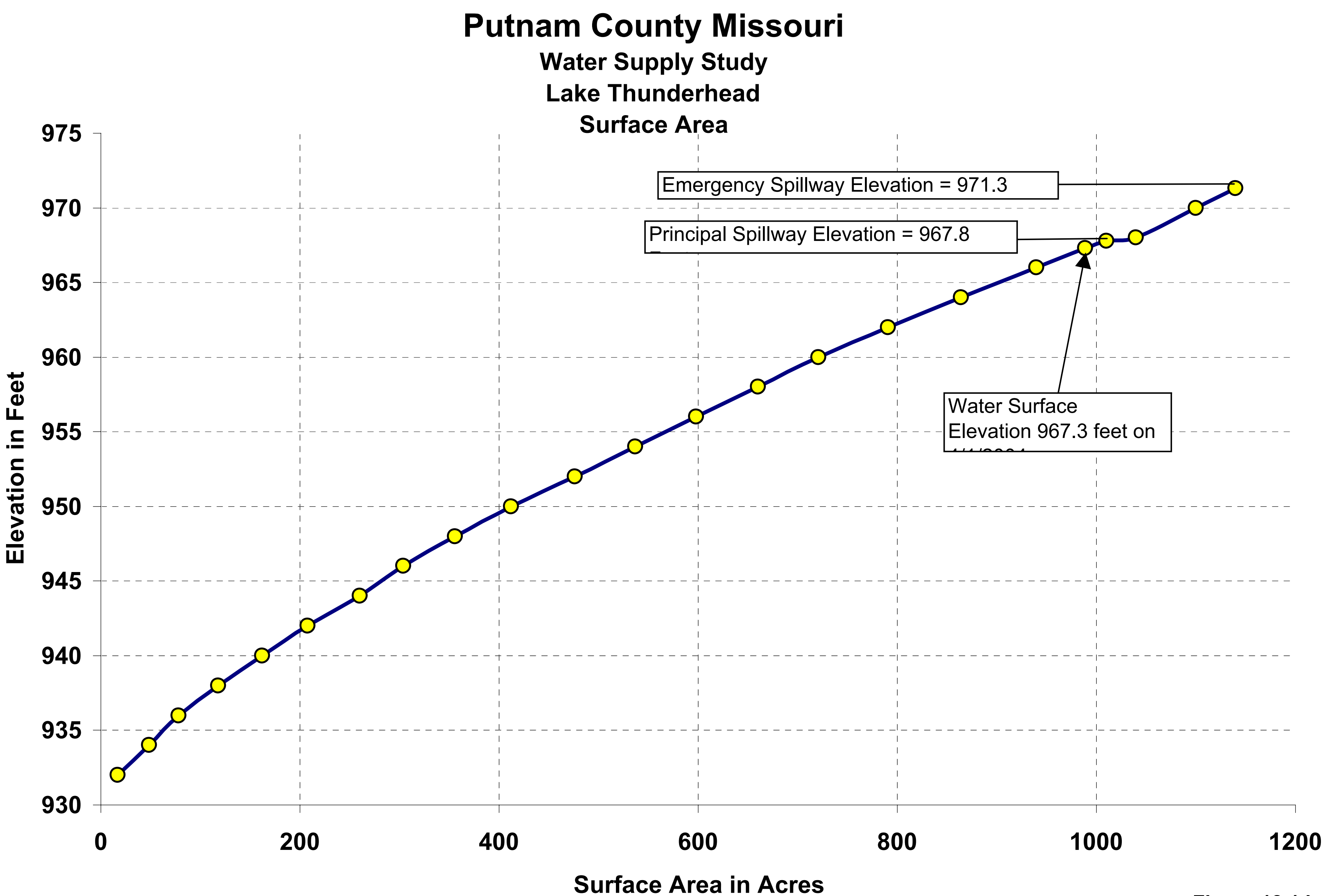

Putnam County Missouri
Water Supply Study
Lake Thunderhead
Surface Area
Emergency Spillway Elevation = 971.3
Principal Spillway Elevation = 967.8
Water Surface
Elevation 967.3 feet on
Elevation in Feet
975
970
965
960
955
950
945
940
935
930
0
200
400
600
800
1000
1200
Surface Area in Acres

Figure 18.1.b

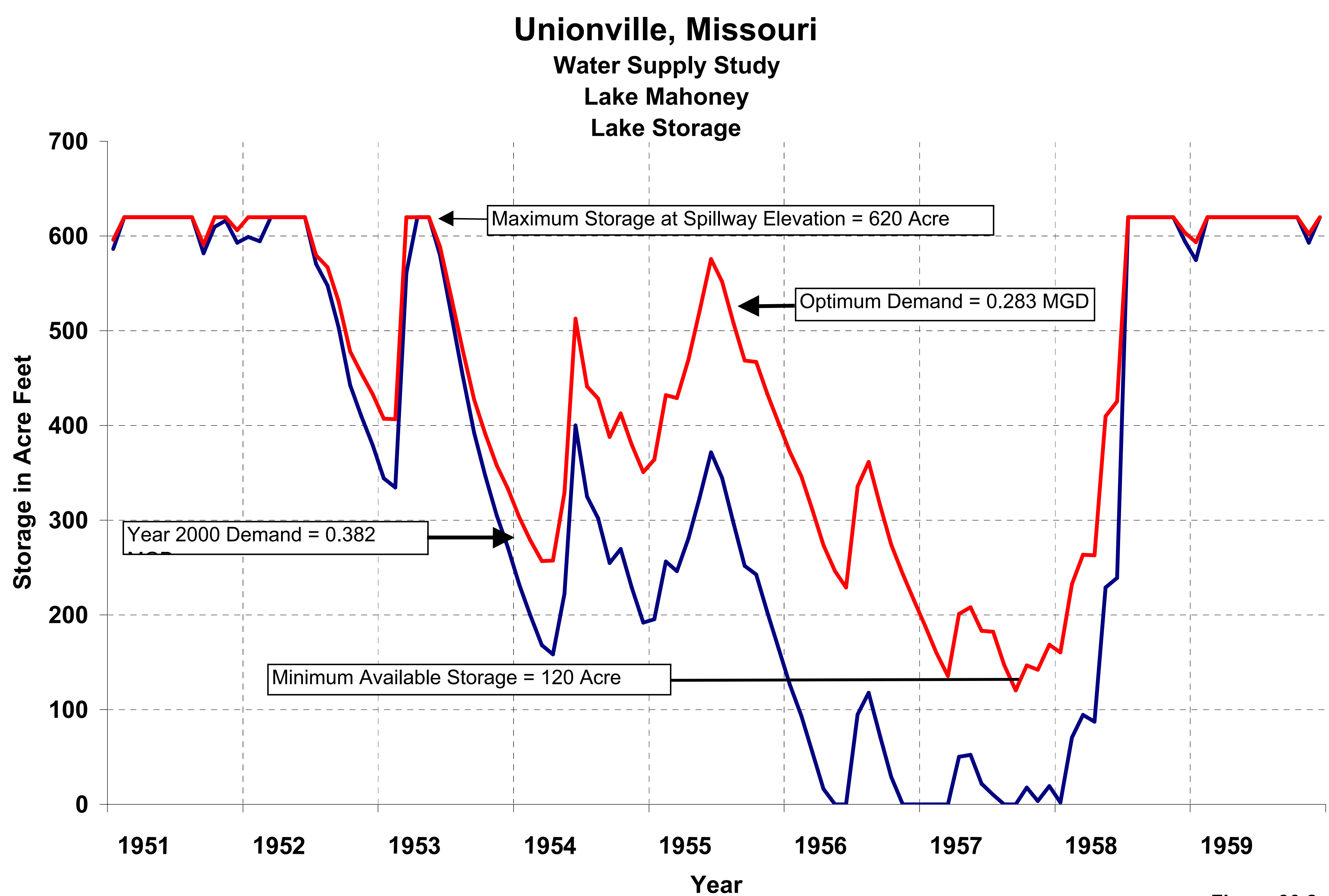
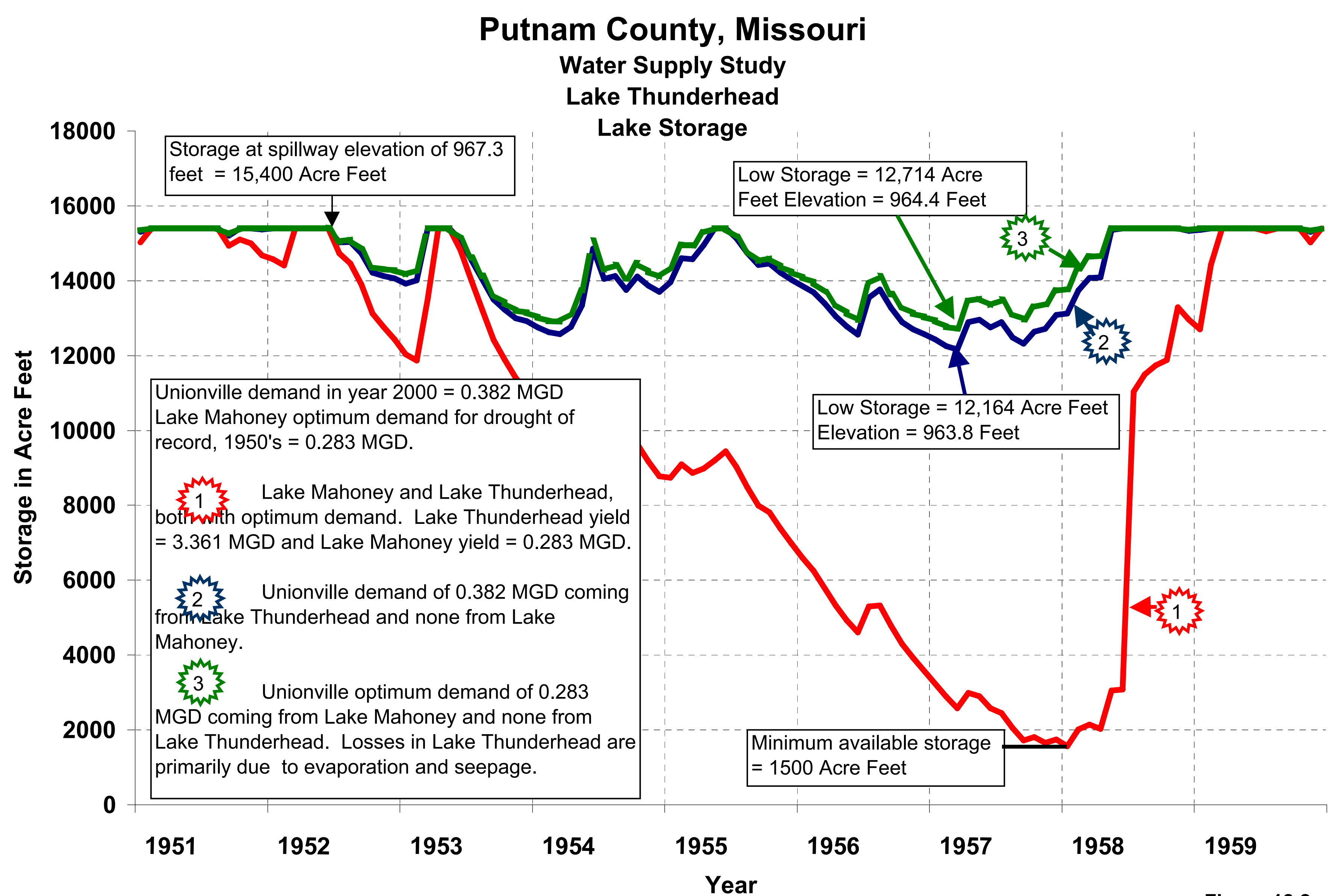

Unionville, Missouri
Water Supply Study
Lake Mahoney
Lake Storage
Storage in Acre Feet
700
600
500
400
300
200
100
0
Maximum Storage at Spillway Elevation = 620 Acre
Optimum Demand = 0.283 MGD
Year 2000 Demand = 0.382
Minimum Available Storage = 120 Acre
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year

Figure 30.2



Putnam County, Missouri
Water Supply Study
Lake Thunderhead
Lake Storage
Storage in Acre Feet
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year
Storage at spillway elevation of 967.3 feet = 15,400 Acre Feet
Low Storage = 12,714 Acre Feet Elevation = 964.4 Feet
Low Storage = 12,164 Acre Feet Elevation = 963.8 Feet
Minimum available storage = 1500 Acre Feet
Unionville demand in year 2000 = 0.382 MGD Lake Mahoney optimum demand for drought of record, 1950's = 0.283 MGD.
1 Lake Mahoney and Lake Thunderhead, both with optimum demand. Lake Thunderhead yield = 3.361 MGD and Lake Mahoney yield = 0.283 MGD.
2 Unionville demand of 0.382 MGD coming from Lake Thunderhead and none from Lake Mahoney.
3 Unionville optimum demand of 0.283 MGD coming from Lake Mahoney and none from Lake Thunderhead. Losses in Lake Thunderhead are primarily due to evaporation and seepage.

Figure 18.2.a

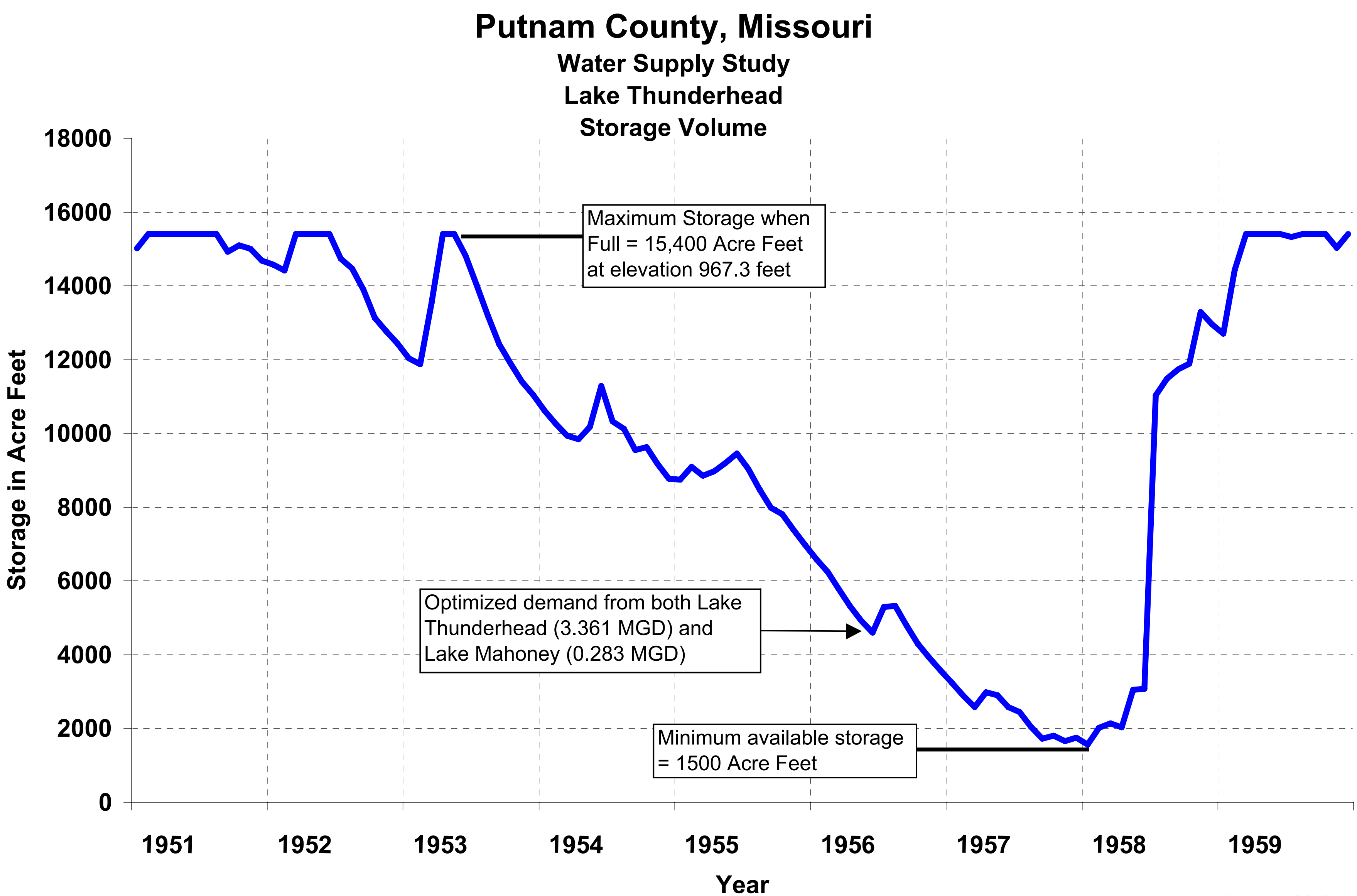
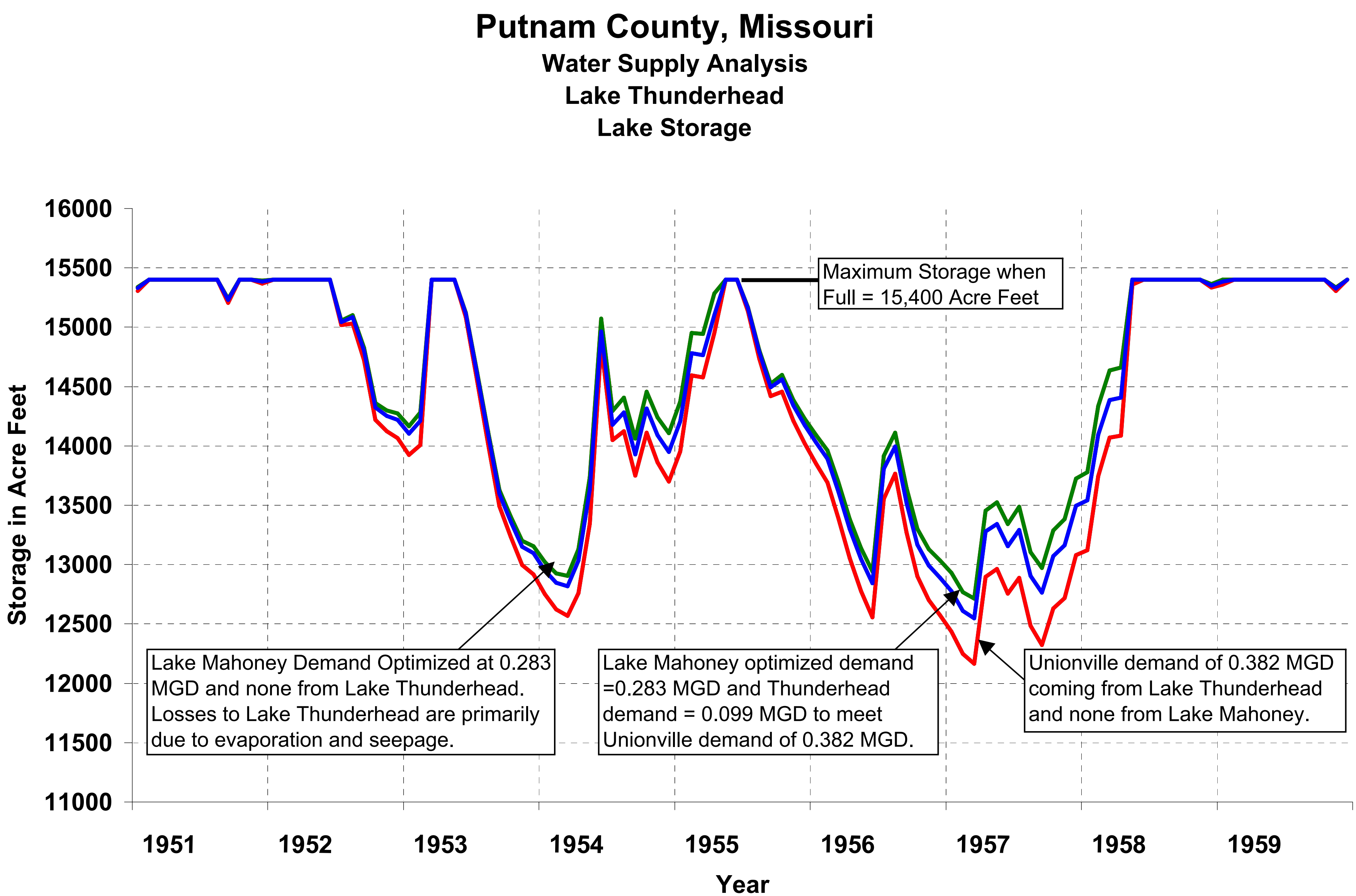

Putnam County, Missouri
Water Supply Study
Lake Thunderhead
Storage Volume
Storage in Acre Feet
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year
Maximum Storage when
Full = 15,400 Acre Feet
at elevation 967.3 feet
Optimized demand from both Lake
Thunderhead (3.361 MGD) and
Lake Mahoney (0.283 MGD)
Minimum available storage
= 1500 Acre Feet

Figure 18.2.b


Putnam County, Missouri
Water Supply Analysis
Lake Thunderhead
Lake Storage
Storage in Acre Feet
16000
15500
15000
14500
14000
13500
13000
12500
12000
11500
11000
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year
Maximum Storage when Full = 15,400 Acre Feet
Lake Mahoney Demand Optimized at 0.283 MGD and none from Lake Thunderhead. Losses to Lake Thunderhead are primarily due to evaporation and seepage.
Lake Mahoney optimized demand =0.283 MGD and Thunderhead demand = 0.099 MGD to meet Unionville demand of 0.382 MGD.
Unionville demand of 0.382 MGD coming from Lake Thunderhead and none from Lake Mahoney.
Figure 18.2.c

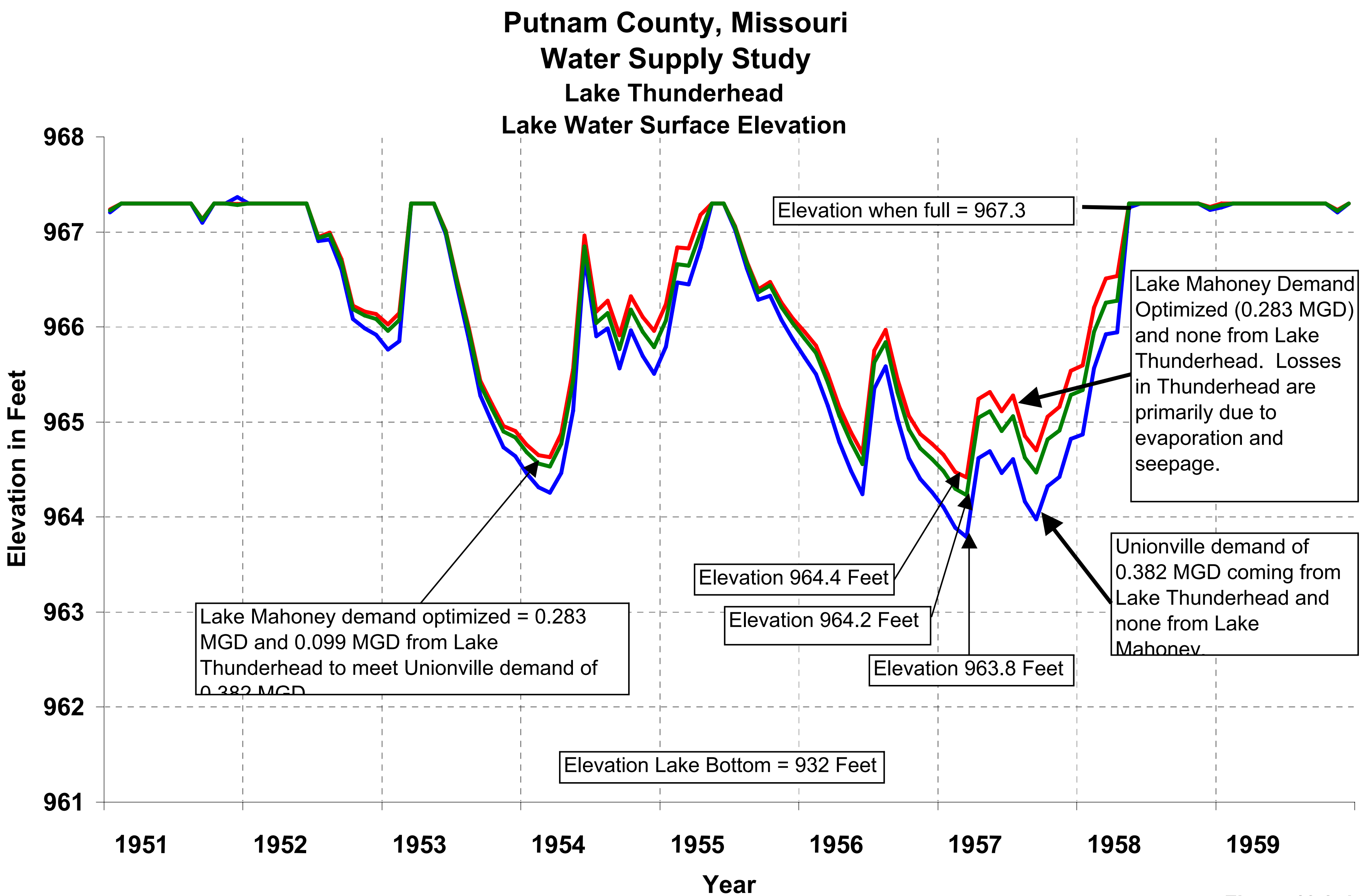
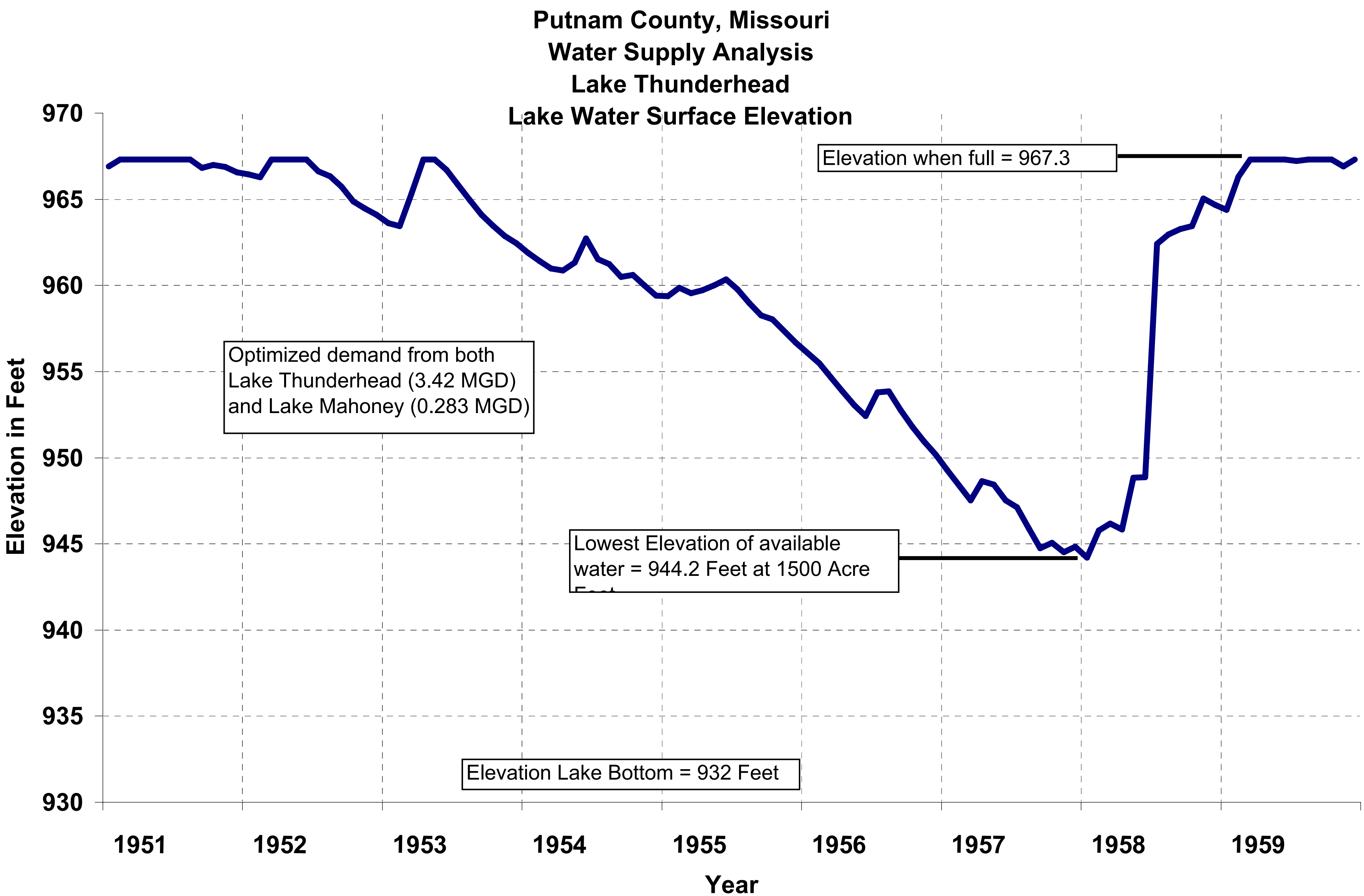
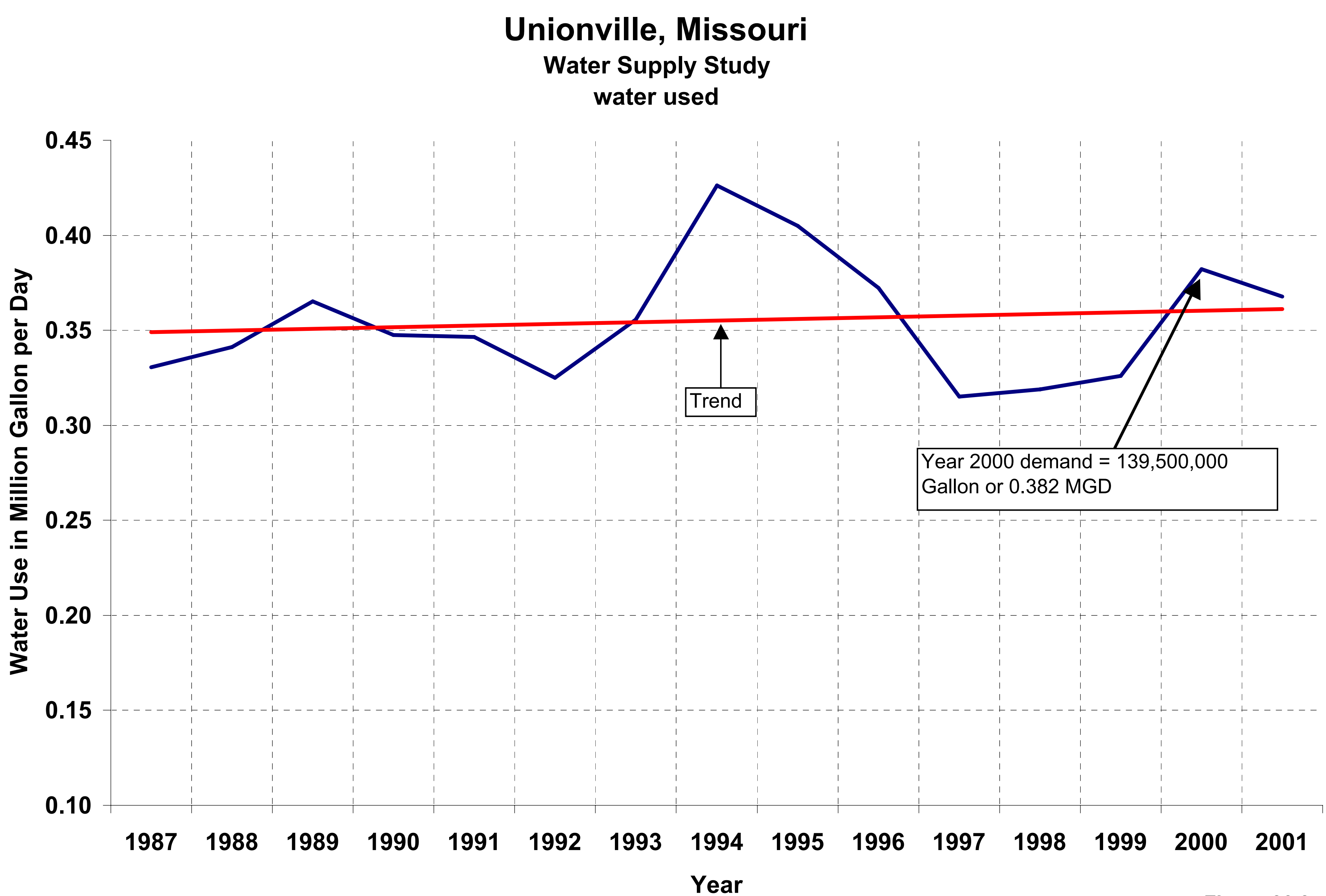

Putnam County, Missouri
Water Supply Study
Lake Thunderhead
Lake Water Surface Elevation
Elevation in Feet
968
967
966
965
964
963
962
961
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year
Elevation when full = 967.3
Lake Mahoney Demand Optimized (0.283 MGD) and none from Lake Thunderhead. Losses in Thunderhead are primarily due to evaporation and seepage.
Unionville demand of 0.382 MGD coming from Lake Thunderhead and none from Lake
Lake Mahoney demand optimized = 0.283 MGD and 0.099 MGD from Lake Thunderhead to meet Unionville demand of
Elevation 964.4 Feet
Elevation 964.2 Feet
Elevation 963.8 Feet
Elevation Lake Bottom = 932 Feet

Figure 18.2.d



Putnam County, Missouri
Water Supply Analysis
Lake Thunderhead
Lake Water Surface Elevation
Elevation in Feet
970
965
960
955
950
945
940
935
930
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year
Elevation when full = 967.3
Optimized demand from both
Lake Thunderhead (3.42 MGD)
and Lake Mahoney (0.283 MGD)
Lowest Elevation of available
water = 944.2 Feet at 1500 Acre
Elevation Lake Bottom = 932 Feet

Figure 18.2.e

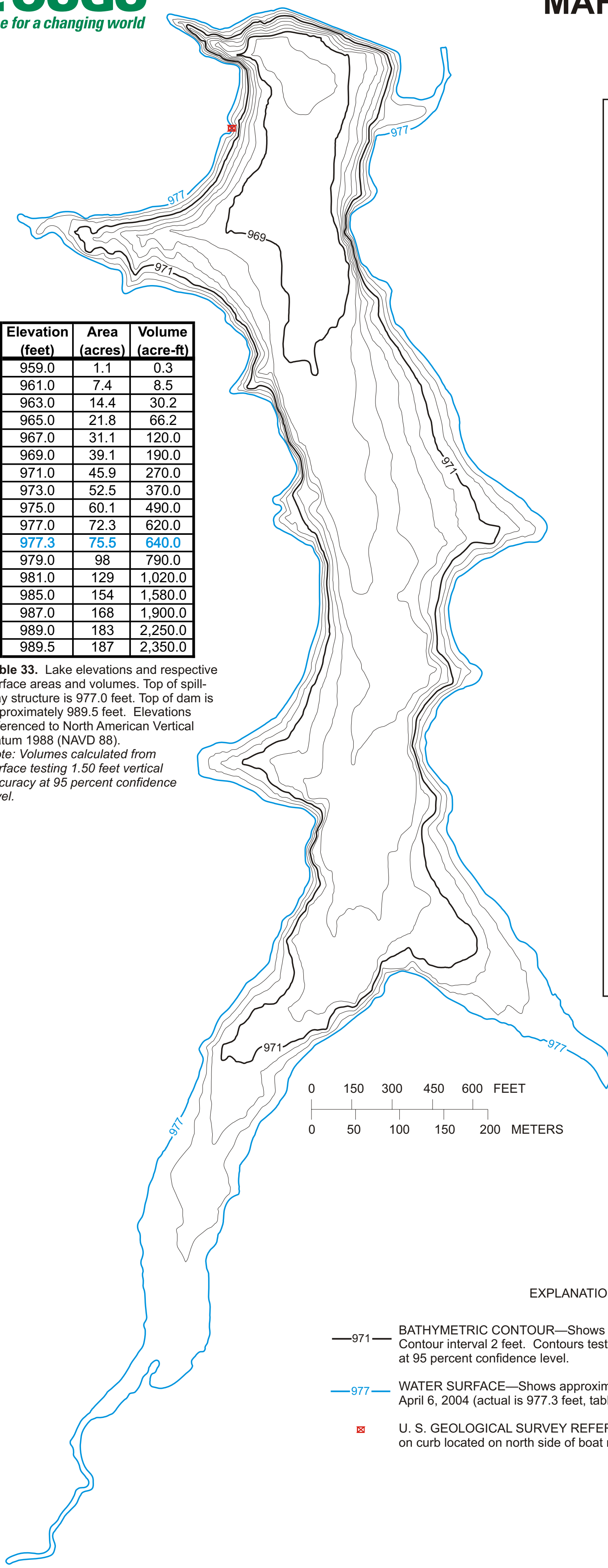


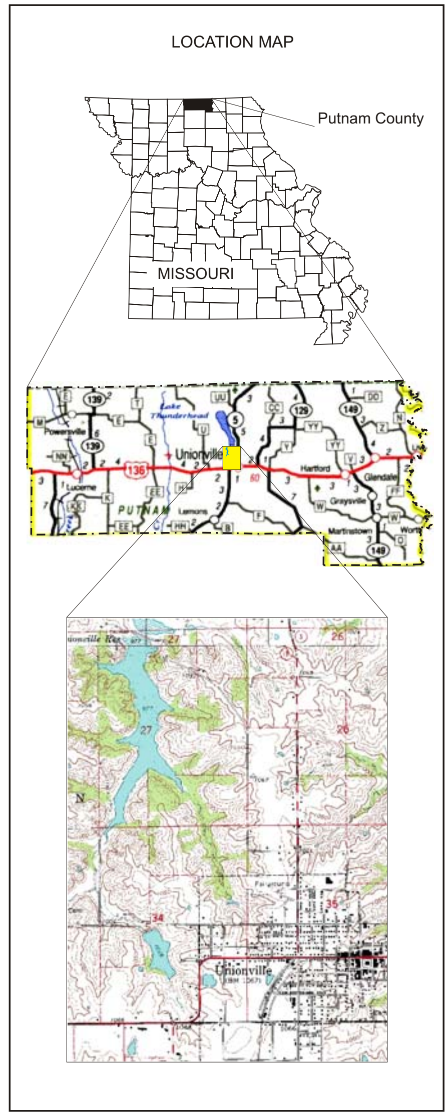
Unionville, Missouri
Water Supply Study
water used
Water Use in Million Gallon per Day
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
Year
Trend
Year 2000 demand = 139,500,000
Gallon or 0.382 MGD

Figure 30.3

USGS
science for a changing world

MAHONEY LAKE





Elevation (feet)	Area (acres)	Volume (acre-ft)
959.0	1.1	0.3
961.0	7.4	8.5
963.0	14.4	30.2
965.0	21.8	66.2
967.0	31.1	120.0
969.0	39.1	190.0
971.0	45.9	270.0
973.0	52.5	370.0
975.0	60.1	490.0
977.0	72.3	620.0
977.3	75.5	640.0
979.0	98	790.0
981.0	129	1,020.0
985.0	154	1,580.0
987.0	168	1,900.0
989.0	183	2,250.0
989.5	187	2,350.0

Table 33. Lake elevations and respective surface areas and volumes. Top of spillway structure is 977.0 feet. Top of dam is approximately 989.5 feet. Elevations referenced to North American Vertical Datum 1988 (NAVD 88).
Note: Volumes calculated from surface testing 1.50 feet vertical accuracy at 95 percent confidence level.

EXPLANATION

—971— BATHYMETRIC CONTOUR—Shows altitude of the reservoir bottom. Contour interval 2 feet. Contours tested 2.47 feet vertical accuracy at 95 percent confidence level.

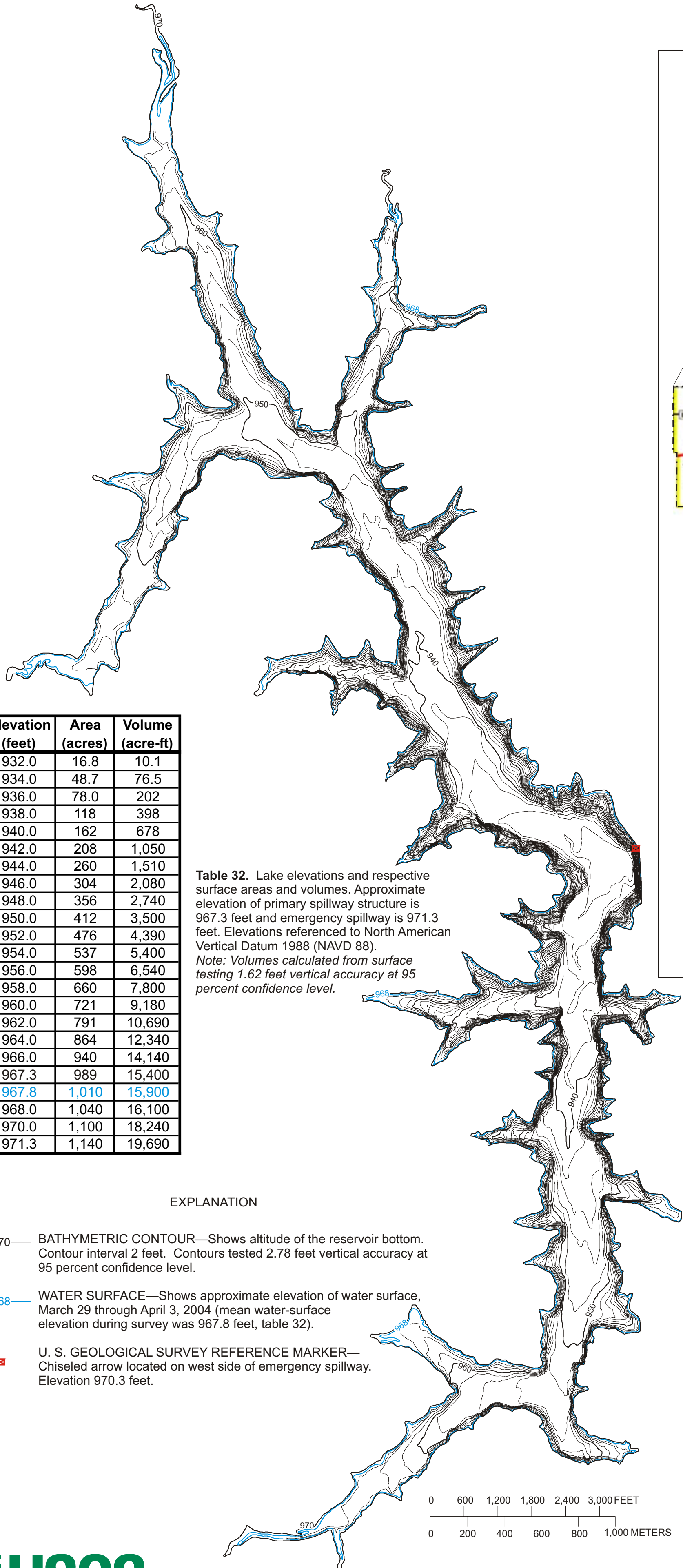
—977— WATER SURFACE—Shows approximate elevation of water surface, April 6, 2004 (actual is 977.3 feet, table 33).

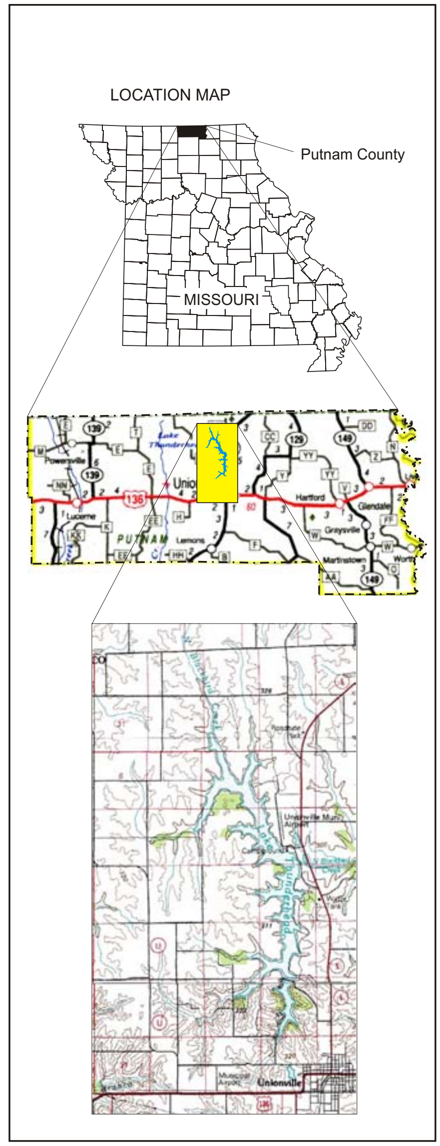
⊠ U. S. GEOLOGICAL SURVEY REFERENCE MARKER—Chiseled arrow on curb located on north side of boat ramp. Elevation 977.4 feet.

Figure 33. Bathymetric map and table of areas/volumes of the Mahoney Lake near Unionville, Missouri.

In cooperation with Missouri Department of Natural Resources

THUNDERHEAD LAKE





Elevation (feet)	Area (acres)	Volume (acre-ft)
932.0	16.8	10.1
934.0	48.7	76.5
936.0	78.0	202
938.0	118	398
940.0	162	678
942.0	208	1,050
944.0	260	1,510
946.0	304	2,080
948.0	356	2,740
950.0	412	3,500
952.0	476	4,390
954.0	537	5,400
956.0	598	6,540
958.0	660	7,800
960.0	721	9,180
962.0	791	10,690
964.0	864	12,340
966.0	940	14,140
967.3	989	15,400
967.8	1,010	15,900
968.0	1,040	16,100
970.0	1,100	18,240
971.3	1,140	19,690

Table 32. Lake elevations and respective surface areas and volumes. Approximate elevation of primary spillway structure is 967.3 feet and emergency spillway is 971.3 feet. Elevations referenced to North American Vertical Datum 1988 (NAVD 88).
Note: Volumes calculated from surface testing 1.62 feet vertical accuracy at 95 percent confidence level.

EXPLANATION

—970— BATHYMETRIC CONTOUR—Shows altitude of the reservoir bottom. Contour interval 2 feet. Contours tested 2.78 feet vertical accuracy at 95 percent confidence level.

—968— WATER SURFACE—Shows approximate elevation of water surface, March 29 through April 3, 2004 (mean water-surface elevation during survey was 967.8 feet, table 32).

⊠ U. S. GEOLOGICAL SURVEY REFERENCE MARKER—Chiseled arrow located on west side of emergency spillway. Elevation 970.3 feet.

USGS
science for a changing world

Figure 32. Bathymetric map and table of areas/volumes of the Thunderhead Lake near Unionville, Missouri.

In cooperation with Missouri Department of Natural Resources

Stream Discharges for Water Supplies

Introduction

Four cities in Missouri that rely on stream flow for their water supply are Joplin, Perryville, Poplar Bluff and Trenton. Joplin depends on Shoal Creek, Perryville uses Saline Creek, Poplar Bluff uses Black River, and Trenton uses Thompson River. Stream flow must be adequate to meet withdrawal by the city. Flow must provide enough for downstream flow to meet in-stream-flow requirements. Monthly low flow-duration analysis was made to determine the probability of stream flow depletion.

Stream Flow Analysis:

Many communities in Missouri utilize creeks and rivers to meet their municipal needs. Some streams do not have enough flow to meet immediate needs and off channel storage is required. Other streams, primarily in the Ozark Region where springs provide sufficient flow, have continuous discharges to meet consumptive use requirements.

Basic data for making stream flow frequency analysis was obtained from USGS published water supply papers. Mean daily discharges were used to analyze stream flow volumes and frequencies. Gages having long term records were used to evaluate extended periods of drought. Gage data is published as mean daily discharge, in cubic feet per second. Analysis was made on a monthly basis. A comparison of a shorter drought of seven days is also presented.

To meet in-stream flow requirements, the 7-day duration, 10-year frequency mean discharge was determined. Only when flows exceeded the in-stream flow requirements were withdrawals allowed for domestic uses.

All frequency analysis was made using the "Log-Pearson Type III Probability Method". This procedure is described on the Water Resource Council Bulletin 17B.

To establish base flow in the streams, USGS computer program "HYSEP" was used. The program separates the base flow hydrograph from the total discharge hydrograph.

The monthly frequency analysis was also compared to historical stream flows of the 1950's drought of record. This identified the months of critical stream flow that could be expected to occur during an extreme drought.

All analysis results are presented in a series of charts displayed for each month of the year.

Glossary

Definition of terms

cfs – Discharge in cubic feet per second.
MG -- million gallon
MGD – million gallon per day
GPM – gallon per minute
USGS – United States Geological Survey
Acre feet – Volume of water covering one acre, one foot deep.
USGS Bulletin 17B - The USGS Guideline for Determining Flood Flow Frequency. It describes the data and procedures for computing flood flow frequency curves where systematic stream gauging records are of sufficient length to warrant statistical analysis.

Log-Pearson Type III Probability Method. The annual values are fit to a Log-Pearson Type III probability distribution. If minimum values are used, the result is non-exceedence probabilities. If the maximum values are used the result is exceedence probabilities.

The observations are fit to the Log-Pearson Type III distribution using the following equation:

$\log Q = X+KS$

where Q is the expected discharge, X is the mean logarithm of the observed values, S is the standard deviation of logarithms of the observed values and K is a factor that is a function of the skew coefficient of the observed values and the selected non-exceedence probability.

7 day Q10 – The mean 7-day duration, 10-year frequency low flow is the minimum flow needed for in-stream flow requirements.

HYSEP - A USGS computer program that separates the base flow hydrograph from the total hydrograph.

Runoff in Watershed (inches) – The volume of runoff from the entire drainage area of the Basin, in inches.

WHPA Report – Report on problems of the Ozark aquifer and associated problems with supply and demand. Titled "Source of Supply Investigation for Southwestern Missouri." Prepared by Wittman and associates.

JOPLIN, MISSOURI
Water Supply Study
Shoal Creek

Introduction:

This analysis was made to assess the availability of Joplin's water supply. Joplin obtains their water supplies from a combination of Shoal Creek and wells. Shoal Creek being the major contributor. There are 8 to 14 million gallon per day pumped from Shoal Creek, which is fed by numerous springs throughout its drainage area. Wells contribute 1.2 to 1.9 million gallons per day. The first part of this report discusses availability of stream flow and withdrawals from Shoal Creek. The second part of the report addresses contributions by wells. The "WHPA" report assesses the problems associated with excessive use of ground water in the region.

Discussion:

Shoal Creek:

Shoal Creek Stream gage above Joplin is located 1400 feet downstream of state Highway 86. The drainage area above the stream gage is 427 square miles. The water supply is provided by "Missouri-American Water Company". The pump intake is located ¾ mile downstream of highway I-44, about 4.5 miles downstream of the gage (NE ¼, sec 28, T27N, R33W). Stream flow data was obtained from USGS water supply papers, daily values. Mean daily discharges were used to analyze stream flow volumes and frequencies. Continuous records have been kept from 1941 through 2002. Neosho also uses water from Shoal Creek. Their intake is about 25 miles upstream of the stream gage above Joplin. Neosho takes an average of 1.6 MGD from Shoal Creek.

Joplin has no facility for storing raw water off channel.

Annual precipitation amounts for most of Missouri have been increasing. This is shown in the state water plan. The study was recently made for the state by Steve Hue (Former state climatologist at University of Missouri) to update Climate data. Annual rainfall has increased several inches in the last 30 years. **Figure 40.1** illustrates the annual precipitation and trend for Joplin. This station shows the trend in annual precipitation increasing from 35 inches to 50 inches, an increase of 42% for the years 1950 through 2000.

Figures 40.2.a and 40.2.b show the effect of increased annual rainfall on runoff. The trend indicates an increase in total annual runoff from 12.5 inches to 19 inches or approximately 52% from 1950 to year 2000. These two figures are displayed in terms of watershed inches and also cubic feet per second.

The drought of record was in the 1950's. Non-excedence probabilities for the 1%, 2% and 4% chance flows in **figure 40.7** are compared to actual stream flow records in **figures 40.3.a through 40.3.d** for the drought of record (1953 through 1956). All flows exceeded 7-day Q-10 flow for these years except August 1954, when mean flow fell to 37 cfs or 57.2 million gallons per day.

Figure 40.3.a compares 1953 mean monthly flow to monthly probability shown in figure 7.
Figure 40.3.b compares 1954 mean monthly flow to monthly probability shown in figure 7.
Figure 40.3.c compares 1955 mean monthly flow to monthly probability shown in figure 7.
Figure 40.3.d compares 1956 mean monthly flow to monthly probability shown in figure 7.

Base flow separation was made using the USGS computer program, HYSEP. HYSEP separates the base flow hydrograph from the total hydrograph. This analysis was made to estimate sustained flow, in order to establish availability of continuous stream flow. **Figure 40.4.a** is the base flow index and is the ratio of base flow to total stream flow. This chart shows the yearly fluctuation in base flow indexes and indicates the trend. The trend has increased from 26% of total runoff in 1955 to 38% in 2000. About 50 percent increase. **Figure 40.4.b** displays volume of base flow in terms of watershed inches of runoff. **Figure 40.4.c** shows the base flow in terms of mean cfs. The trend shows the mean base flow to be about 450 cfs or 696 million gallons per day for year 2000.

To determine the rate of flow needed to meet in-stream flow requirements, the 7-day Q-10 low flow was determined using the period of record, 1950 through 2000. **Figure 40.5** shows the results of the frequency analysis to be 43 cfs. For purposes of pumping from the creek, discharge needed to exceed 43 cfs.

Mean seven-day annual low flows for 1942 through 2000 were calculated and are shown in **figure 40.6.** The lowest 7-day discharge occurred September 1954 with a mean value of 16 cfs.

Monthly non-excedence probabilities (low flows) for 1% chance of occurrence (1 time in 100 years), 2% chance (1 time in 50 years) and 4% chance (1 time in 25 years) were established from stream flow data for the years 1951 through 2000. **Figure 40.7** displays these results. The mean monthly flows for the 1% chance of occurrence are equal to, or slightly below the 7-day 10-year frequency low flow (43 cfs or 66.5 million gallons per day) for 7 months. The months are January, through March, August and October through December. The remaining months exceed 7-day Q-10 flows. The 2% and 4% flows exceed the 7-day Q-10 for all months. For this report, all statistical determinations were made using the Log Pearson type 3 method as described in Water Resource Council bulletin 17B.

Figure 40.8.a shows low flow not expected to be less than, or non-excedence probability for the 1% chance of low flow compared to the flow needed to meet demand. This indicates that eight months out of the year stream flow is adequate for pumping and allowing the 7-day 10-year frequency discharge to pass down stream. **Figure 40.8.b** is the two percent chance of occurrence and indicates only 2 months, November and December, are close to the minimum but probably would allow pumping. **Figure 40.8.c** shows that the 4% chance of occurring is able to provide enough flow so that there is only a very small deficit in November. **Figures 40.8.d and 40.8.e** display the deficits in bar charts, one showing the deficit in acre-feet and the other in terms of cfs.

The following shows the average daily and yearly water withdrawal from Shoal Creek, at Joplin, for the period 1995 through 2002. Usage has been fairly constant. Daily data for this time period was submitted by the "Missouri-American Water Company" and can be observed in file "Shoal Creek pumpage.xls".

Year	Daily Withdrawal	Yearly Withdrawal
1995	0.467 MGD	3,453.290 million gallon
1996	10.916 MGD	3,995.330 million gallon
1997	10.650 MGD	3,878.840 million gallon
1998	12.068 MGD	4,406.896 million gallon
1999	11.207 MGD	4,090.036 million gallon
2000	10.990 MGD	4,024.792 million gallon
2001	10.608 MGD	3,876.281 million gallon
2002	10.825 MGD	3,957.166 million gallon

Figure 40.9 shows the trend in annual water withdrawal for Joplin, from Shoal Creek, is slowly increasing from 10.6 million gallon per day in 1995 to 11.2 million gallon in 2002. A 5.5 percent increase. This figure also shows the volume of water that is used from wells to be about 1 MGD to supplement Shoal Creek withdrawal.

Neosho also obtains their water supply from Shoal Creek. Their intake point is about 25 miles upstream of Joplin. Their remaining needs, not met by Shoal Creek, are obtained from wells. Following are the average daily and yearly water withdrawal, from Shoal Creek, for Neosho for the period 1997 through 2001. Monthly data for this time period was obtained from the "Missouri Major Water Users Unit" of Missouri Department of Natural Resources. Because Neosho is located upstream of the Joplin stream gage, this withdrawal is accounted for in the analysis of stream flow data.

Neosho water use from Shoal Creek.

Year	Daily Withdrawal	Yearly Withdrawal
1997	1.220 MGD	445.335 million gallon

1998	1.233 MGD	499.965 million gallon
1999	1.617 MGD	590.220 million gallon
2000	1.916 MGD	699.344 million gallon
2001	1.943 MGD	709.376 million gallon

Additional comparisons for the 1950's drought were made at the Joplin intake point using the mean 7-day low flow for examination of a shorter duration. These comparisons are shown in **figures 40.10.a, 40.10.b, 40.10.c and 40.10.d**. These figures indicate short-term (7-day duration) mean low flows during the drought of record, by months, for years 1953, 1954, 1955 and 1956. For 1953, September and October, flows nearly equaled 43 cfs (7-day Q-10 flow). In 1954, the driest year on record, June through September mean flows were below 43 cfs. In 1955 and 1956 all mean flows were at or above 43 cfs except for October 1956 when mean flow was 39 cfs.

JOPLIN, MISSOURI
Water Supply Study

Wells

Deep wells in this region are in the Ozark aquifer. Because of the increasing demand in the area, it is becoming harder for this aquifer to meet the needs. A ground water study has been made for the region by "WHPA". Titled "Community Data Report, Source of Supply Investigation for Southwestern Missouri". It is available on the Internet at www.wittmanhydro.com.

This report describes wells in the region and associated problems.
Following is information on wells and withdrawal rates that are reported for each city. These are:

Carl Junction, Mo. has 7 wells with 6 currently in use and plan to drill 2 more.
In 2000 they pumped 201.5 million gallon, an increase of 37% since 1987.

Carterville, Mo. has one well and yielded 74 million-gallon in 2001, an increase of 16% since 1994.

Carthage, Mo. has 17 wells of which 16 are currently being used. In year 2000, there were 1,126 million gallons were pumped, an increase of 39% since 1987.

Duenweg, Mo. has 2 wells in use pumping 41 million gallons per year. The demand has increased 18% since 1987.

Jasper rural water district number one has one well and pumped 60 million-gallon per year in 2001. Two additional wells are planned.

Neosho, Mo. has 5 wells that pump 429 million gallons per year in year 2000, an increase of 28% since 1997, when they began pumping from wells.

Oronogo, Mo. has two wells that pump a combined amount or 45 million-gallon, an increase of 81% from 1990 to 2000.

Pittsburg Ks. has 4 wells and pump about 1,000 million gallons annually with very little change in demand.

Webb City Mo. has 13 wells with only 7 in use. They are pumping 400 million gallons per year.

Not found in the summary report is the Joplin well usage.
Joplin has 6 wells to supplement their water supply from Shoal Creek. The combined annual pumping rates for 1996 through 2002 are listed below. Monthly values are available and may be observed in file "well_pumpage.xls".

JOPLIN, MISSOURI, Water Supply
Drought Study

Year	Yearly Withdrawal
1996	143.366 million gallons
1997	176.914 million gallons
1998	140.504 million gallons
1999	201.697 million gallons
2000	342.766 million gallons
2001	244.248 million gallons
2002	431.388 million gallons

Conclusion:

Because of the many springs in the drainage area of Shoal Creek, the mean monthly minimum flows were never depleted. The minimum low flow for the period of record was 16 cfs in August and September of 1954. This low flow stayed below 20 cfs for 14 days in succession. For the period 1979 through 2000, the minimum mean daily low flow was 30 cfs in 1981 and was below 55 cfs for 2 days. These two times are the only times flow was below the 7-day Q-10 low flow for the period of record.

Joplin's water demand has increased during the period 1995 through 2002 at a rate of 0.20 MGD or 1.9% per year.

The 7-day 10-year frequency discharge of 43 cfs exceeded the 1% chance or 1 year in 100 years, low flows for seven months, mean monthly Shoal Creek discharges were between 2 and 5 cfs less. These months are January, February, March, August, October, November and December. For the 2% chance or 1 year in 50 years, all monthly mean flows exceeded the 7-day Q-10 flows.

During the 1950's there were no months that flow in Shoal Creek would not allow pumping for at least some of the month. However there would be shorter periods of time flows would be too low for pumping. This is indicated by the 7-day low mean discharge values for 1953, 1954, 1955 and 1956. Each year had mean 7-day duration flows below pumping range.

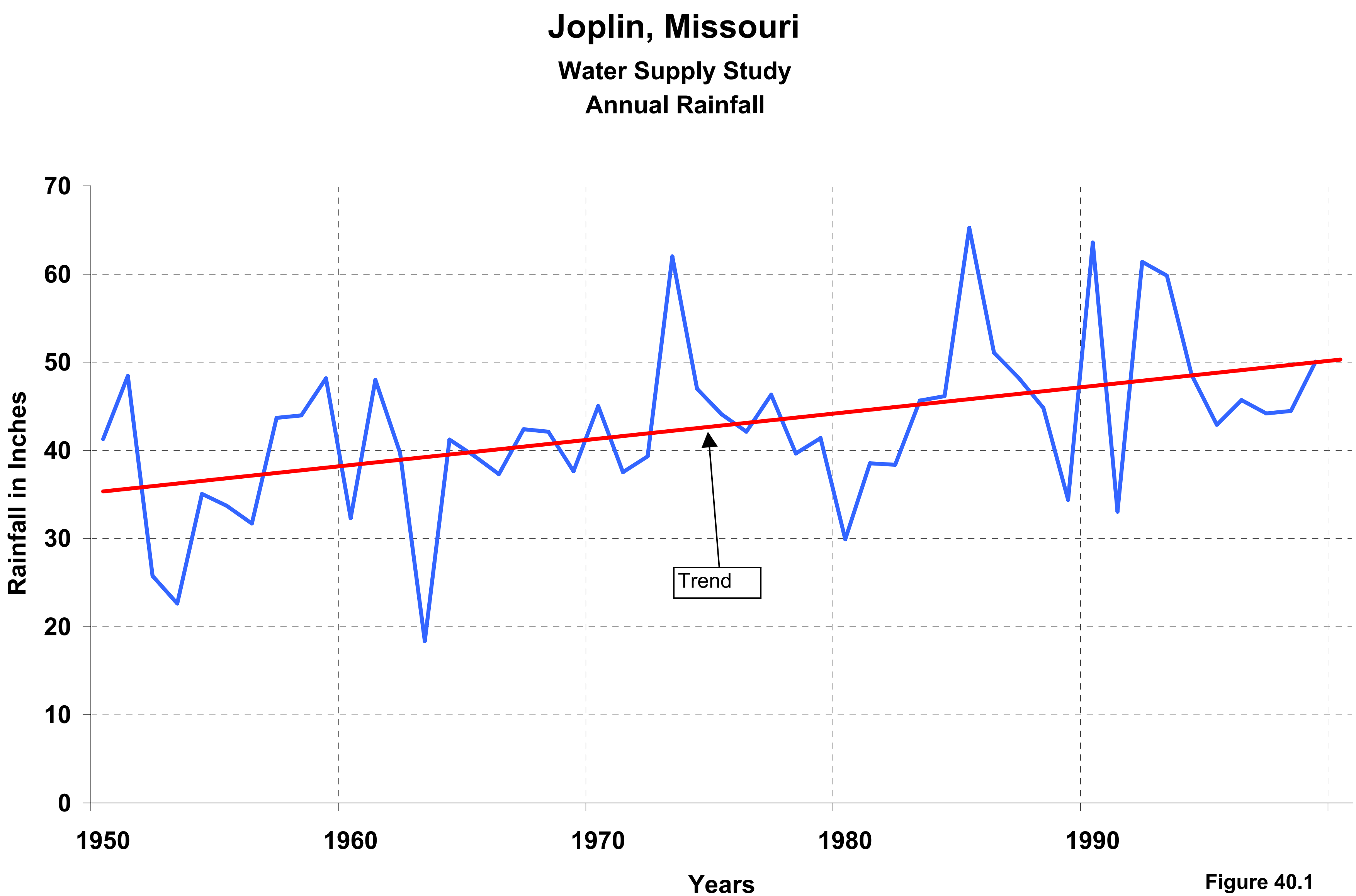
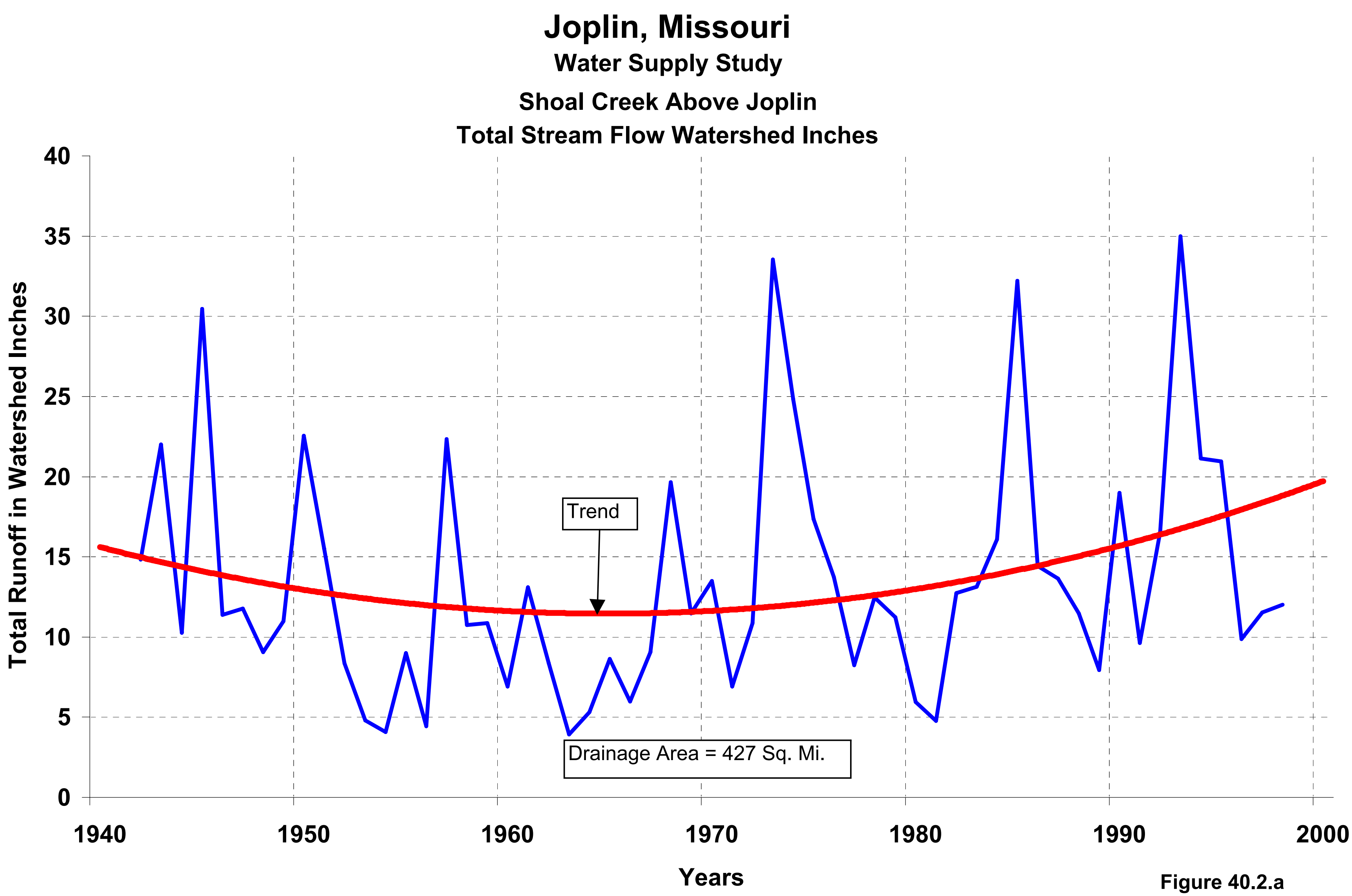
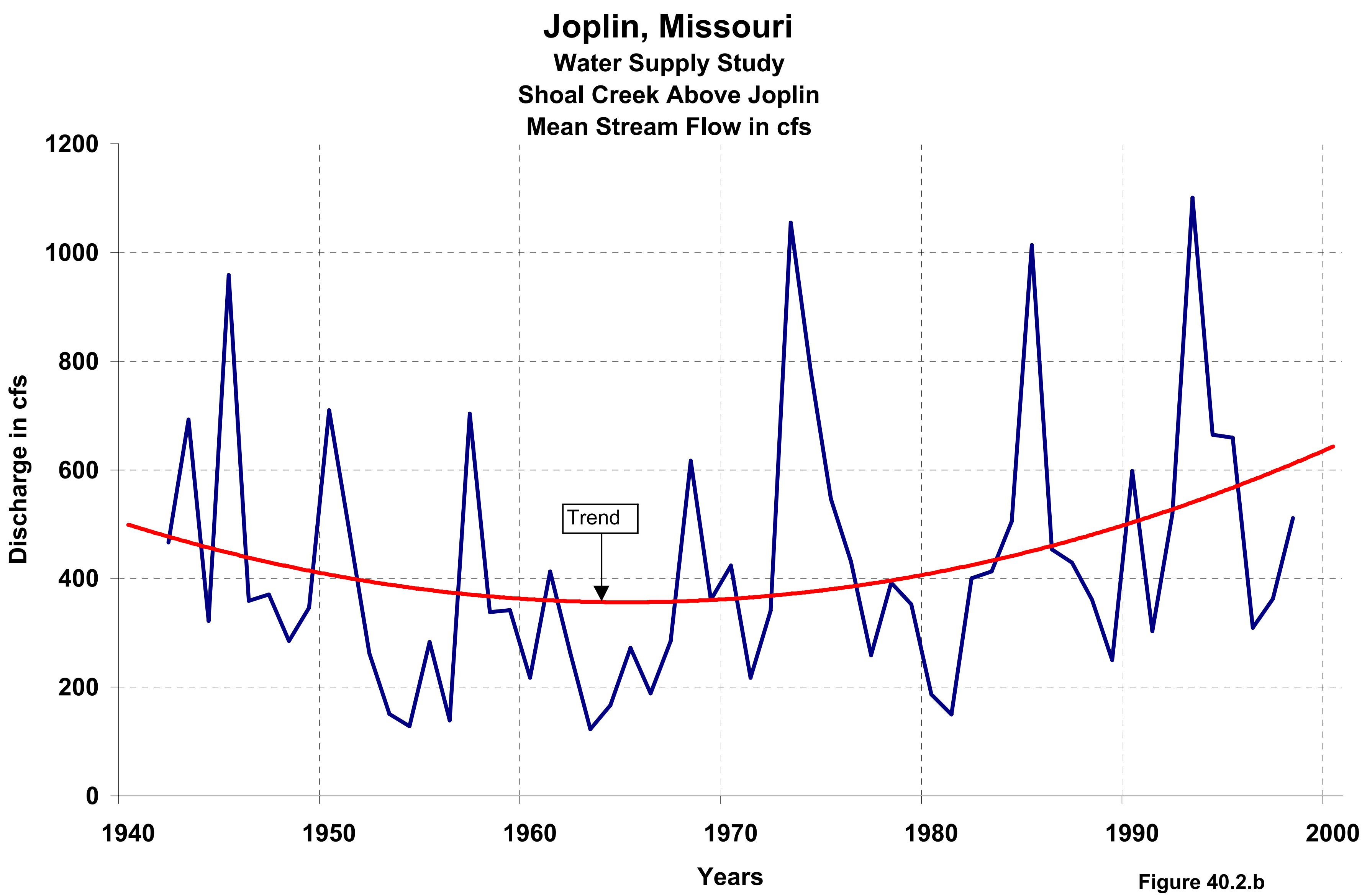

Joplin, Missouri
Water Supply Study
Annual Rainfall
Rainfall in Inches
70
60
50
40
30
20
10
0
Trend
1950
1960
1970
1980
1990
Years

Figure 40.1



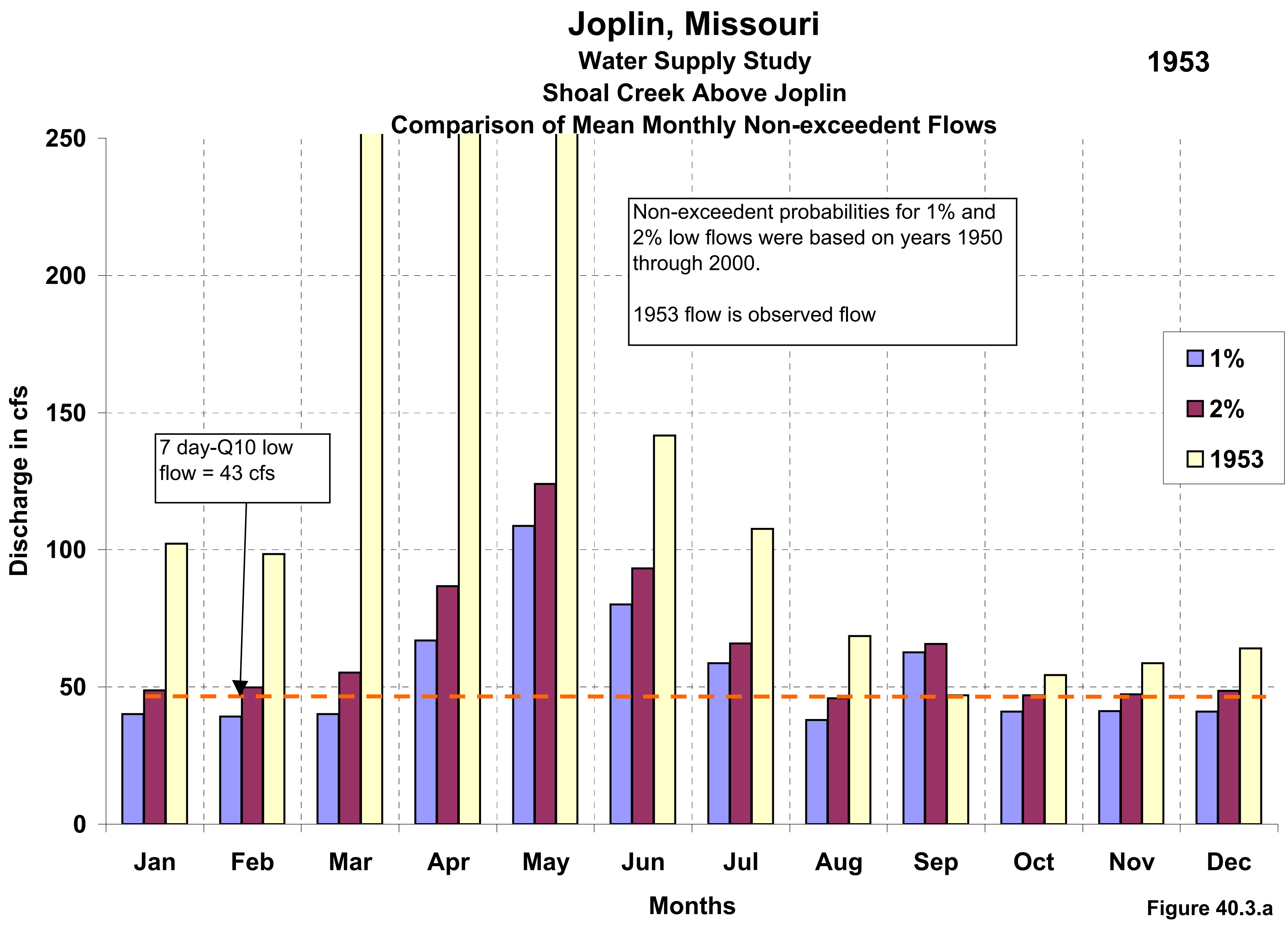
Joplin, Missouri
Water Supply Study
Shoal Creek Above Joplin
Total Stream Flow Watershed Inches
Total Runoff in Watershed Inches
0
5
10
15
20
25
30
35
40
1940
1950
1960
1970
1980
1990
2000
Years
Trend
Drainage Area = 427 Sq. Mi.

Figure 40.2.a



Joplin, Missouri
Water Supply Study
Shoal Creek Above Joplin
Mean Stream Flow in cfs
Discharge in cfs
0
200
400
600
800
1000
1200
1940
1950
1960
1970
1980
1990
2000
Years
Trend

Figure 40.2.b



Joplin, Missouri
Water Supply Study
Shoal Creek Above Joplin
Comparison of Mean Monthly Non-exceedent Flows
1953
Discharge in cfs
250
200
150
100
50
0
7 day-Q10 low
flow = 43 cfs
Non-exceedent probabilities for 1% and 2% low flows were based on years 1950 through 2000.
1953 flow is observed flow
1%
2%
1953
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Months

Figure 40.3.a

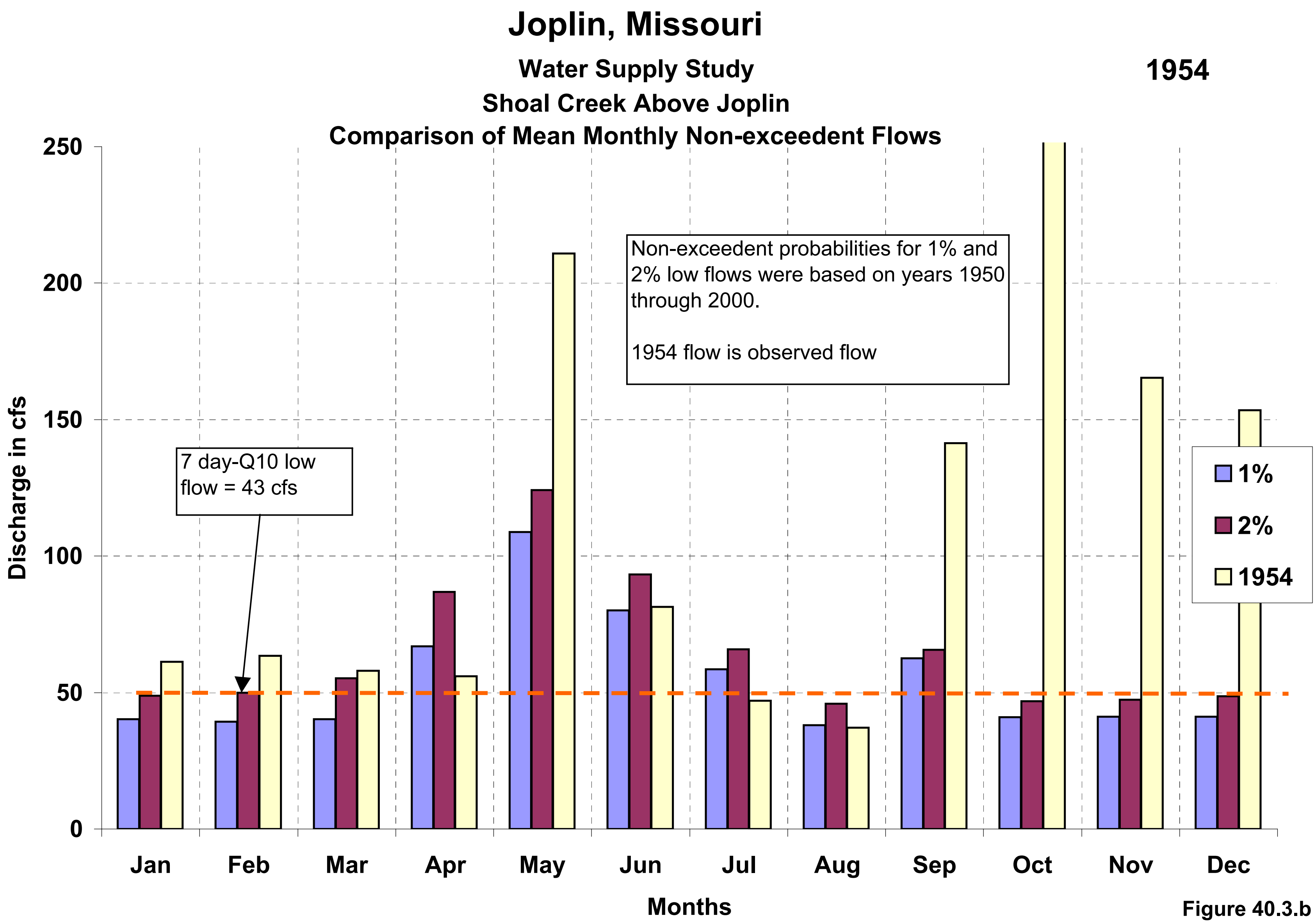

Joplin, Missouri
Water Supply Study
Shoal Creek Above Joplin
Comparison of Mean Monthly Non-exceedent Flows
1954
Discharge in cfs
0
50
100
150
200
250
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Months
7 day-Q10 low flow = 43 cfs
Non-exceedent probabilities for 1% and 2% low flows were based on years 1950 through 2000.
1954 flow is observed flow
1%
2%
1954

Figure 40.3.b

Joplin, Missouri

Water Supply Study

Shoal Creek Above Joplin

Comparison of Mean Monthly Non-exceedent Flows

1955

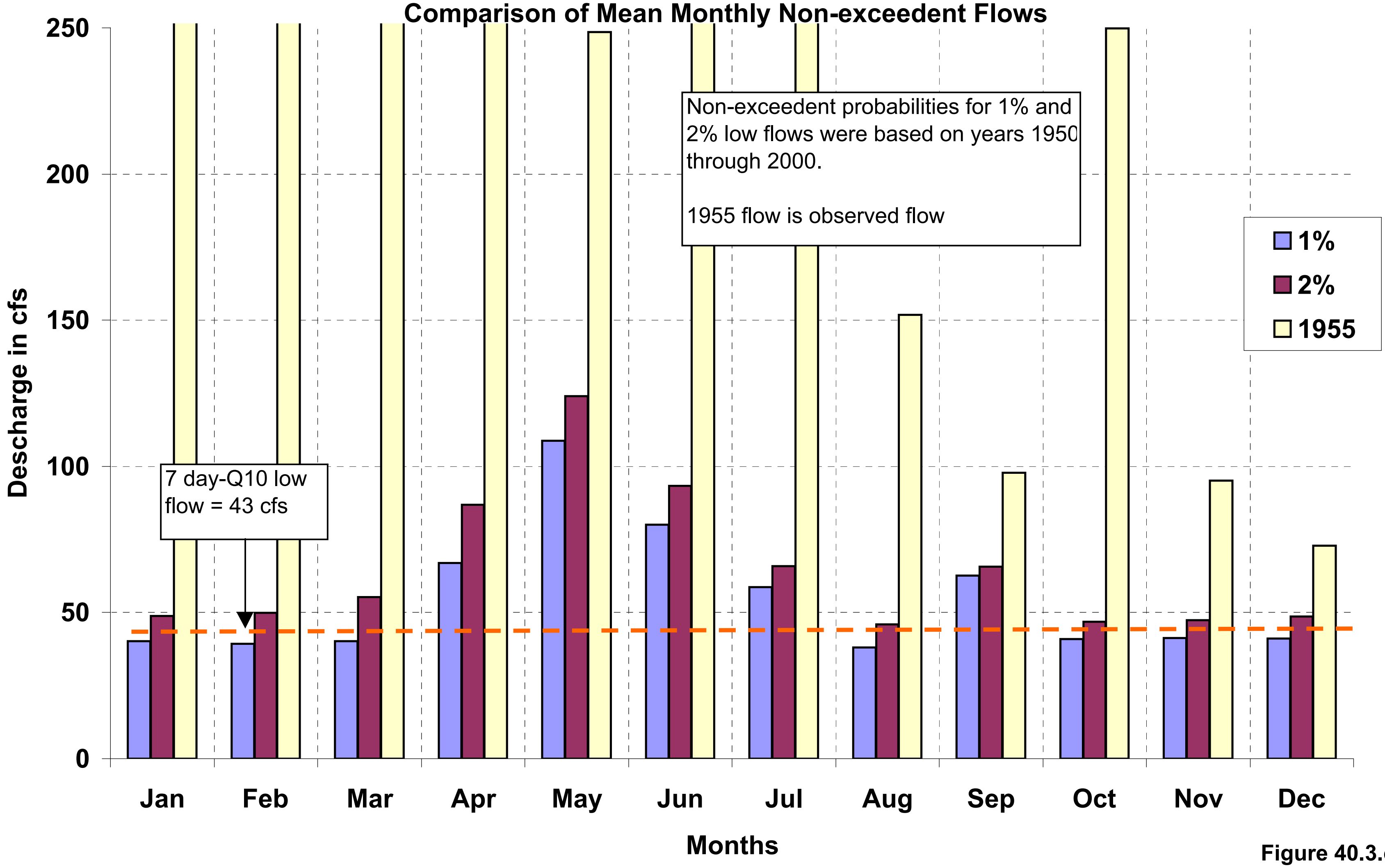
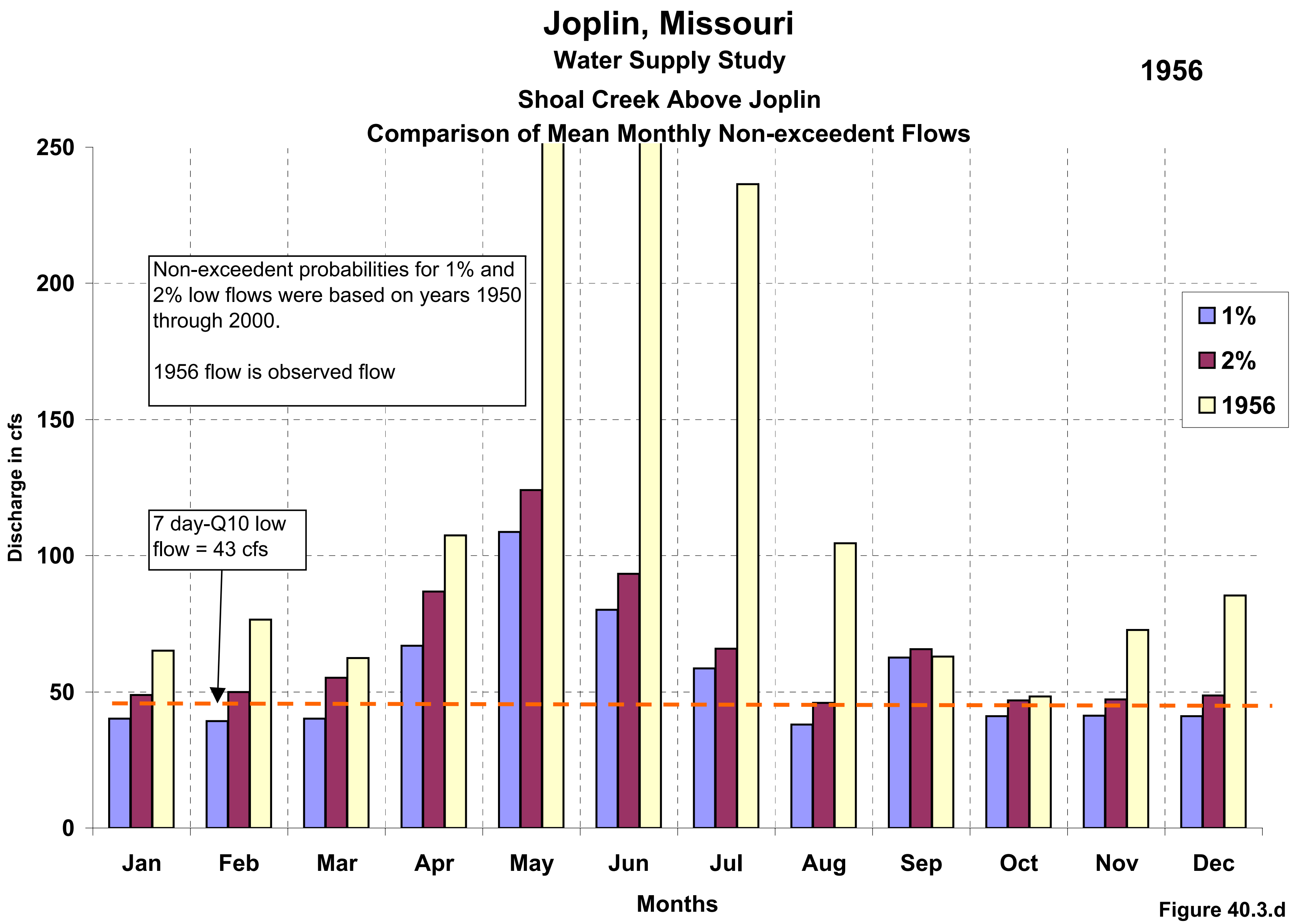
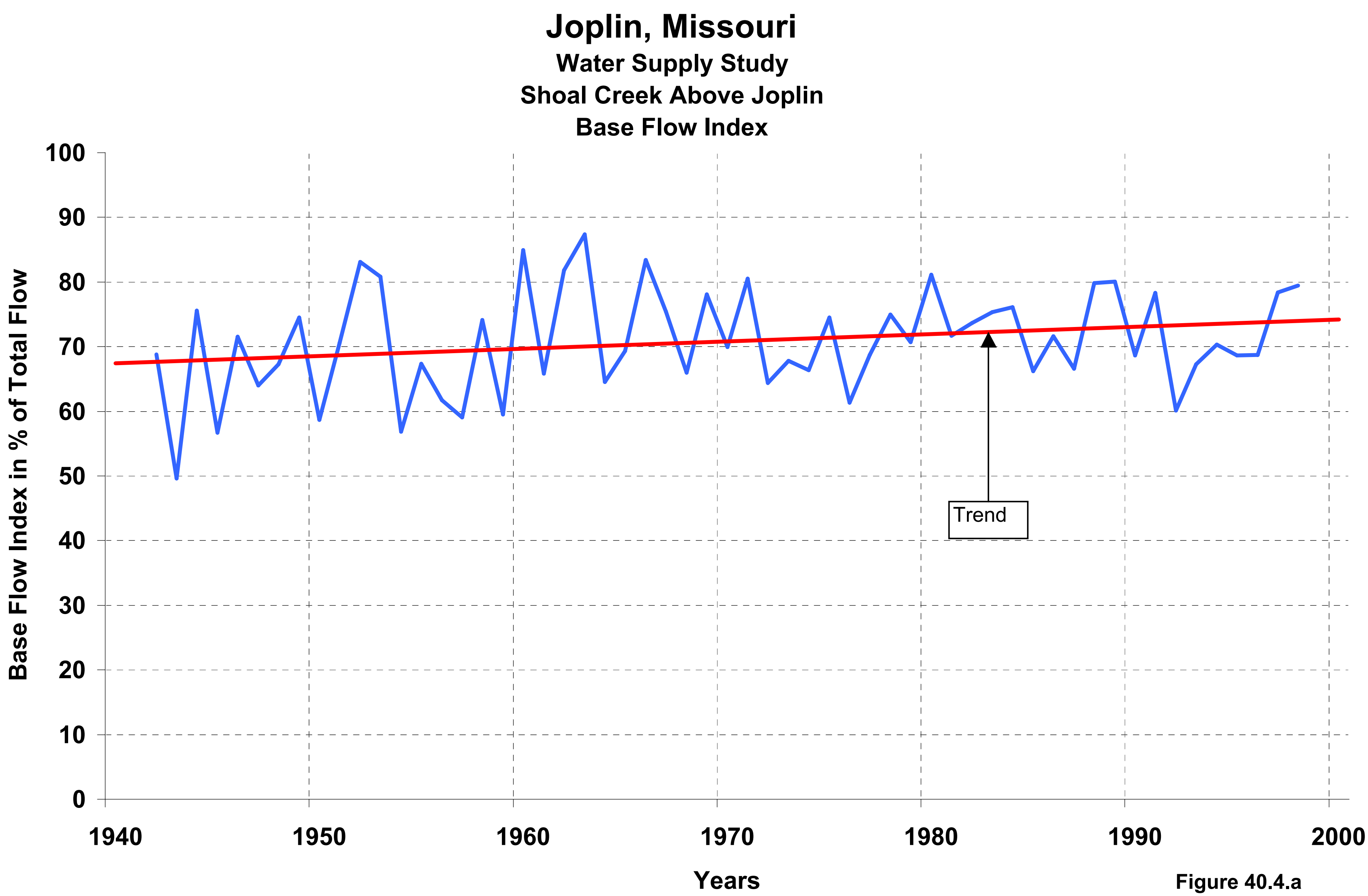


Figure 40.3.c



Joplin, Missouri
Water Supply Study
1956
Shoal Creek Above Joplin
Comparison of Mean Monthly Non-exceedent Flows
Non-exceedent probabilities for 1% and 2% low flows were based on years 1950 through 2000.
1956 flow is observed flow
7 day-Q10 low flow = 43 cfs
1%
2%
1956
Discharge in cfs
0
50
100
150
200
250
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Months

Figure 40.3.d



Joplin, Missouri
Water Supply Study
Shoal Creek Above Joplin
Base Flow Index
Base Flow Index in % of Total Flow
100
90
80
70
60
50
40
30
20
10
0
1940
1950
1960
1970
1980
1990
2000
Years
Trend

Figure 40.4.a

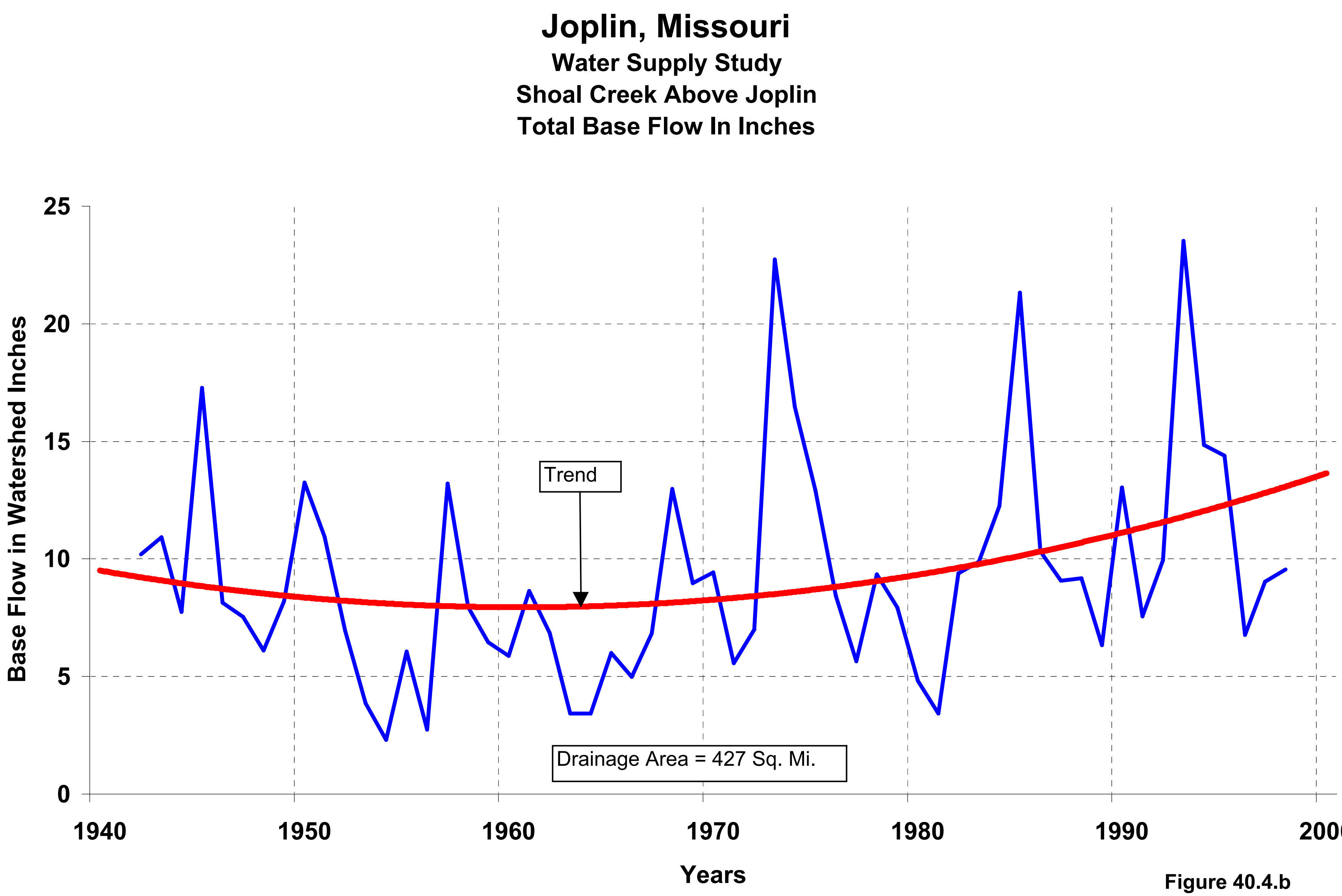
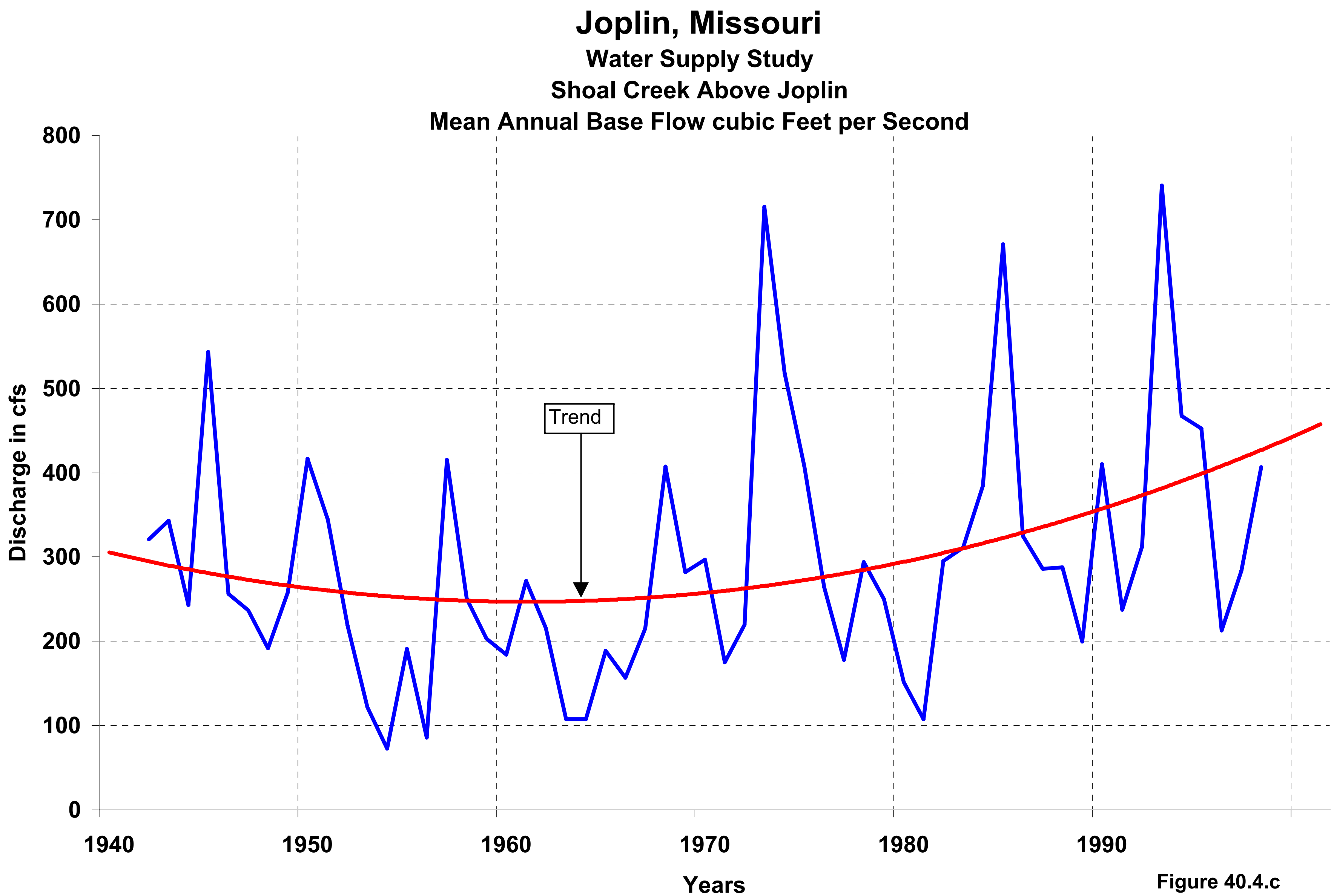
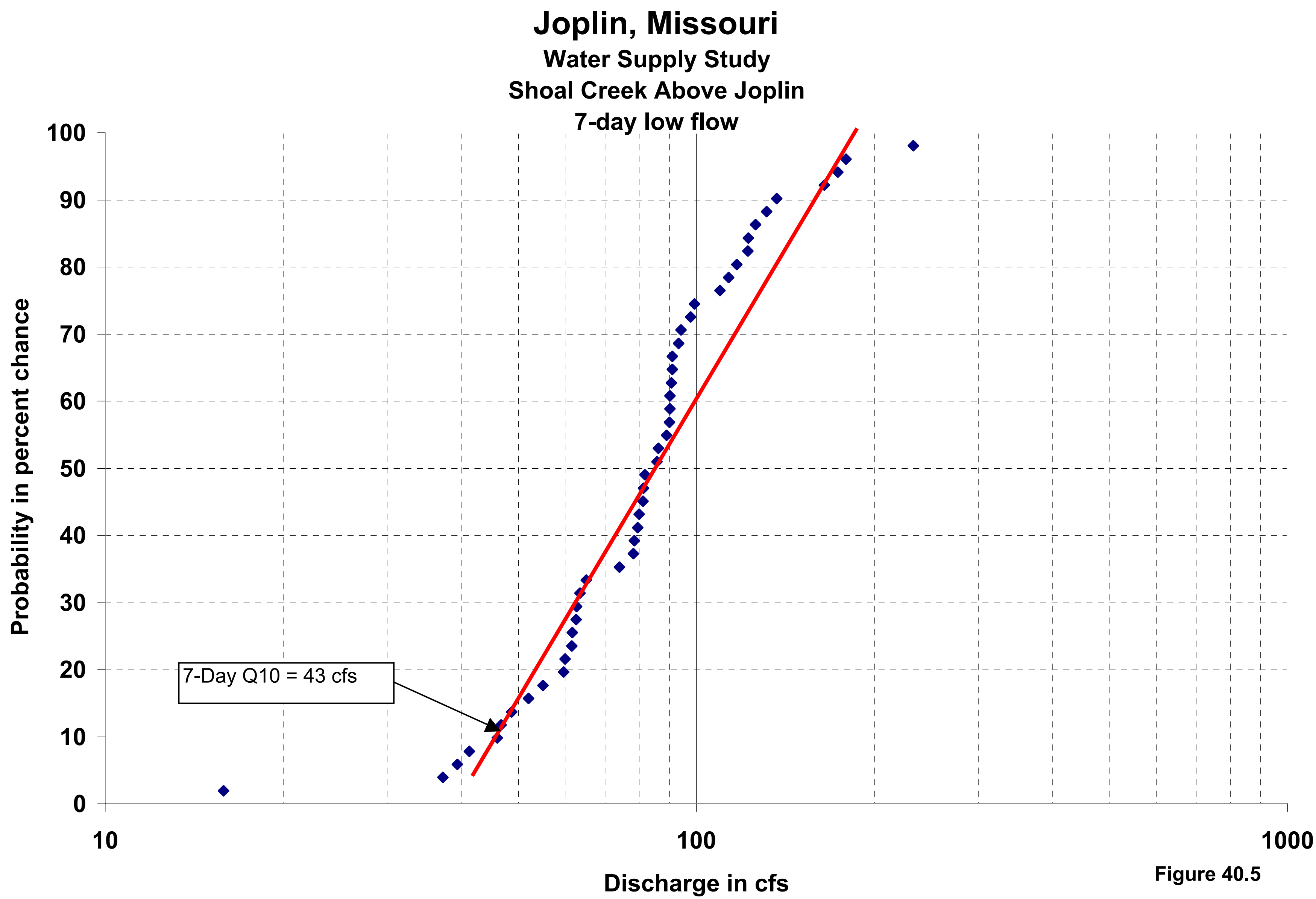

Joplin, Missouri
Water Supply Study
Shoal Creek Above Joplin
Total Base Flow In Inches
Base Flow in Watershed Inches
0
5
10
15
20
25
1940
1950
1960
1970
1980
1990
2000
Years
Trend
Drainage Area = 427 Sq. Mi.

Figure 40.4.b



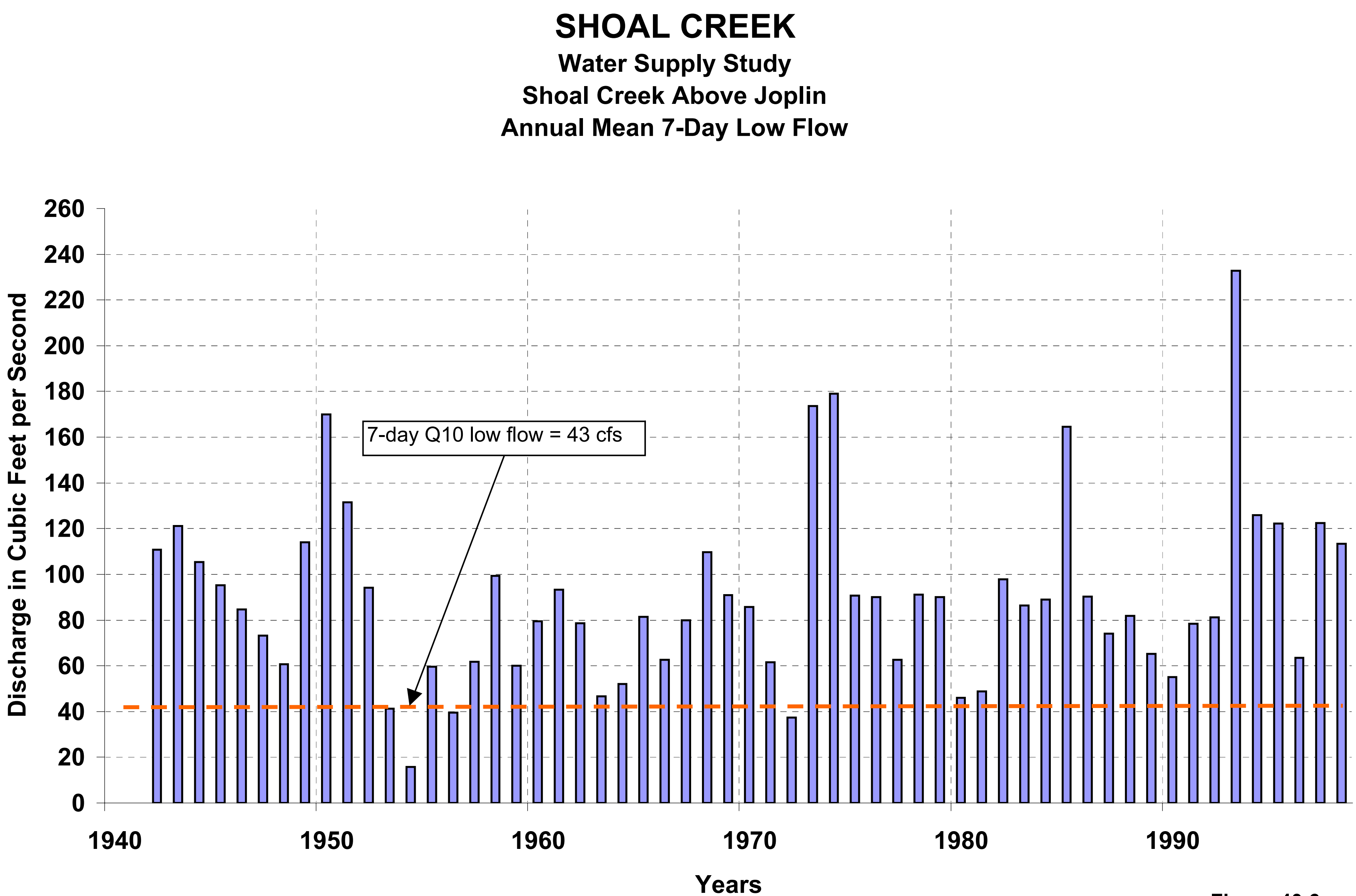
Joplin, Missouri
Water Supply Study
Shoal Creek Above Joplin
Mean Annual Base Flow cubic Feet per Second
Discharge in cfs
0
100
200
300
400
500
600
700
800
1940
1950
1960
1970
1980
1990
Years
Trend

Figure 40.4.c



Joplin, Missouri
Water Supply Study
Shoal Creek Above Joplin
7-day low flow
Probability in percent chance
100
90
80
70
60
50
40
30
20
10
0
10
100
1000
Discharge in cfs
7-Day Q10 = 43 cfs

Figure 40.5



SHOAL CREEK
Water Supply Study
Shoal Creek Above Joplin
Annual Mean 7-Day Low Flow
Discharge in Cubic Feet per Second
260
240
220
200
180
160
140
120
100
80
60
40
20
0
7-day Q10 low flow = 43 cfs
1940
1950
1960
1970
1980
1990
Years

Figure 40.6

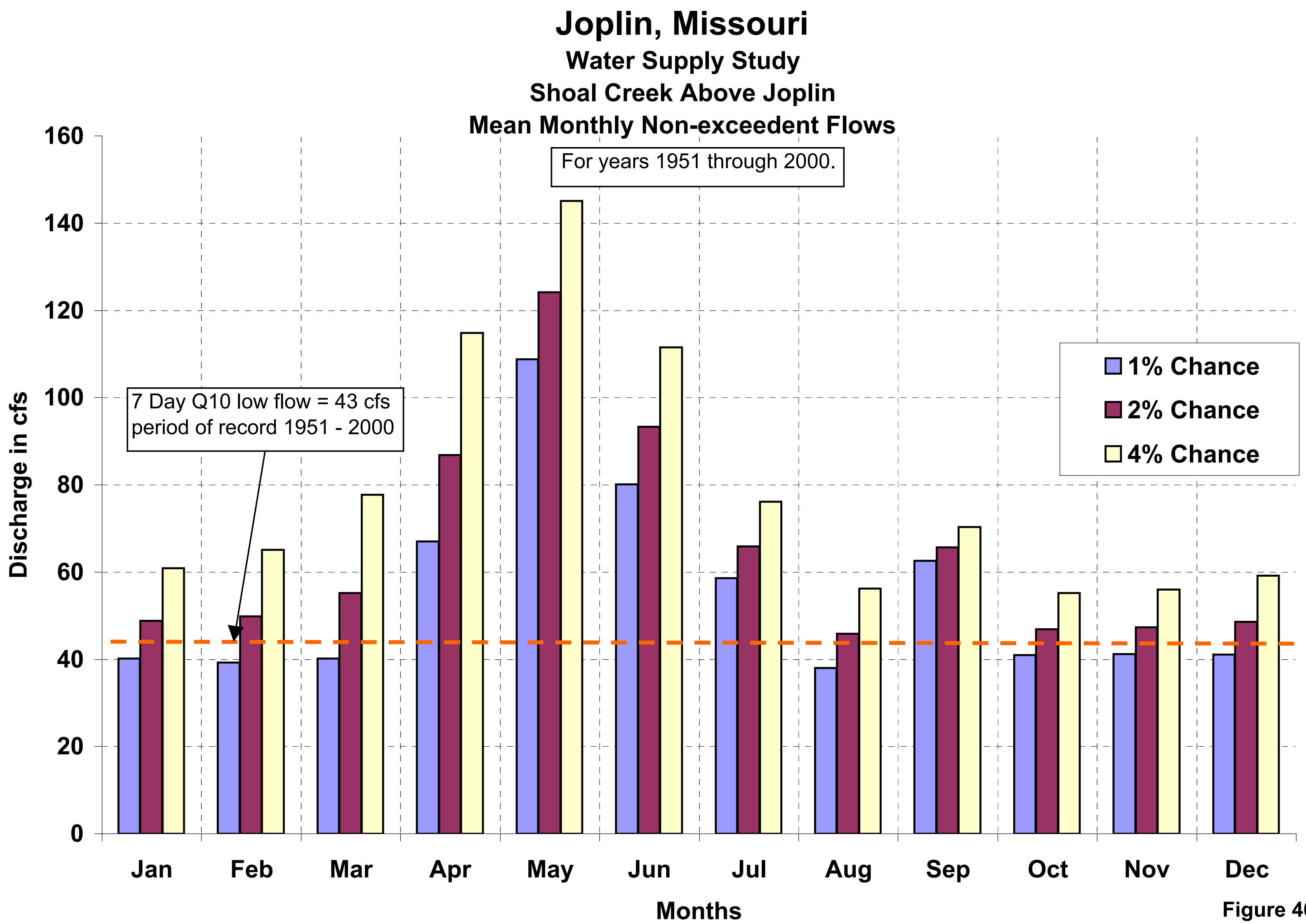
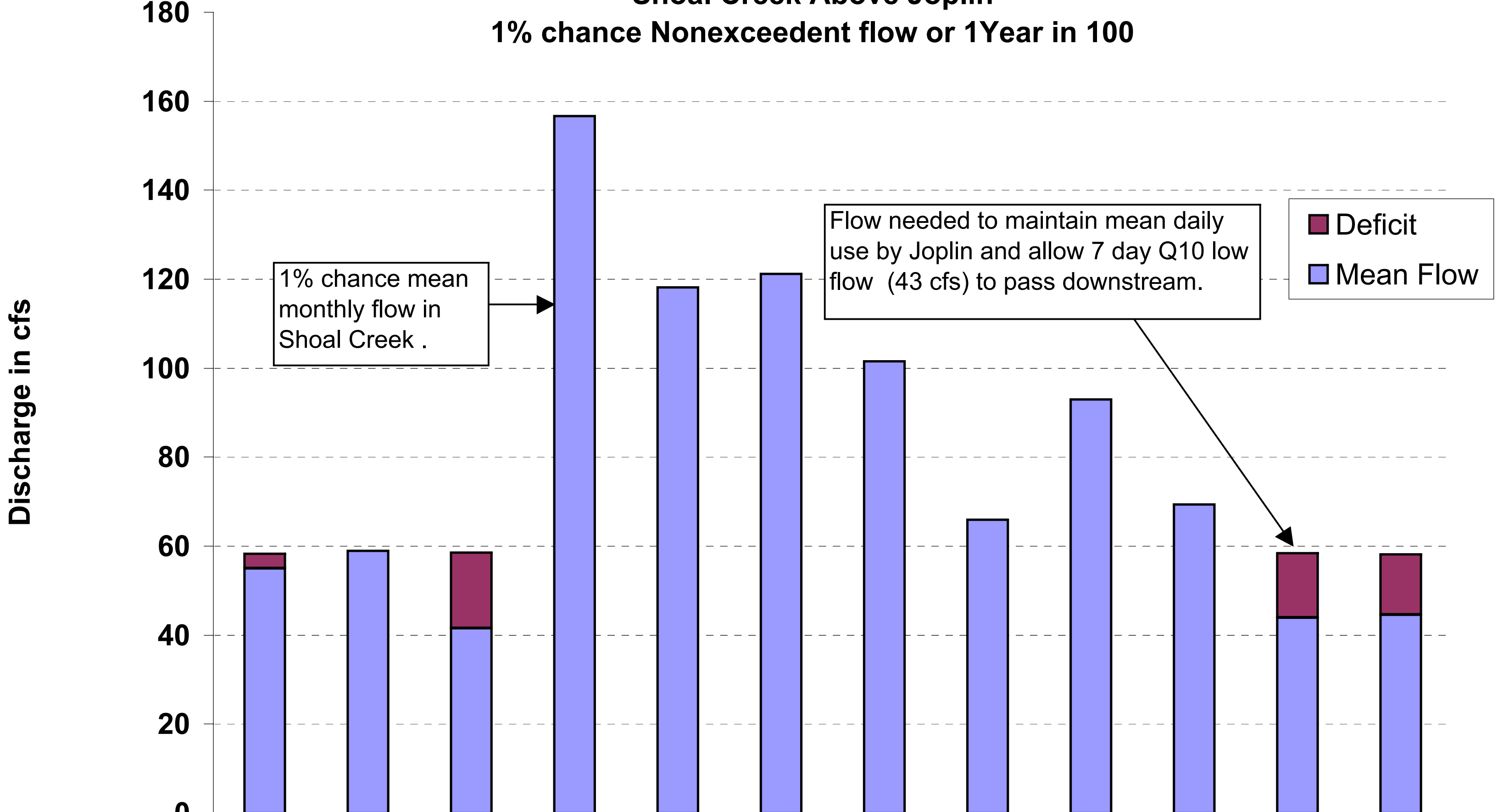

Joplin, Missouri
Water Supply Study
Shoal Creek Above Joplin
Mean Monthly Non-exceedent Flows
For years 1951 through 2000.
7 Day Q10 low flow = 43 cfs
period of record 1951 - 2000
1% Chance
2% Chance
4% Chance
Discharge in cfs
160
140
120
100
80
60
40
20
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Months

Figure 40.7

Joplin, Missouri
Water Supply Study
Shoal Creek Above Joplin
1% chance Nonexceedent flow or 1Year in 100

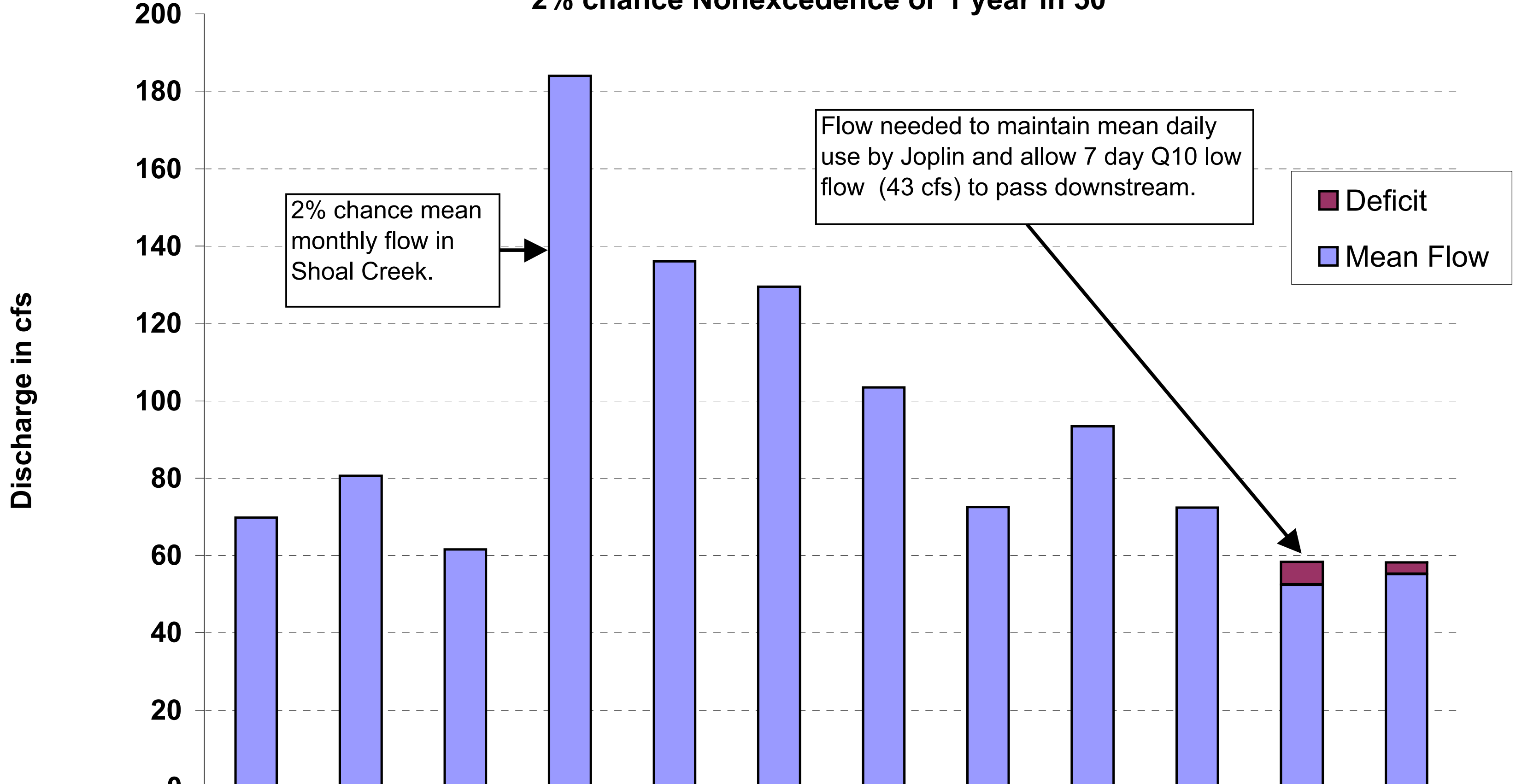


	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Deficit	3.27	0.00	17.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	14.49	13.61
Mean Flow	55	58.9	41.5	156.6	118.1	121.2	101.5	66	93	69.3	43.9	44.6

Months

Figure 40.8.a

Joplin, Missouri
Water Supply Study
Shoal CreekAbove Joplin
2% chance Nonexcedence or 1 year in 50

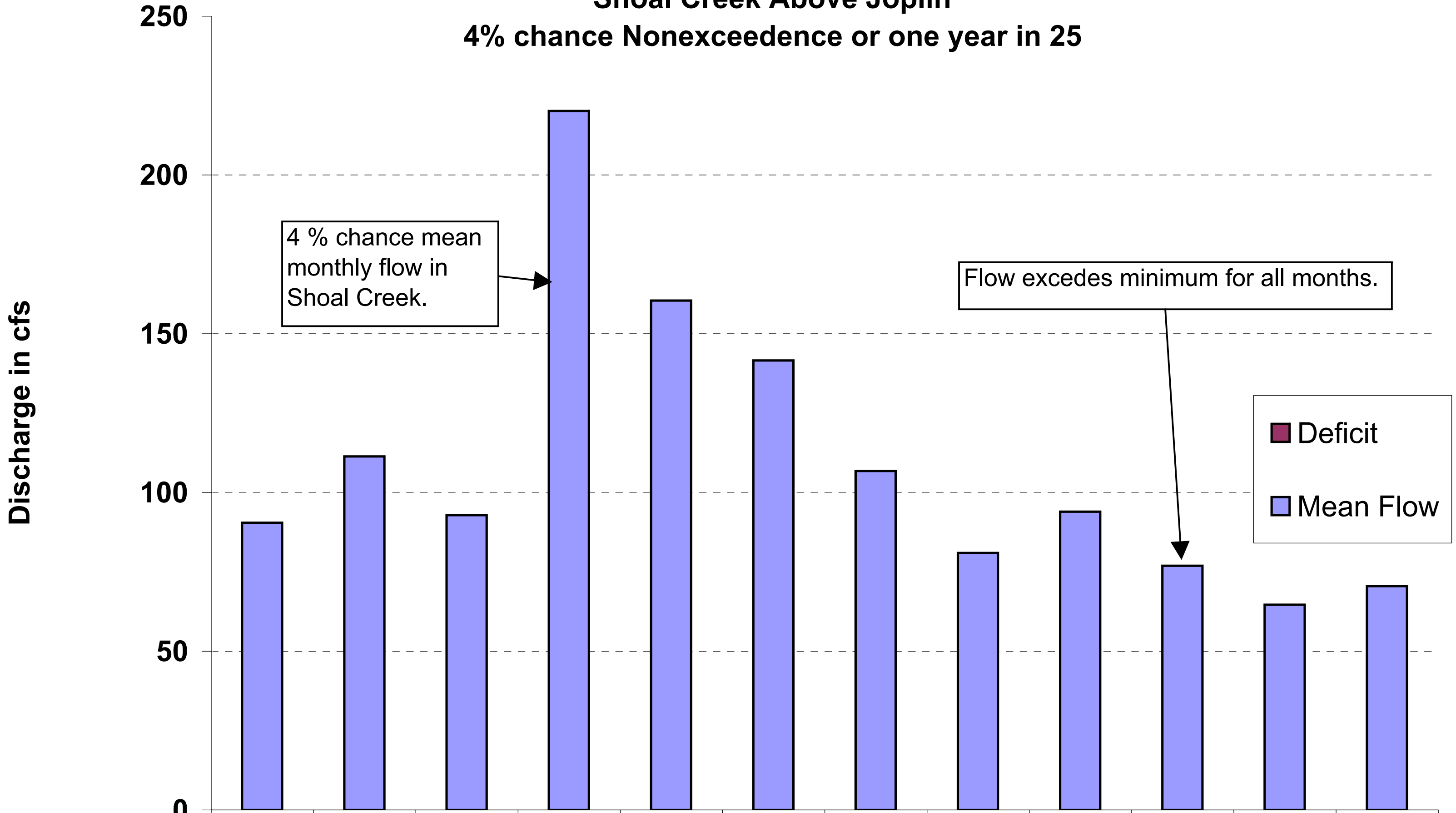


	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Deficit	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.99	3.01
Mean Flow	69.8	80.6	61.6	184	136.1	129.5	103.4	72.5	93.3	72.3	52.4	55.2

Months

Figure 40.8.b

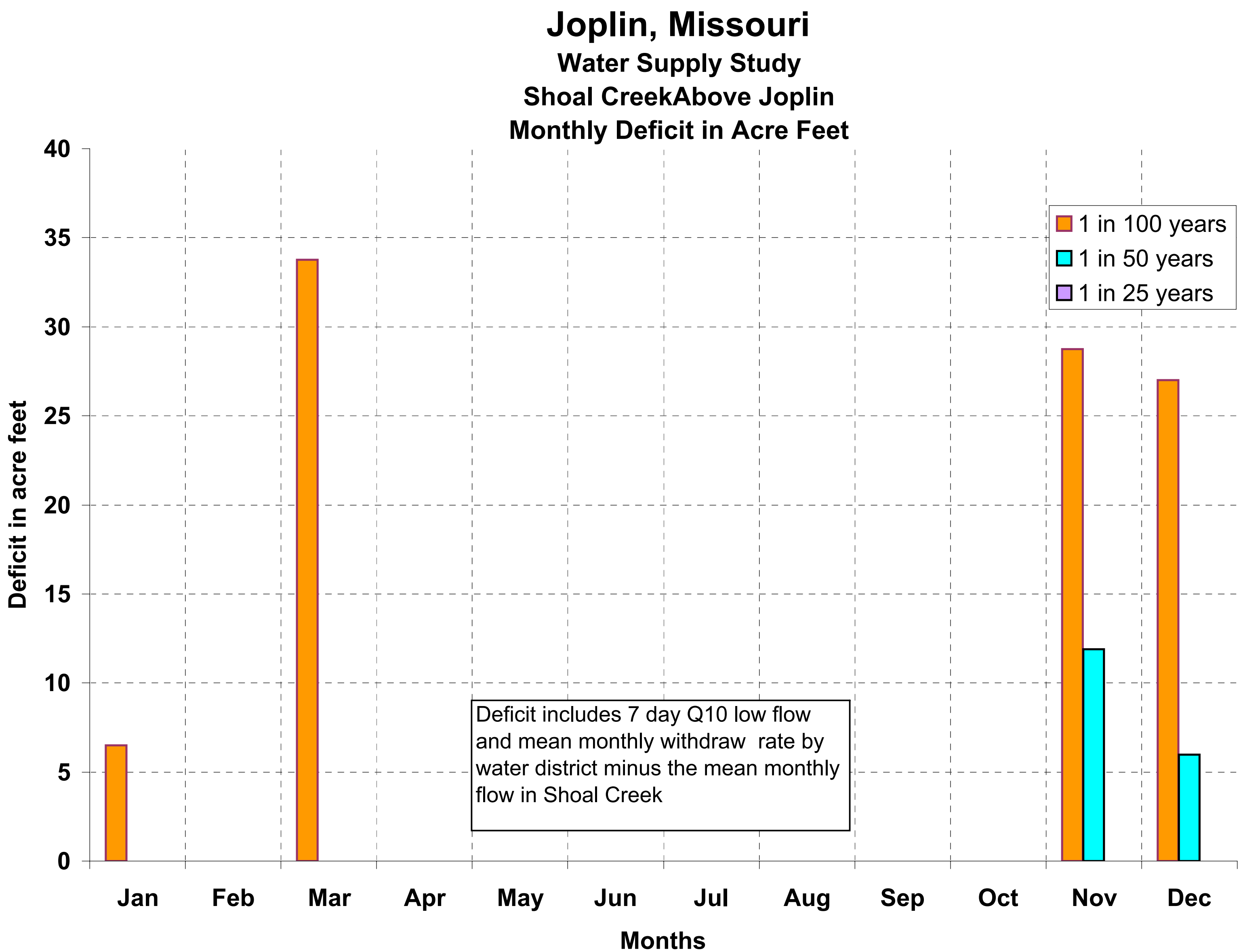
Joplin, Missouri
Water Supply Study
Shoal Creek Above Joplin
4% chance Nonexceedence or one year in 25



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Deficit	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mean Flow	90.4	111.4	92.9	220.1	160.5	141.6	106.7	80.9	94	76.9	64.6	70.6

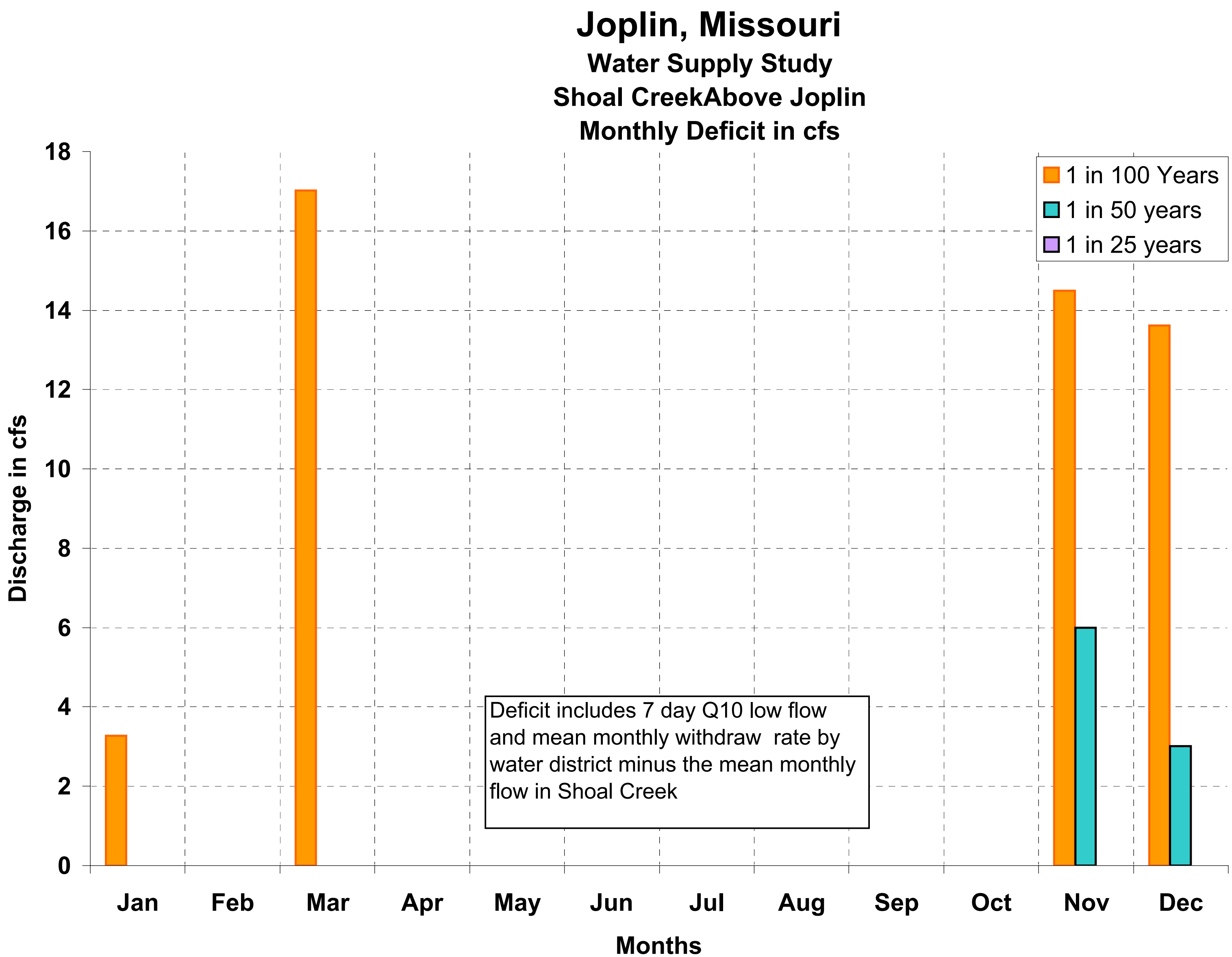
Months

Figure 40.8.c



Joplin, Missouri
Water Supply Study
Shoal CreekAbove Joplin
Monthly Deficit in Acre Feet
Deficit in acre feet
0
5
10
15
20
25
30
35
40
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Months
1 in 100 years
1 in 50 years
1 in 25 years
Deficit includes 7 day Q10 low flow and mean monthly withdraw rate by water district minus the mean monthly flow in Shoal Creek

Figure 40.8.d



Joplin, Missouri
Water Supply Study
Shoal CreekAbove Joplin
Monthly Deficit in cfs
Discharge in cfs
0
2
4
6
8
10
12
14
16
18
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Months
1 in 100 Years
1 in 50 years
1 in 25 years
Deficit includes 7 day Q10 low flow and mean monthly withdraw rate by water district minus the mean monthly flow in Shoal Creek

Figure 40.8.e

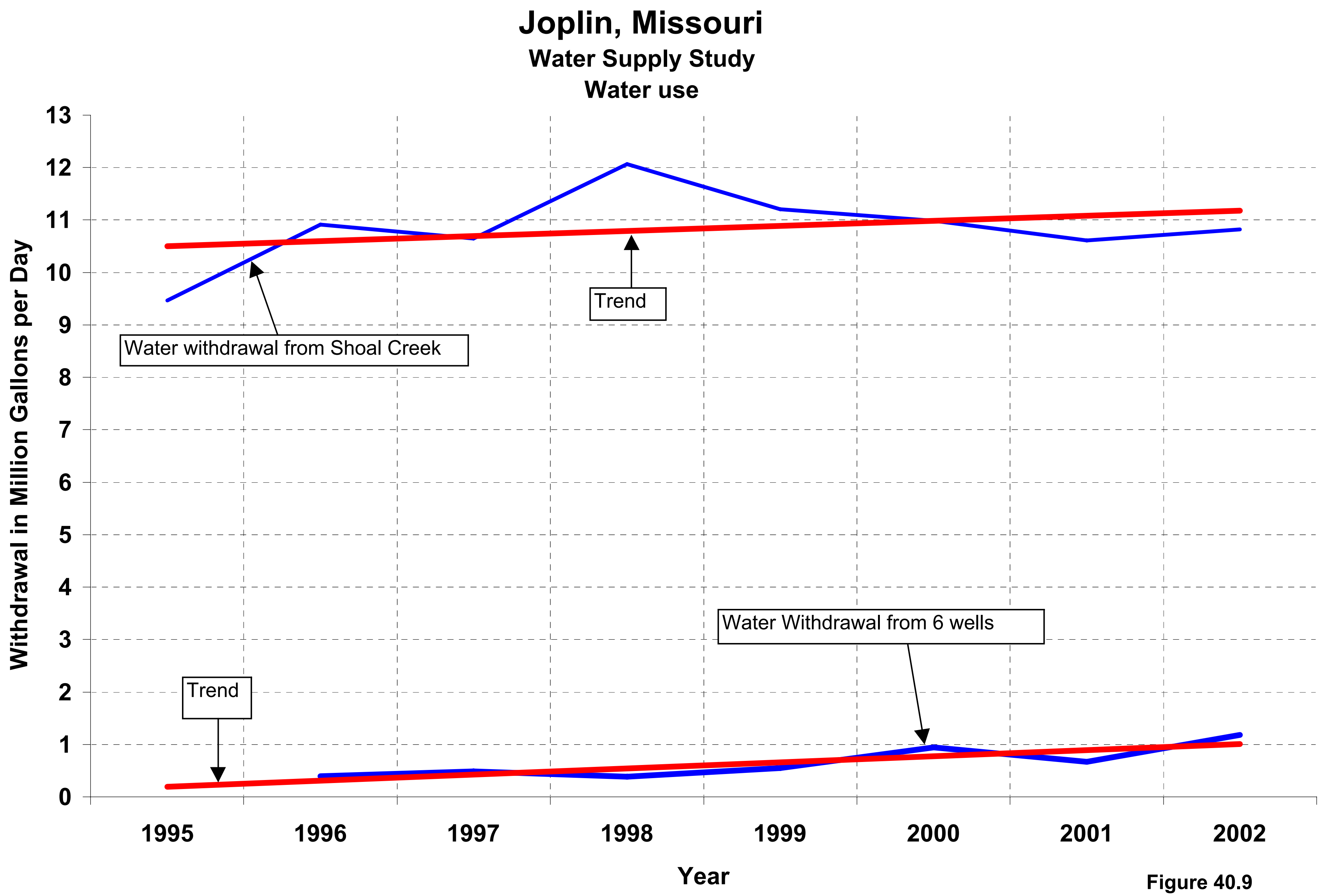

Joplin, Missouri
Water Supply Study
Water use
Withdrawal in Million Gallons per Day
13
12
11
10
9
8
7
6
5
4
3
2
1
0
Water withdrawal from Shoal Creek
Trend
Water Withdrawal from 6 wells
Trend
1995
1996
1997
1998
1999
2000
2001
2002
Year

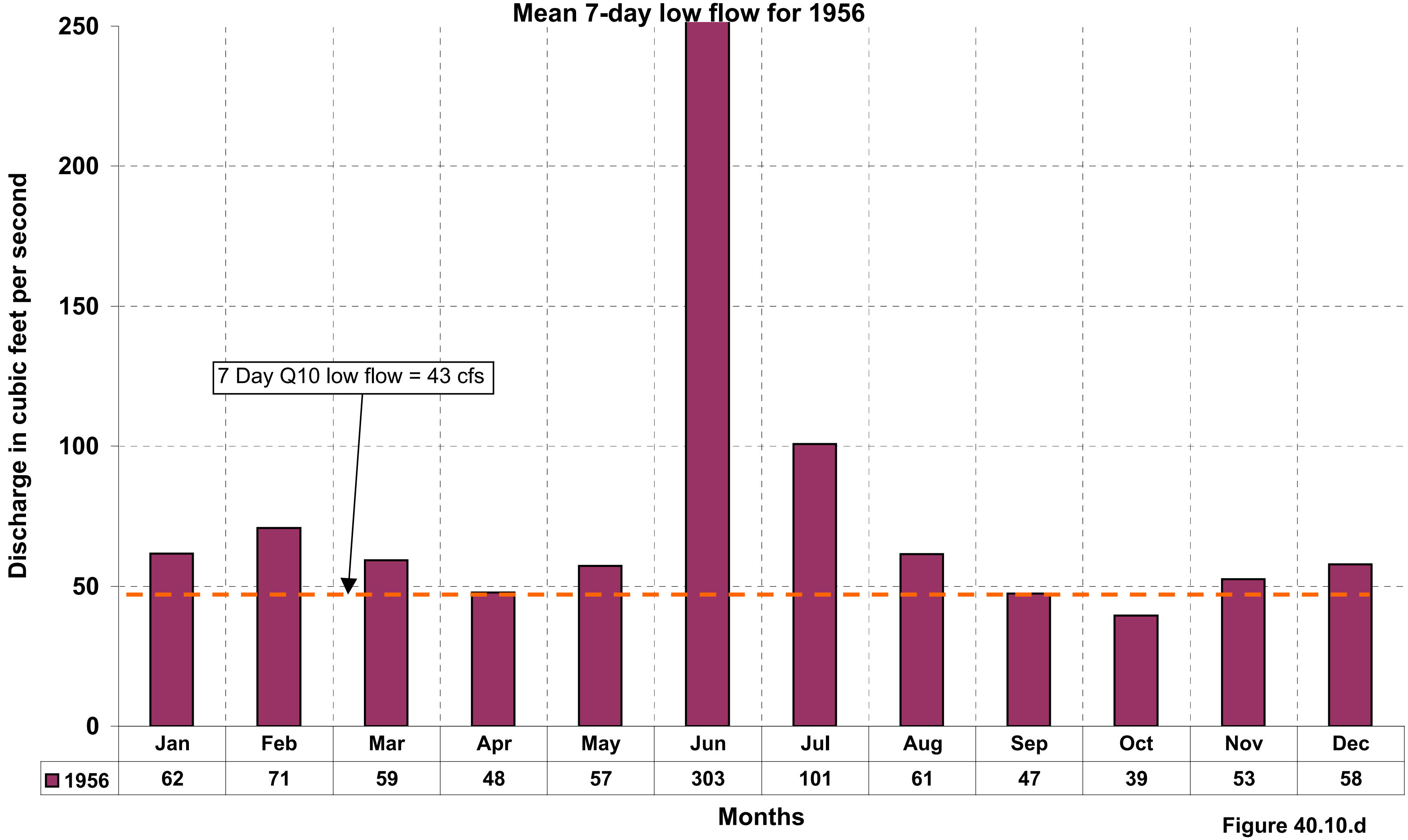
Figure 40.9

Joplin, Missouri

Water Supply Study

Shoal CreekAbove Joplin

Mean 7-day low flow for 1956



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1956	62	71	59	48	57	303	101	61	47	39	53	58

Figure 40.10.d

Joplin, Missouri

Water supply Study

Shoal Creek Above Joplin

Mean 7 day low flow by months for 1955

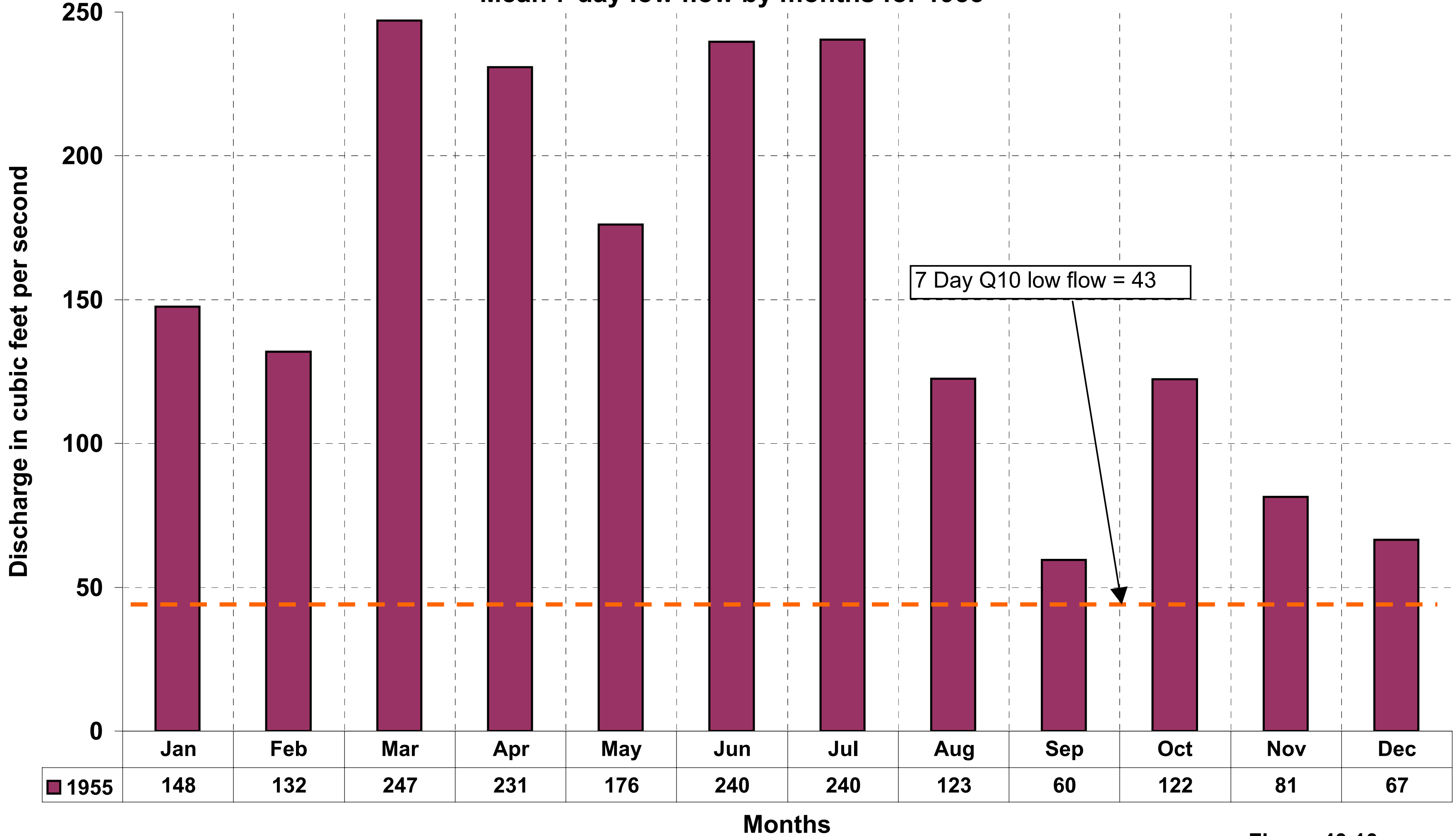


Figure 40.10.c

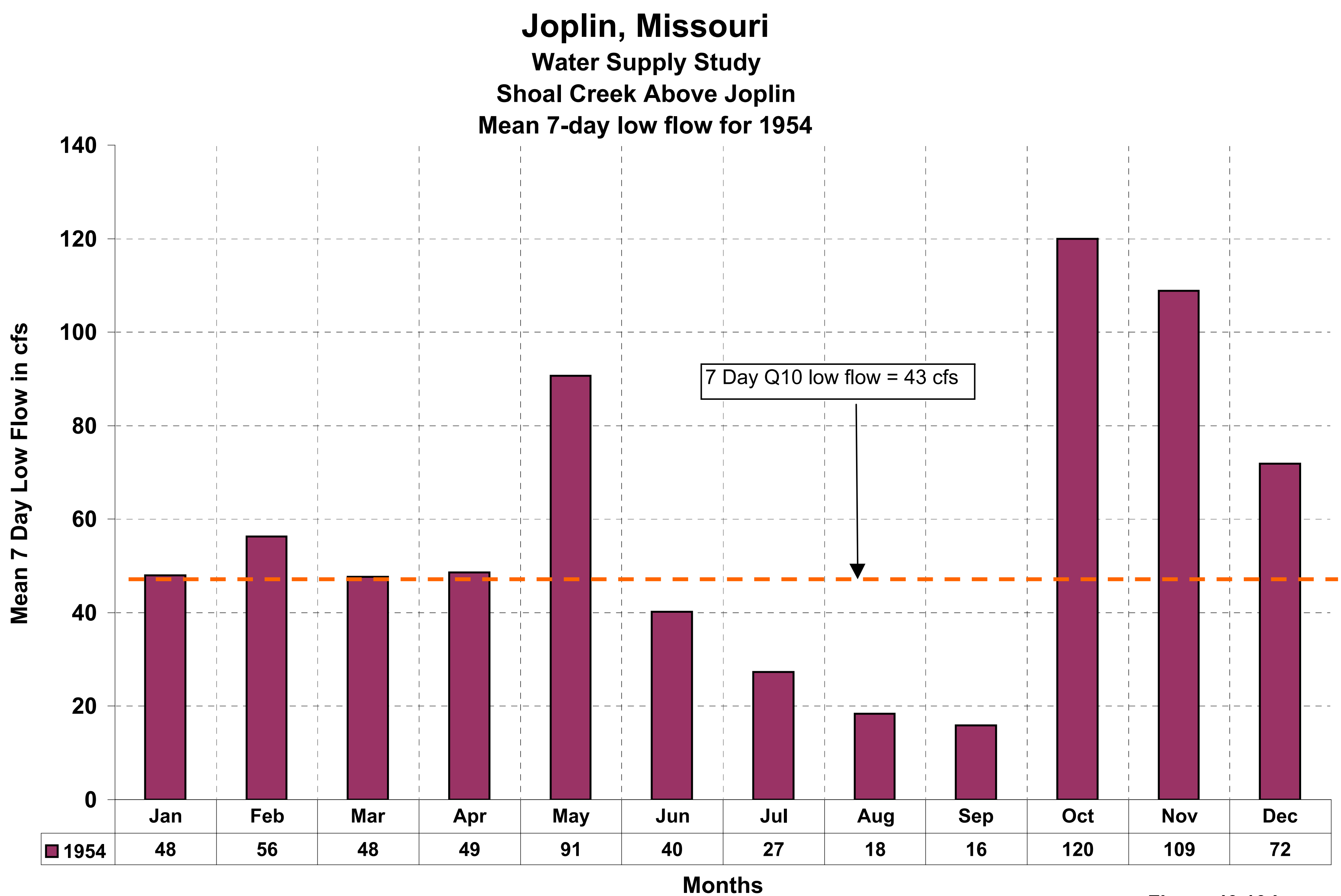


Figure 40.10.b

Perryville, Missouri
Water Supply Study
Saline Creek

INTRODUCTION:

This analysis was made to assess the availability of Perryville's water supply. Perryville obtains their water supply from two sources, Saline Creek and three wells. In year 2000, demand used a total 414,459,000 gallons from both sources, 289,448,000 gallons from Saline Creek and 125,011,000 gallons from the wells. This report addresses the stream flow in Saline creek.

DISCUSSION:

Perryville has no off channel storage to draw upon during periods of low flow, they would need to rely on their 3 wells. The drainage area at the creek intake for Perryville is 55.83 square miles. In the year 2000 Perryville used 1.14 MGD, 0.79 from Saline Creek and 0.34 from wells. The intake is located at the Southwest side of Perryville. It would be necessary to continuously pump 550 gpm to obtain 0.79 MGD from Saline Creek.

There is no stream gage on Saline Creek. Two stream gages on St. Francis River were correlated and results found to be nearly equal when adjusted to a per square mile basis. These gages are the long-term gage on St. Francis River at Patterson, drainage area of 370.45 square miles, and Little St. Francis River at Fredericktown, drainage area of 90.5 square miles. The upper reaches of Little St. Francis River border the drainage area of Saline Creek. Adjustments to runoff for Saline Creek were made based on drainage area. **Figure 50.1** shows the annual rainfall at Perryville for the period 1950 through 2001. This indicates the precipitation trend to be nearly uniform for the period of record with the trend averaging about 41 inches annually. **Figure 50.2.a** shows the annual runoff for Saline Creek at the intake point. The trend indicates runoff to be nearly uniform for the period of 1950 to year 2000. **Figure 50.2.b** shows the runoff in terms of mean annual cubic feet per second.

Stream gage records show the drought of record to be in the 1950's. The following **figures 50.3.a, 50.3.b, 50.3.c, 50.3.d, 50.3.e, and 50.3.f** compare the 1-%, 2% and 4% chance mean monthly non-exceedence flows (low flow) to measured flows for 1952, 1953, 1954, 1955, 1956 and 1957. All frequencies exceeded or equaled the adjusted 7-day Q-10 discharges in 1952, 1954, and 1957. September mean flows tended to be the lowest in all years. In 1953, 1955, and 1956 the flows were very low and equaled the 7-day Q-10 low flow needed to meet in-stream flow requirements.

Base flow separation was made using the USGS computer program, HYSEP. HYSEP separates the base flow hydrograph from the total hydrograph. This analysis was made to estimate sustained flow for meeting water supply needs during a drought. **Figure 50.4.a** is the base flow index and is the ratio of base flow to total stream flow. This chart shows the yearly fluctuation in base flow indexes and indicates the trend. The trend shows the base flow index increasing from about 46% to 53% during the period of 1950 through 2000. Base flow was calculated and is shown in **figure 50.4.b** in terms of cfs for the period of 1950 through 2000. Trend shows that mean base flow has increased from about 29 cfs to approximately 33 cfs for that period. Total flow was also calculated and is shown in **figure 50.4.c**. The trend for mean total flow has increased from 45 cfs to 53 cfs for the 50-year period.

Because Saline Creek has no stream gage to make flow analysis it was necessary to compare flow data at several gages for their period of record. Gages chosen were the long term gage on St. Francis River at Patterson, Little St. Francis River at Fredericktown having a period of record 1986 through 1998, and Little Black River near Annapolis. The results are on a runoff per square mile basis and show nearly like results. They are shown in **figures 50.4.d and 50.4.e**.

To determine the rate of flow needed to maintain in-stream flow requirements, the 7-day Q-10 low flow was determined using the period of record, 1950 through 2000. The computer program named 'DURFREK' (a duration frequency computer program developed by Hydrosphere) was used to determine discharge values. **Figure 50.5.a** shows the plot of the values for a frequency analysis. The 7-day Q-10 frequency analysis was determined to be 1.0 cfs. Seven-day annual low flows for 1950 through 2000 were calculated and are shown **figure 50.6**. Visual observation shows that the trend for 7-day annual low flows is nearly constant for the 50 years between 1950 and 2000.

Monthly non-exceedence probabilities (low flows) for 1% chance of occurrence (1 time in 100 years), 2% chance (1 time in 50 years) and 4% chance (1 time in 25 years) were established from stream flow data for the years 1950 through 2000. **Figure 50.7** displays these results. Mean monthly low flow probabilities exceed the 7-day Q-10 discharge of 1.0 cfs for all frequencies except for August and September when mean flows are approximately equal to the 7-day Q-10 flow. The 1% chance low flow is slightly less than 7-day Q-10 in these months. For this report, all statistical determinations were made using the Log Pearson type 3 method as described in Water Resource Council bulletin 17B. **Figures 50.8a, 50.8b, and 50.8c** show the mean deficits in stream flow for the 1%, 2% and 4% chance of low flow being discharge needed to allow for pumping and maintain the 7-day Q-10 low flow. For the 1% chance low flows, every month has a chance of not meeting flow requirements. The 2% chance shows that the months of February, March, April and May have potential of meeting demands. For the 4% chance low flows there are four months that have the potential of not meeting needs. These months are August, September, October and November.

Figure 50.9 is the daily demand by Perryville, in million gallons per year. During the period of 1994 through 2001 their demand has been constant at approximately 1.1 MGD.

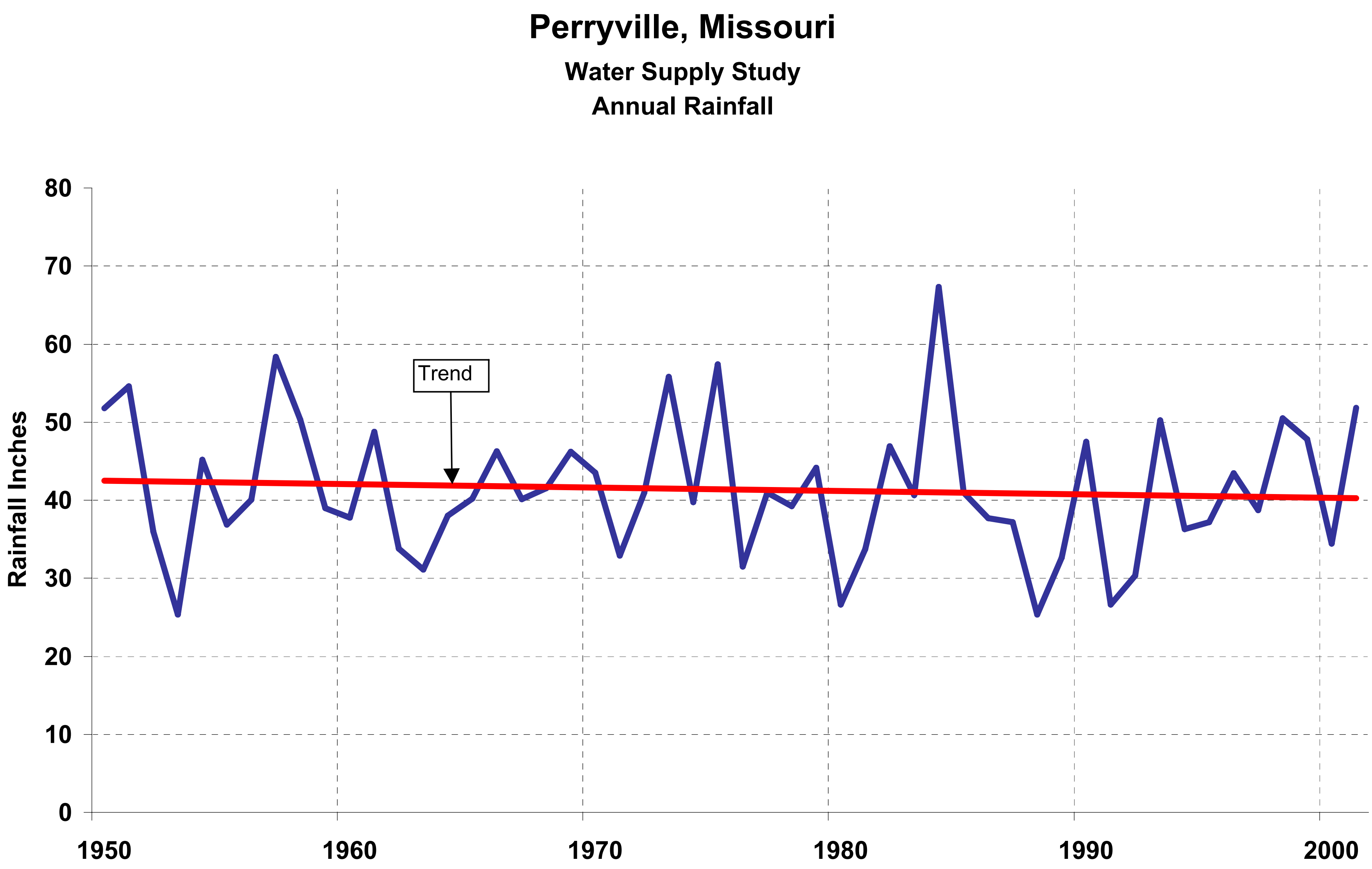
Additional comparisons for the 1950's drought were made using the mean 7-day low flow for examining a shorter duration. These comparisons are shown in **figures 50.10.a, 50.10.b, 50.10.c and 50.10.d**. These figures compare mean seven-day low flows to 7 day Q10 flow, and indicate short-term critical periods. In the 4 years period of 1953 through 1956 there were 12 months that had mean seven-day flows below 7 day Q10 discharge.

Conclusion:

In year 2000 the city used a total of 414,459,000 gallons of which 289,448,000 gallons came from Saline Creek, resulting in a mean annual withdraw of 1.14 MGD.

The probability of adequate stream flow in Saline Creek during the months of August, September and October is very low. To meet the mean daily demand from the creek of 1.22 cfs plus the in-stream flow requirement of 1 cfs, at least 2.22 cfs would need to be flowing in the stream before pumping. Every month of the year has the possibility of having the 1% chance low flow below that which would allow pumping from the stream. For the 2% chance of occurrence, only the spring months of February, March, April and May could be expected to have mean flows of sufficient quantity to allow pumping. During the months of August, September and October, Saline Creek could not be depended upon to allow pumping, even at the 4% chance low flow range.

Perryville's water demand has remained nearly constant for the period 1994 through 2001.


Perryville, Missouri
Water Supply Study
Annual Rainfall
Rainfall Inches
80
70
60
50
40
30
20
10
0
Trend
1950
1960
1970
1980
1990
2000
Year
Figure 50.1

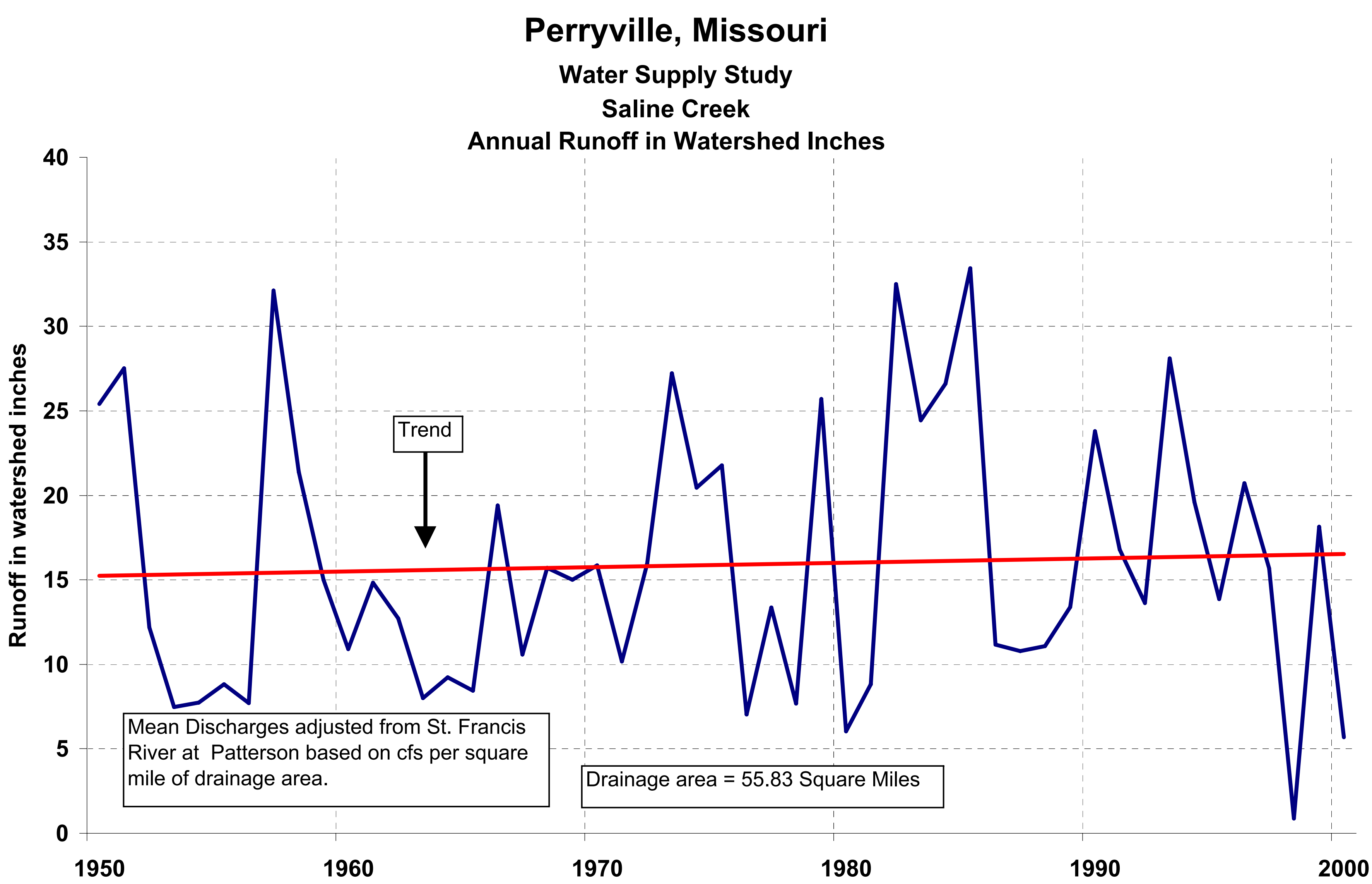

Perryville, Missouri
Water Supply Study
Saline Creek
Annual Runoff in Watershed Inches
Runoff in watershed inches
40
35
30
25
20
15
10
5
0
1950
1960
1970
1980
1990
2000
Year
Trend
Mean Discharges adjusted from St. Francis River at Patterson based on cfs per square mile of drainage area.
Drainage area = 55.83 Square Miles

Figure 50.2.a

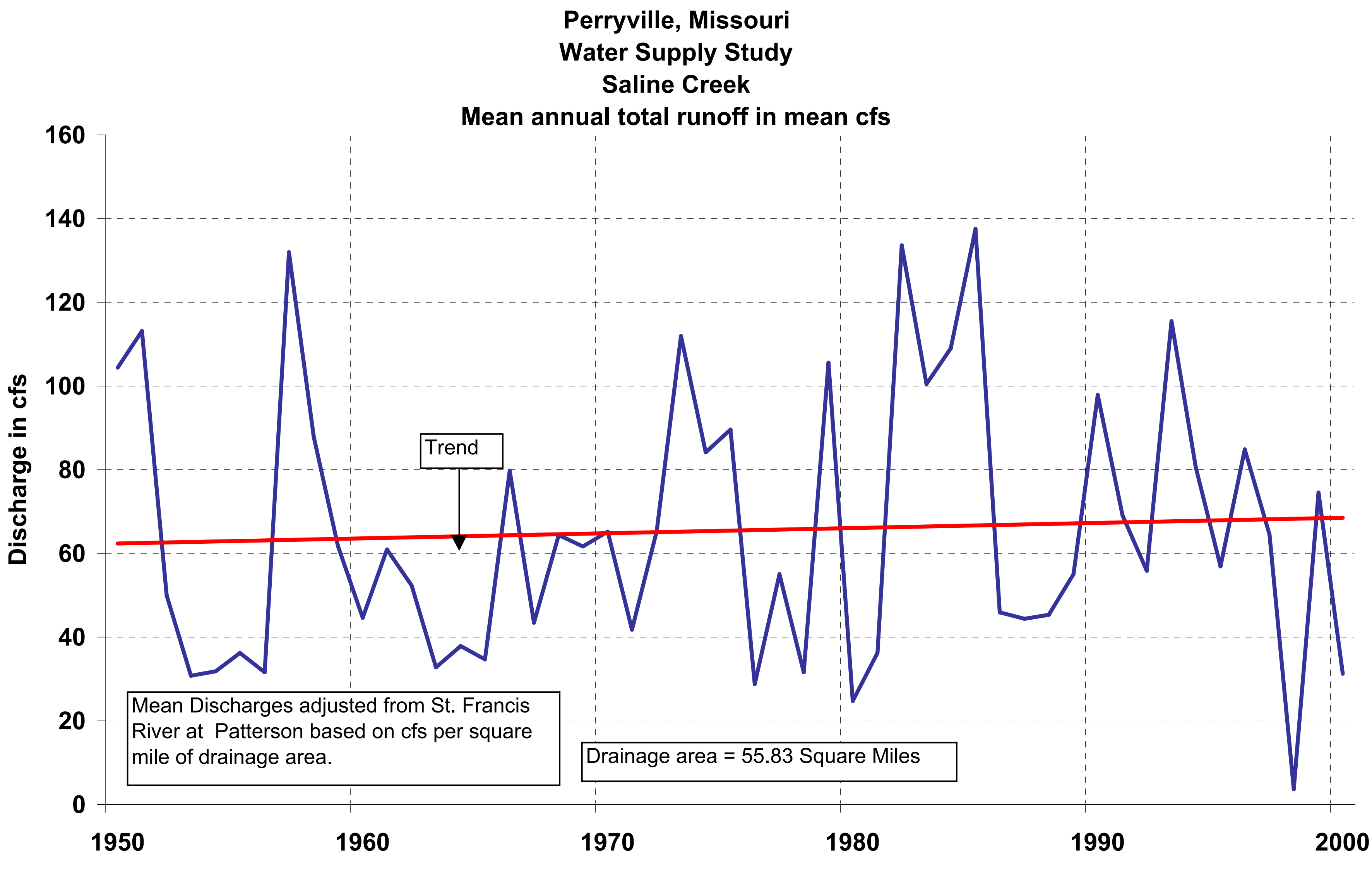
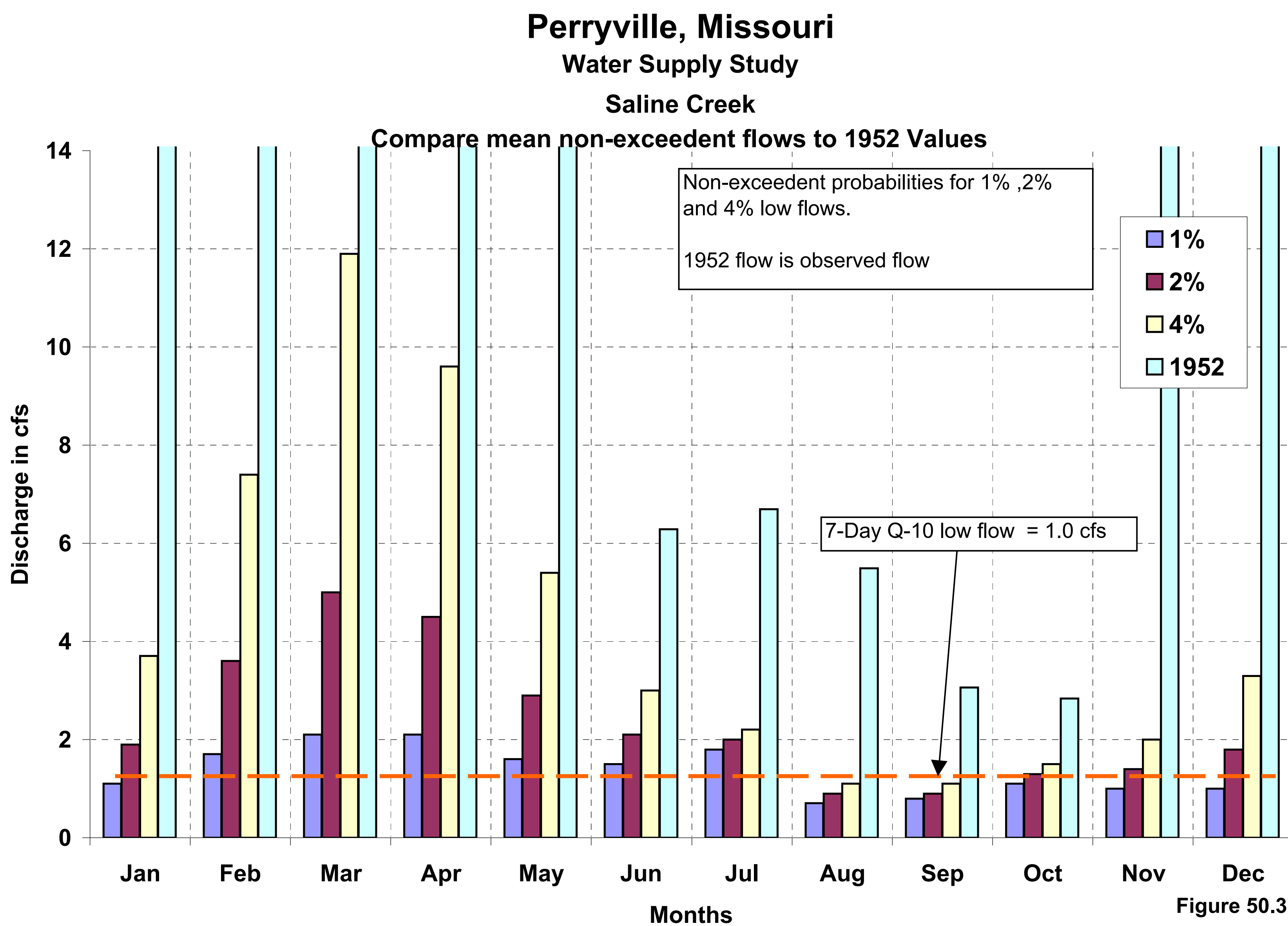

Perryville, Missouri
Water Supply Study
Saline Creek
Mean annual total runoff in mean cfs
Discharge in cfs
160
140
120
100
80
60
40
20
0
1950
1960
1970
1980
1990
2000
Year
Trend
Mean Discharges adjusted from St. Francis River at Patterson based on cfs per square mile of drainage area.
Drainage area = 55.83 Square Miles

Figure 50.2.b



Perryville, Missouri
Water Supply Study
Saline Creek
Compare mean non-exceedent flows to 1952 Values
Discharge in cfs
14
12
10
8
6
4
2
0
Non-exceedent probabilities for 1% ,2% and 4% low flows.
1952 flow is observed flow
1%
2%
4%
1952
7-Day Q-10 low flow = 1.0 cfs
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Months

Figure 50.3.a

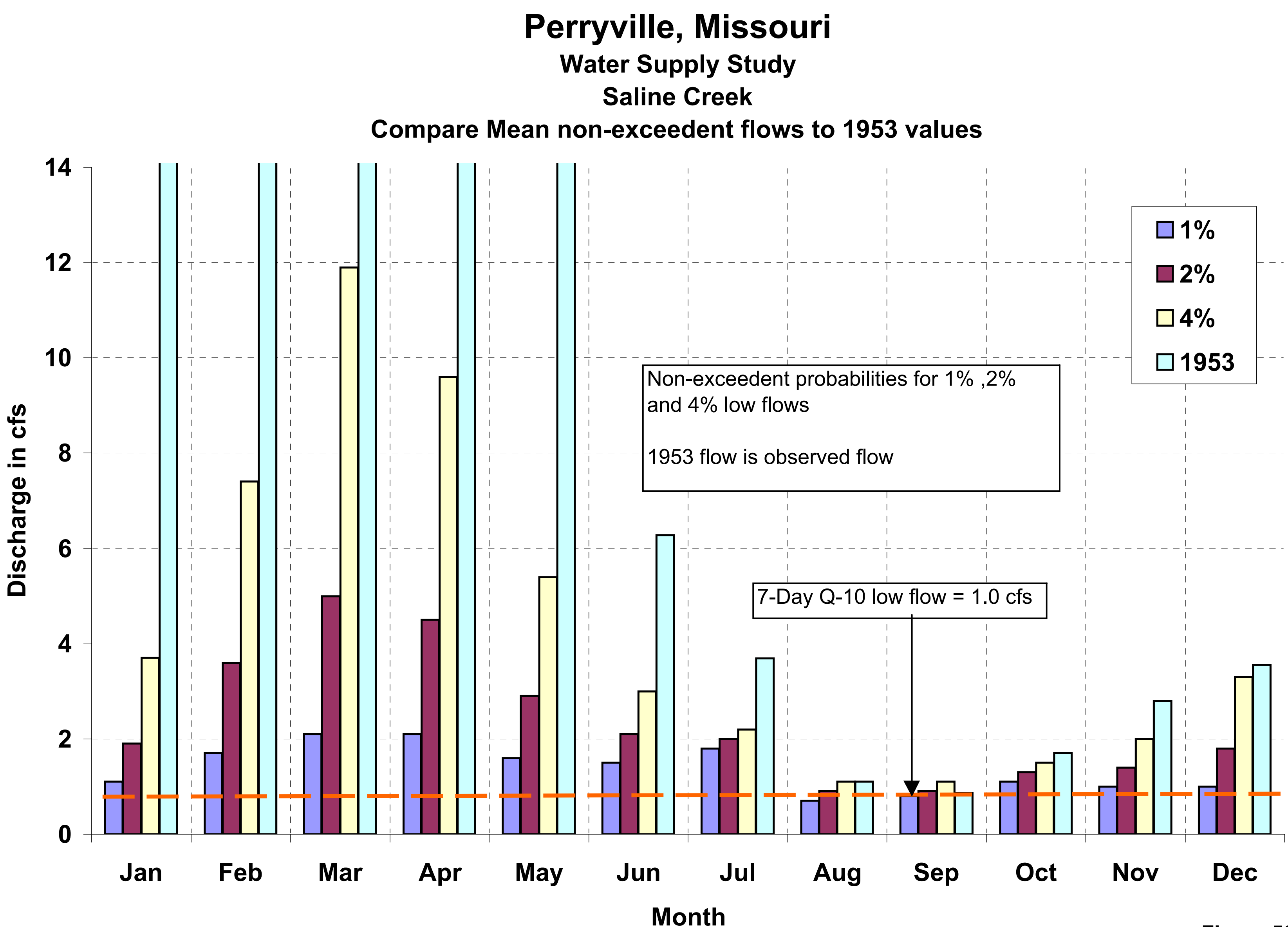

Perryville, Missouri
Water Supply Study
Saline Creek
Compare Mean non-exceedent flows to 1953 values
Discharge in cfs
0
2
4
6
8
10
12
14
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
1%
2%
4%
1953
Non-exceedent probabilities for 1% ,2% and 4% low flows
1953 flow is observed flow
7-Day Q-10 low flow = 1.0 cfs

Figure 50.3.b

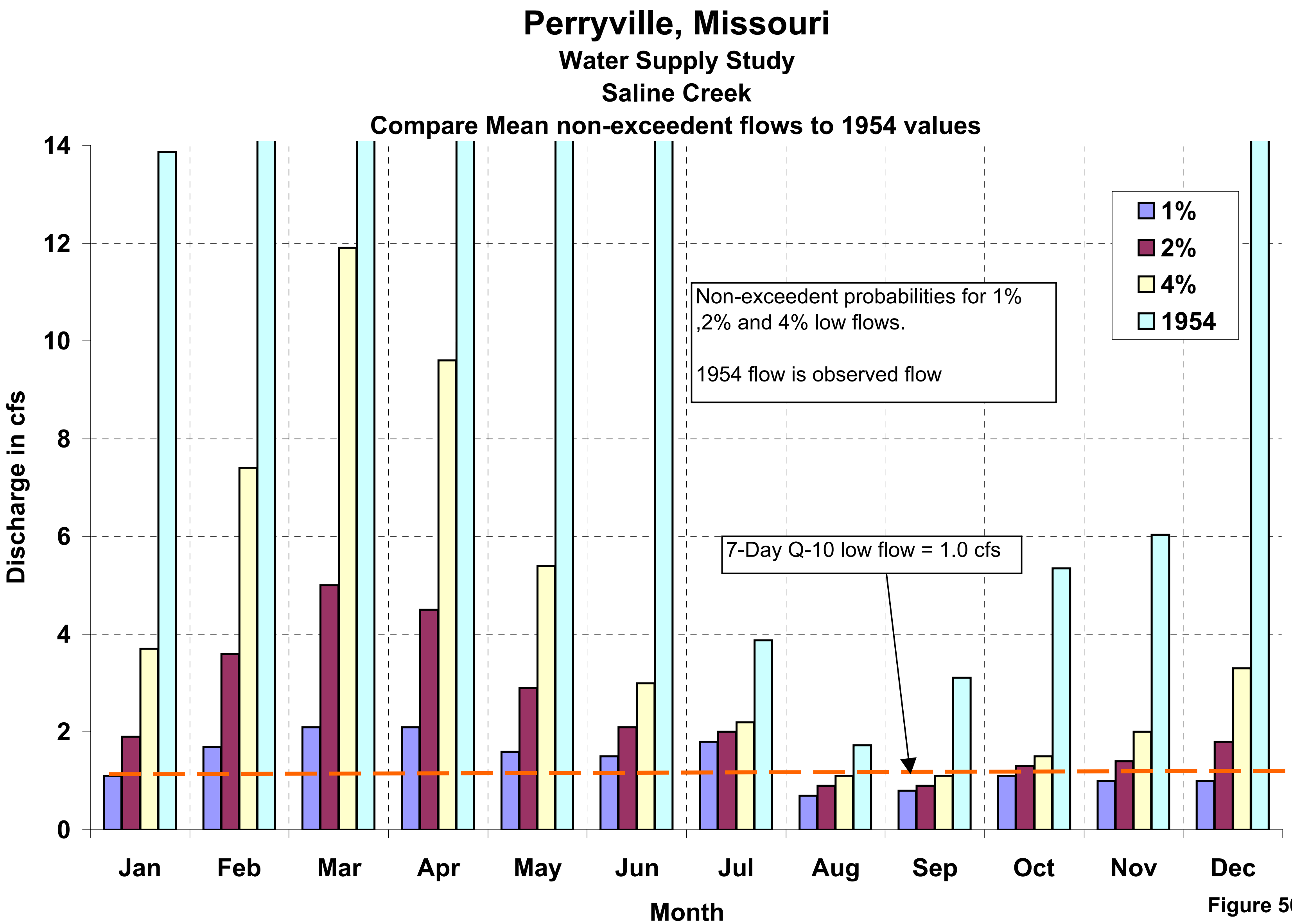
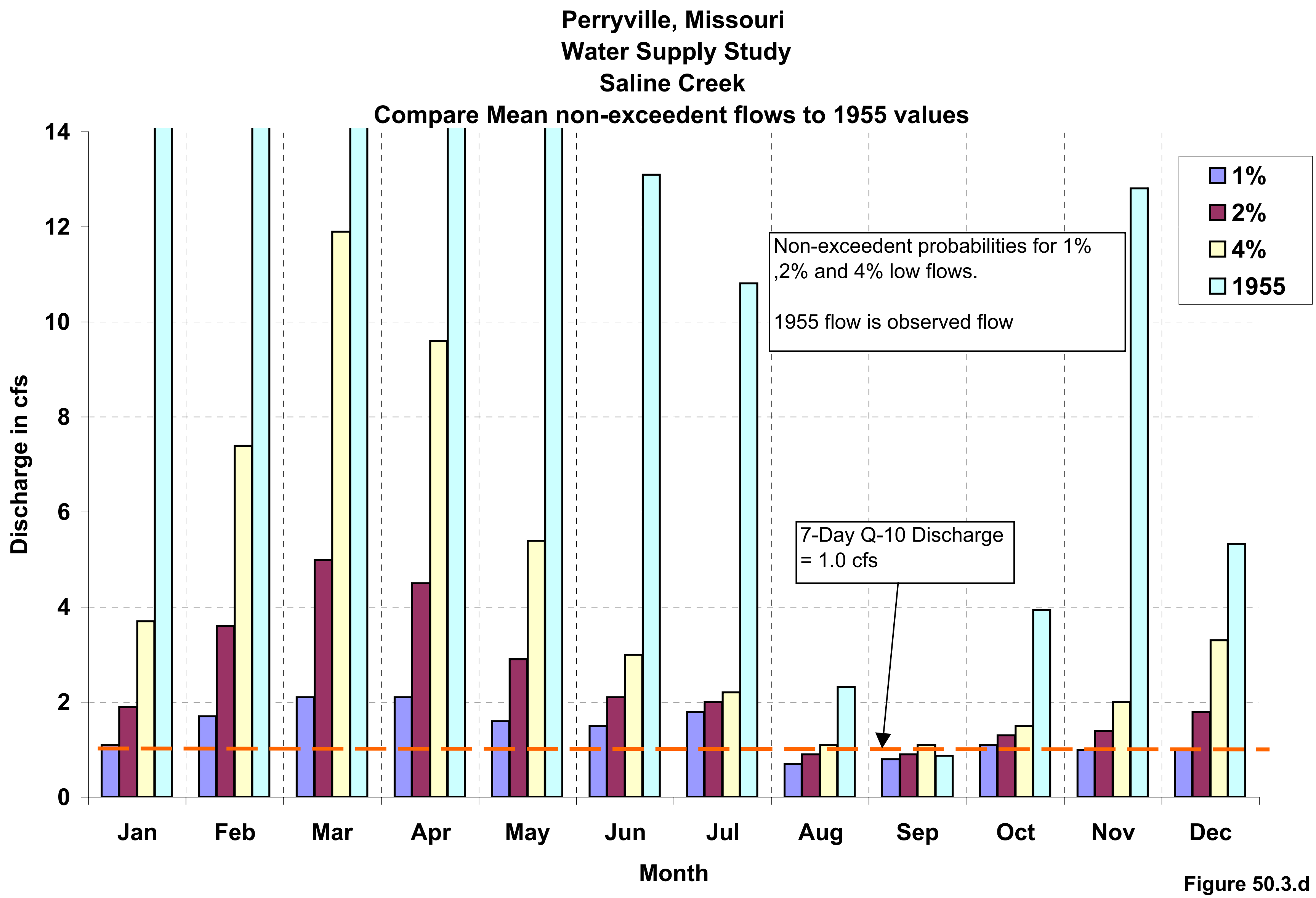
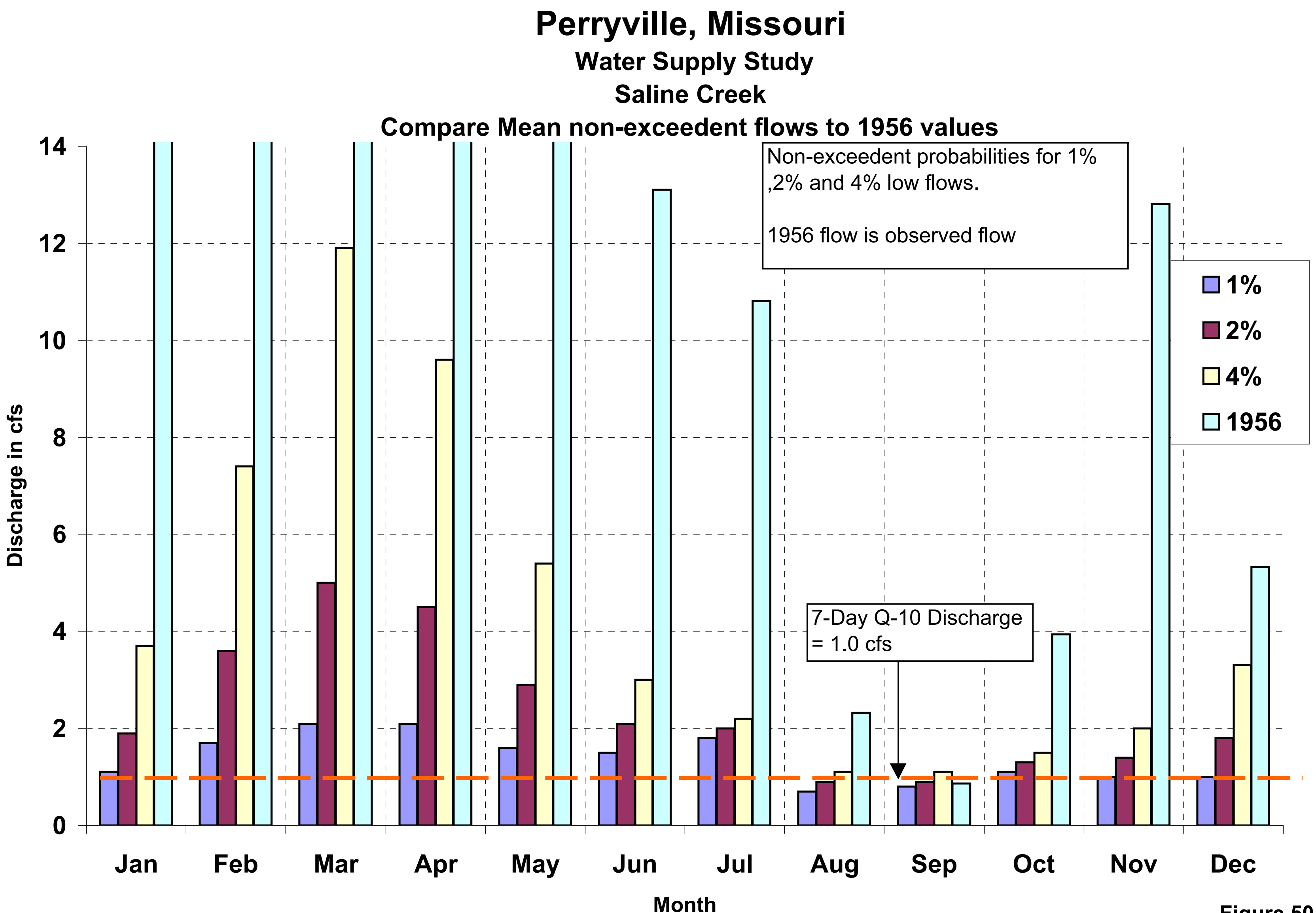

Perryville, Missouri
Water Supply Study
Saline Creek
Compare Mean non-exceedent flows to 1954 values
Discharge in cfs
0
2
4
6
8
10
12
14
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
1%
2%
4%
1954
Non-exceedent probabilities for 1%
,2% and 4% low flows.
1954 flow is observed flow
7-Day Q-10 low flow = 1.0 cfs

Figure 50.3.c



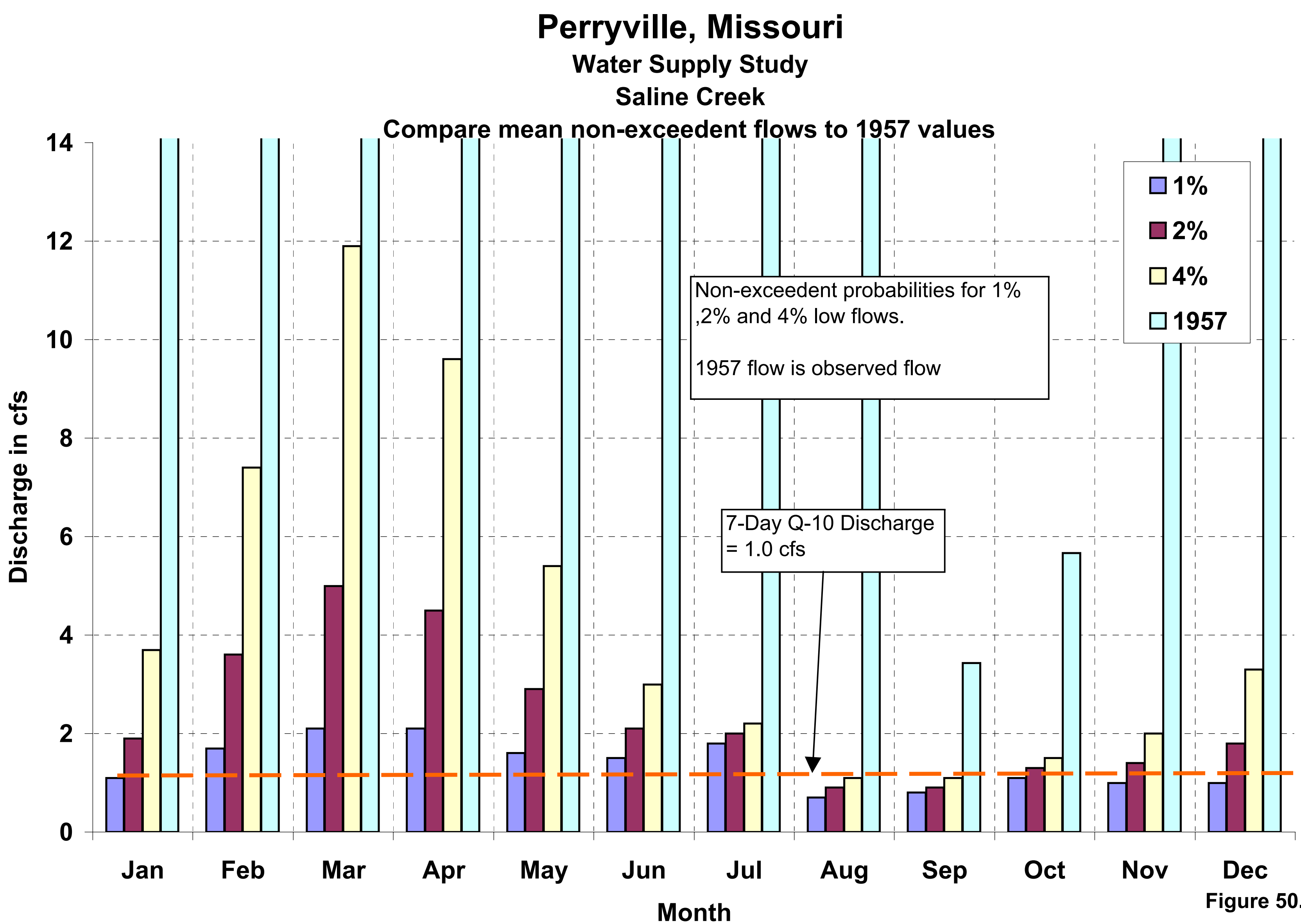
Perryville, Missouri
Water Supply Study
Saline Creek
Compare Mean non-exceedent flows to 1955 values
Discharge in cfs
0
2
4
6
8
10
12
14
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
1%
2%
4%
1955
Non-exceedent probabilities for 1% ,2% and 4% low flows.
1955 flow is observed flow
7-Day Q-10 Discharge = 1.0 cfs

Figure 50.3.d



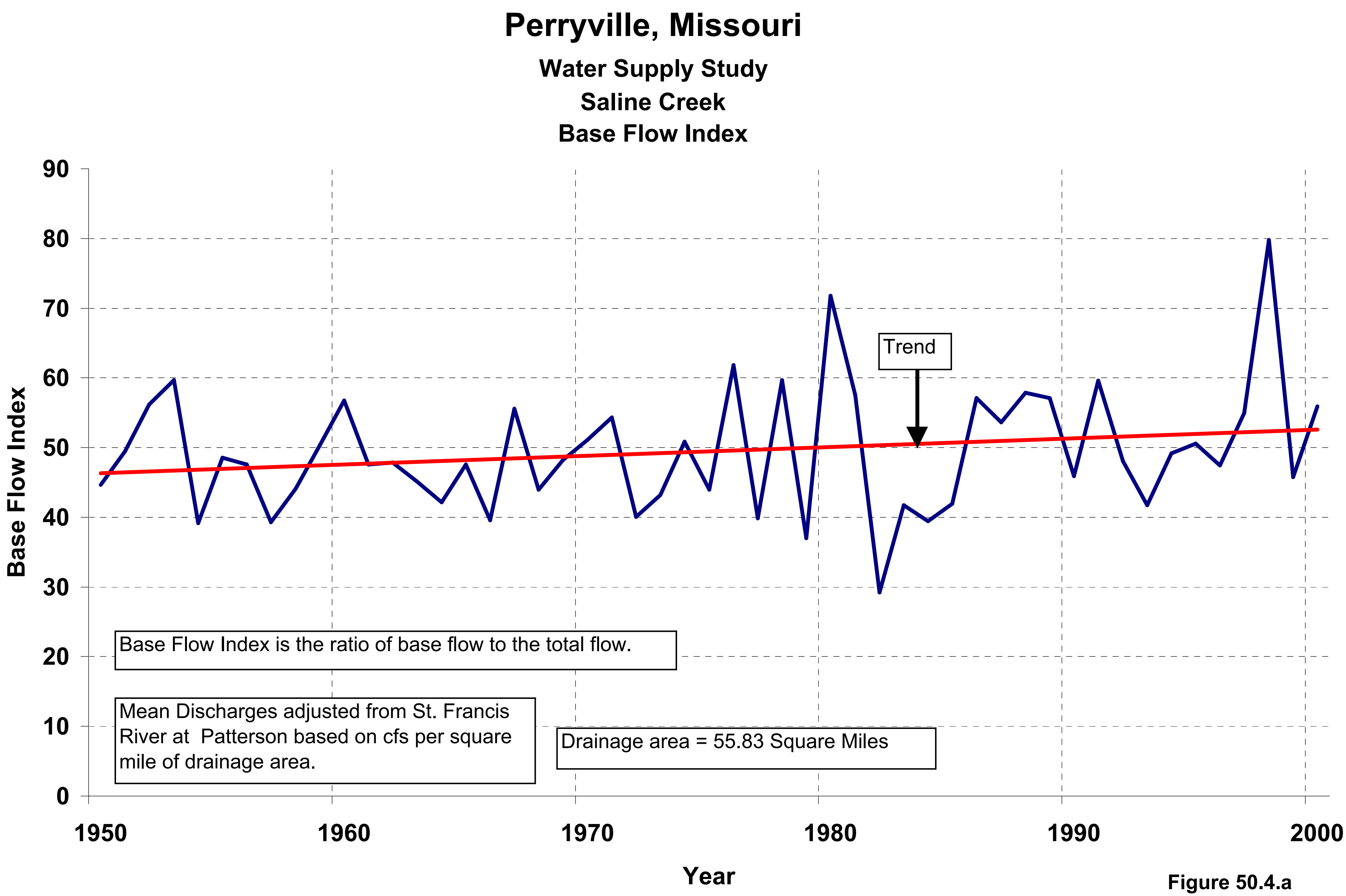
Perryville, Missouri
Water Supply Study
Saline Creek
Compare Mean non-exceedent flows to 1956 values
Non-exceedent probabilities for 1% ,2% and 4% low flows.
1956 flow is observed flow
7-Day Q-10 Discharge = 1.0 cfs
1%
2%
4%
1956
Discharge in cfs
0
2
4
6
8
10
12
14
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

Figure 50.3.e



Perryville, Missouri
Water Supply Study
Saline Creek
Compare mean non-exceedent flows to 1957 values
Discharge in cfs
14
12
10
8
6
4
2
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
1%
2%
4%
1957
Non-exceedent probabilities for 1% ,2% and 4% low flows.
1957 flow is observed flow
7-Day Q-10 Discharge = 1.0 cfs

Figure 50.3.f



Perryville, Missouri
Water Supply Study
Saline Creek
Base Flow Index
Base Flow Index
Year
Trend
Base Flow Index is the ratio of base flow to the total flow.
Mean Discharges adjusted from St. Francis River at Patterson based on cfs per square mile of drainage area.
Drainage area = 55.83 Square Miles
0
10
20
30
40
50
60
70
80
90
1950
1960
1970
1980
1990
2000

Figure 50.4.a

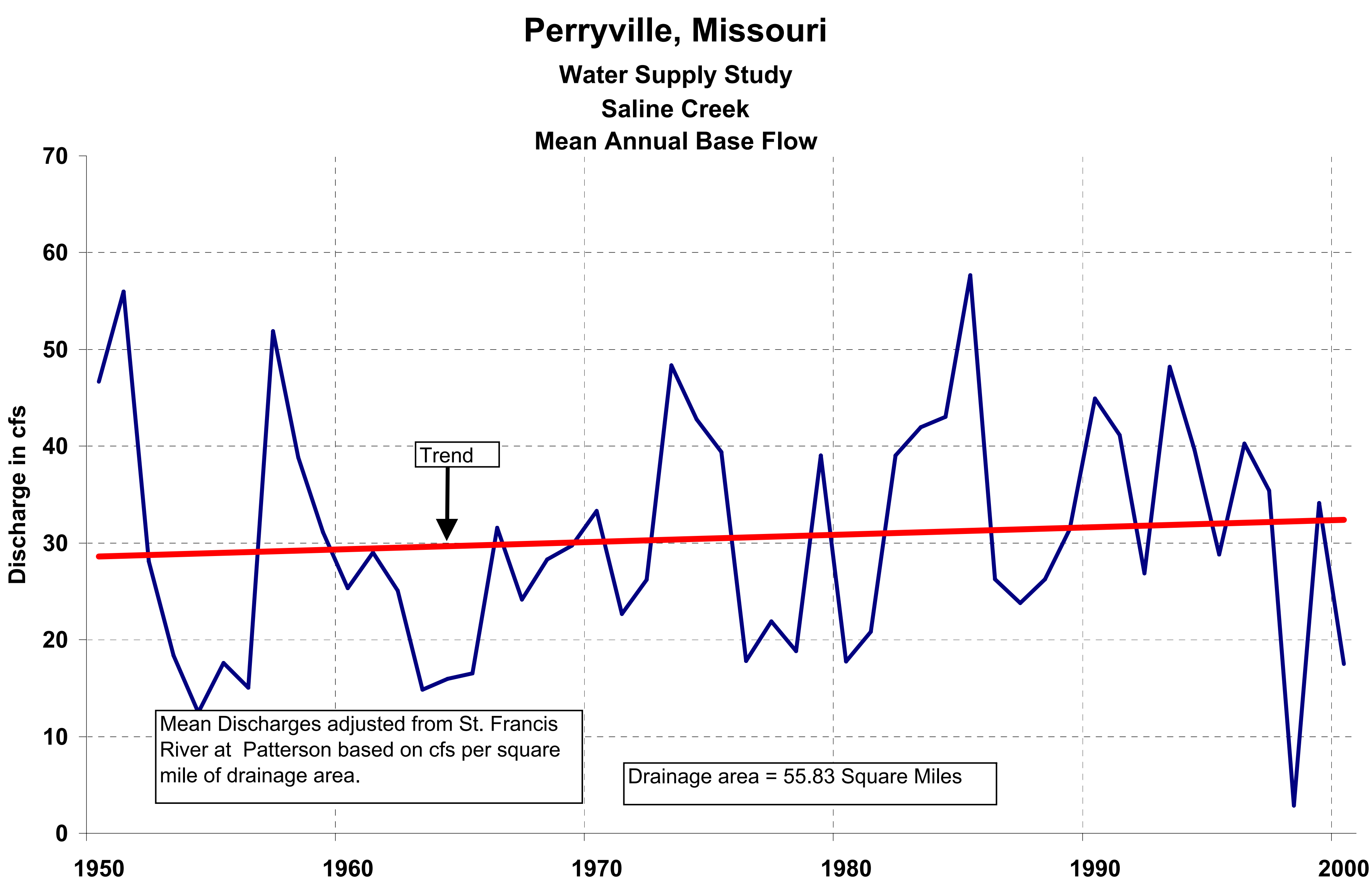
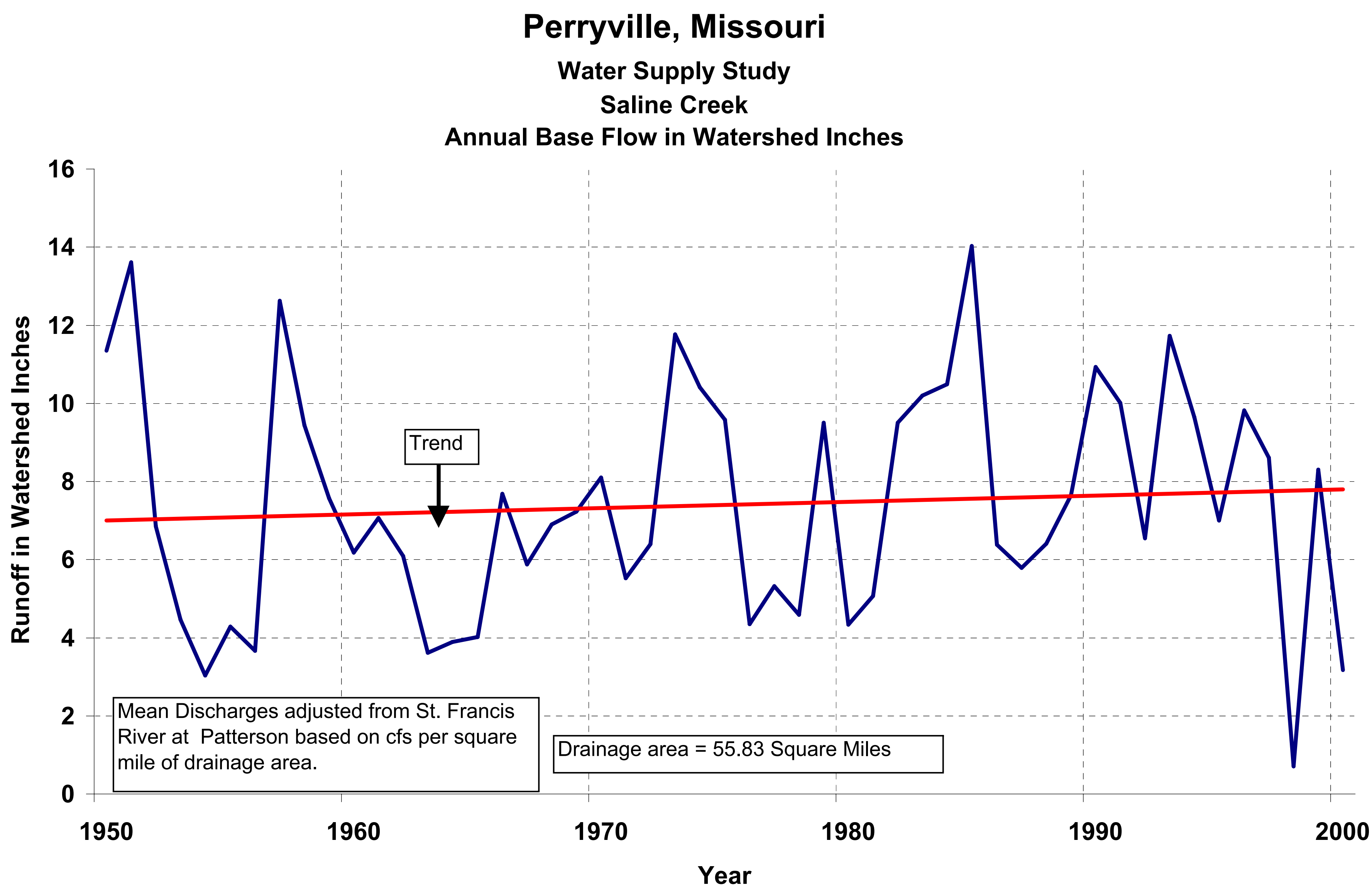
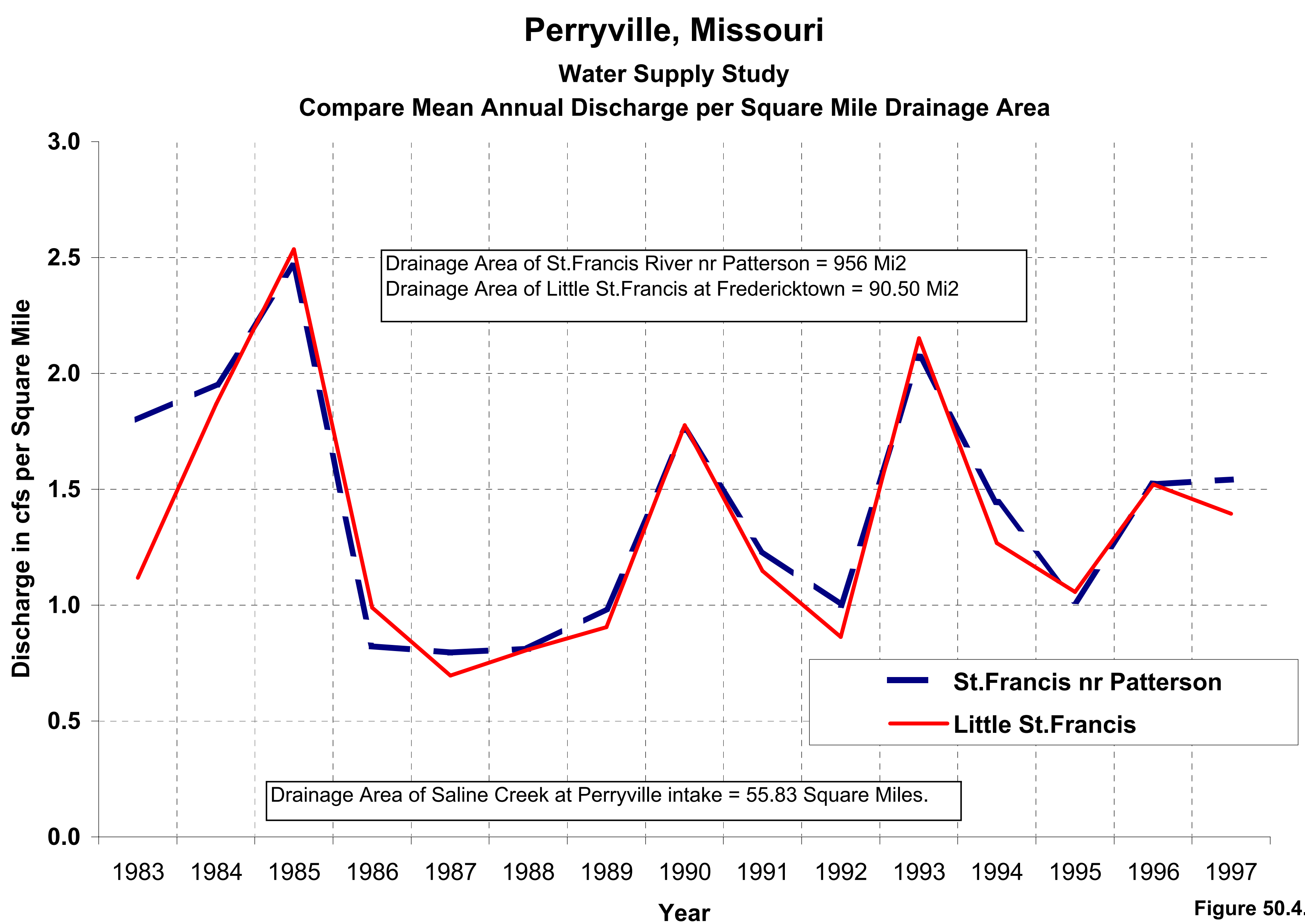

Perryville, Missouri
Water Supply Study
Saline Creek
Mean Annual Base Flow
Discharge in cfs
0
10
20
30
40
50
60
70
1950
1960
1970
1980
1990
2000
Year
Trend
Mean Discharges adjusted from St. Francis River at Patterson based on cfs per square mile of drainage area.
Drainage area = 55.83 Square Miles

Figure 50.4.b


Perryville, Missouri
Water Supply Study
Saline Creek
Annual Base Flow in Watershed Inches
Runoff in Watershed Inches
16
14
12
10
8
6
4
2
0
1950
1960
1970
1980
1990
2000
Year
Trend
Mean Discharges adjusted from St. Francis River at Patterson based on cfs per square mile of drainage area.
Drainage area = 55.83 Square Miles
Figure 50.4.c


Perryville, Missouri
Water Supply Study
Compare Mean Annual Discharge per Square Mile Drainage Area
Drainage Area of St.Francis River nr Patterson = 956 Mi2
Drainage Area of Little St.Francis at Fredericktown = 90.50 Mi2
Drainage Area of Saline Creek at Perryville intake = 55.83 Square Miles.
St.Francis nr Patterson
Little St.Francis
Discharge in cfs per Square Mile
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
Year
Figure 50.4.d

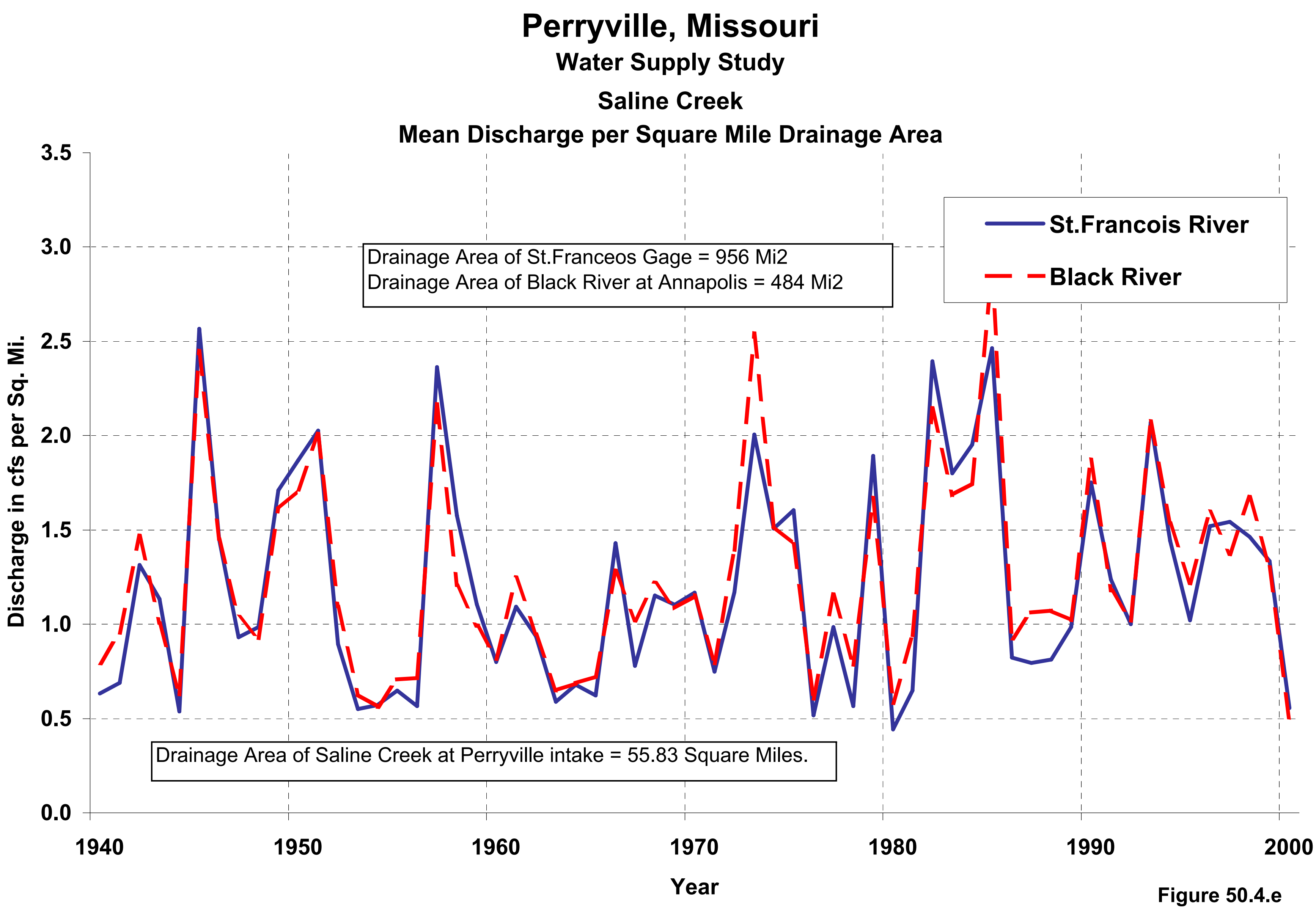

Perryville, Missouri
Water Supply Study
Saline Creek
Mean Discharge per Square Mile Drainage Area
Discharge in cfs per Sq. Mi.
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1940
1950
1960
1970
1980
1990
2000
Year
Drainage Area of St.Franceos Gage = 956 Mi2
Drainage Area of Black River at Annapolis = 484 Mi2
Drainage Area of Saline Creek at Perryville intake = 55.83 Square Miles.
St.Francois River
Black River

Figure 50.4.e

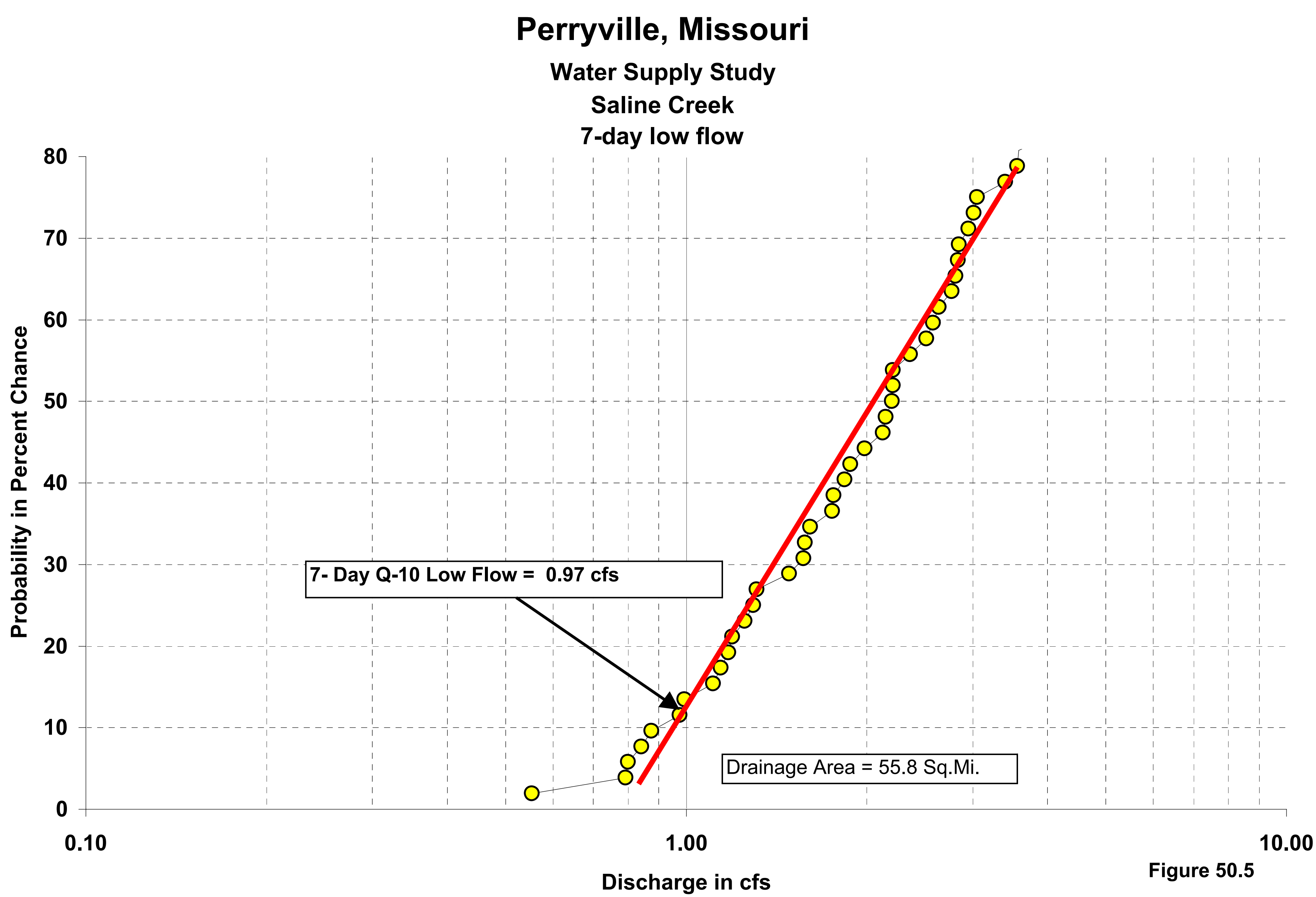

Perryville, Missouri
Water Supply Study
Saline Creek
7-day low flow
Probability in Percent Chance
0
10
20
30
40
50
60
70
80
0.10
1.00
10.00
Discharge in cfs
7- Day Q-10 Low Flow = 0.97 cfs
Drainage Area = 55.8 Sq.Mi.

Figure 50.5

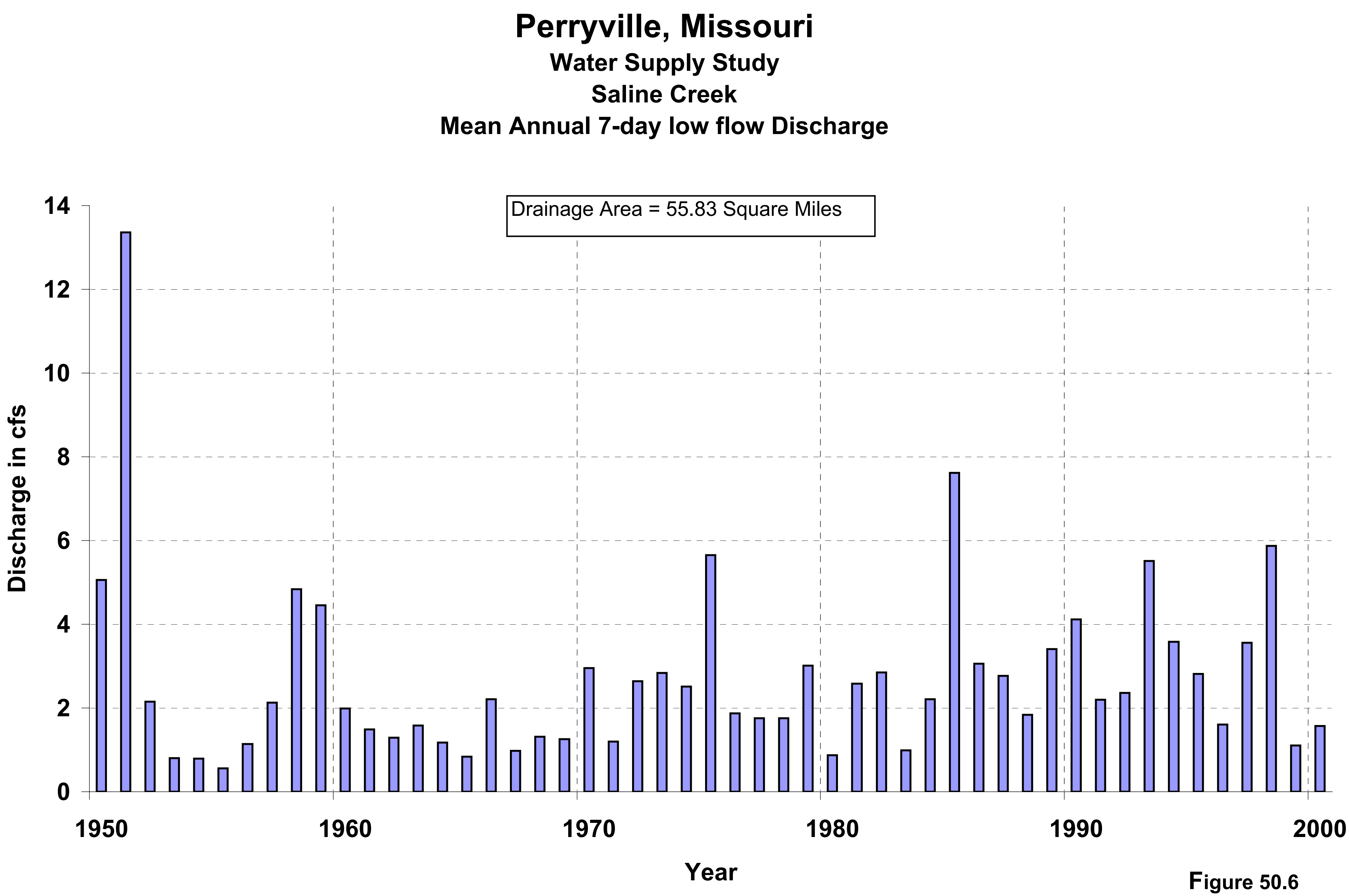

Perryville, Missouri
Water Supply Study
Saline Creek
Mean Annual 7-day low flow Discharge
Drainage Area = 55.83 Square Miles
Discharge in cfs
0
2
4
6
8
10
12
14
1950
1960
1970
1980
1990
2000
Year

Figure 50.6

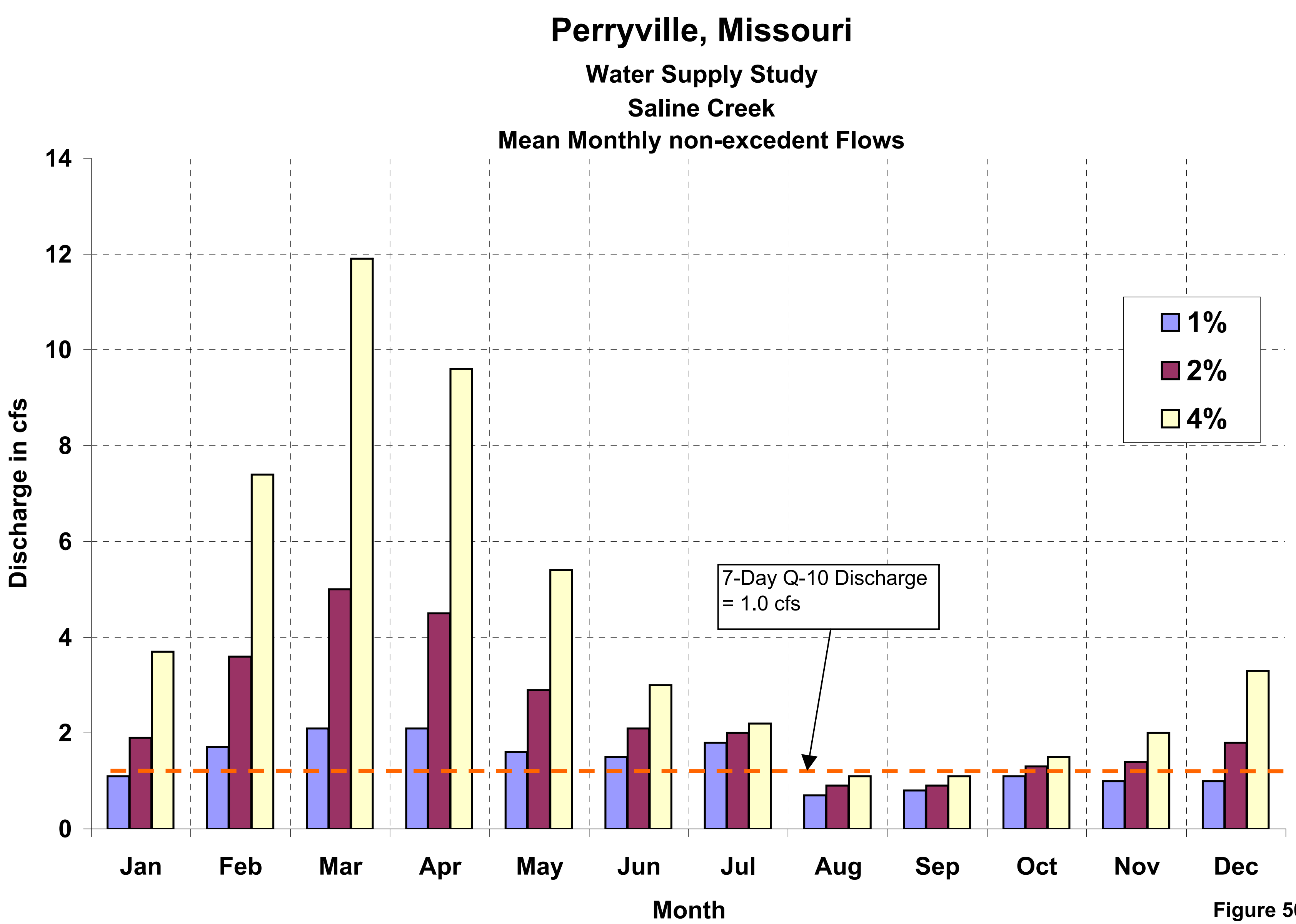
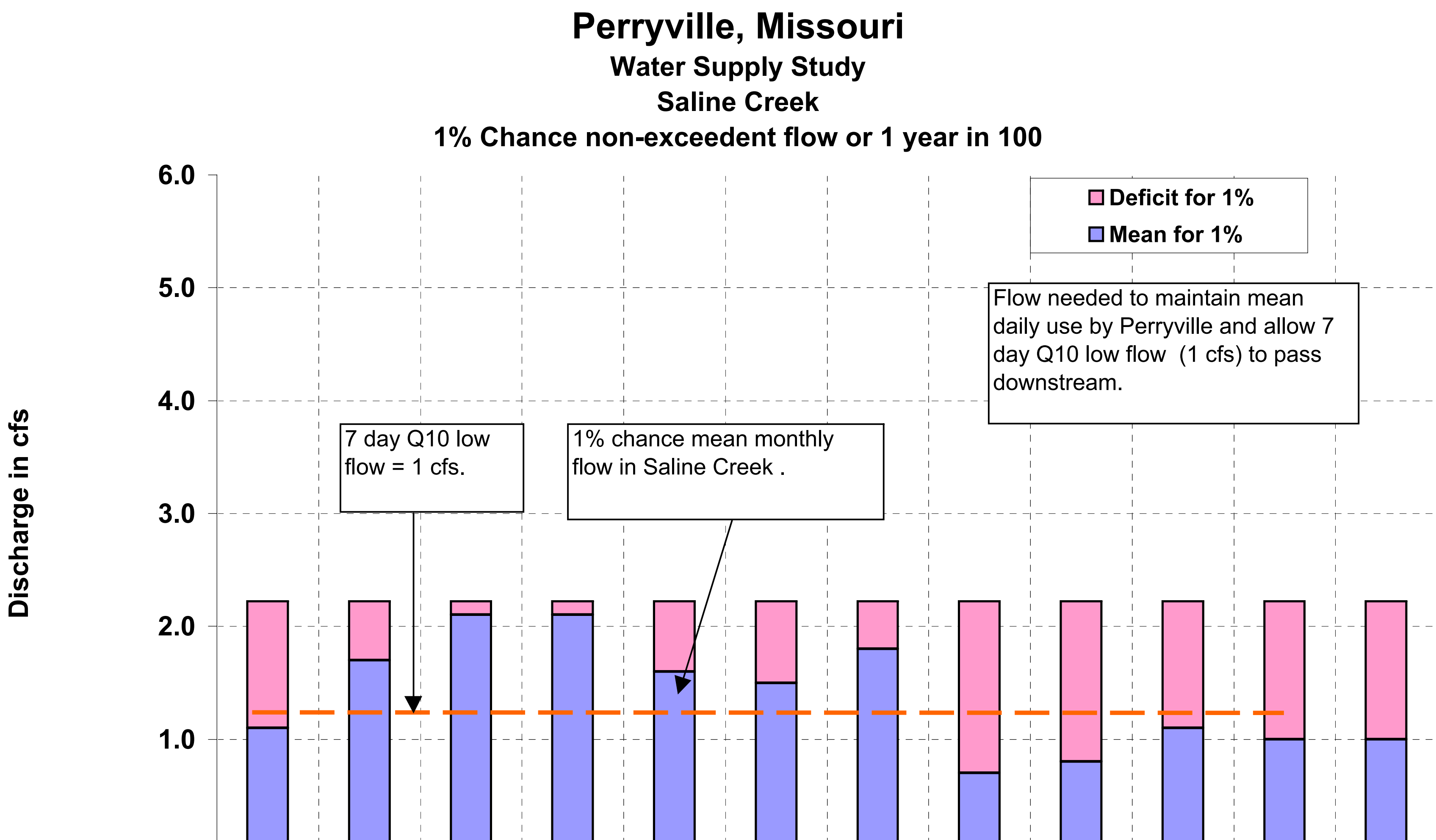

Perryville, Missouri
Water Supply Study
Saline Creek
Mean Monthly non-excedent Flows
Discharge in cfs
14
12
10
8
6
4
2
0
1%
2%
4%
7-Day Q-10 Discharge
= 1.0 cfs
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

Figure 50.7



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Deficit for 1%	1.12	0.52	0.12	0.12	0.62	0.72	0.42	1.52	1.42	1.12	1.22	1.22
Mean for 1%	1.1	1.7	2.1	2.1	1.6	1.5	1.8	0.7	0.8	1.1	1	1

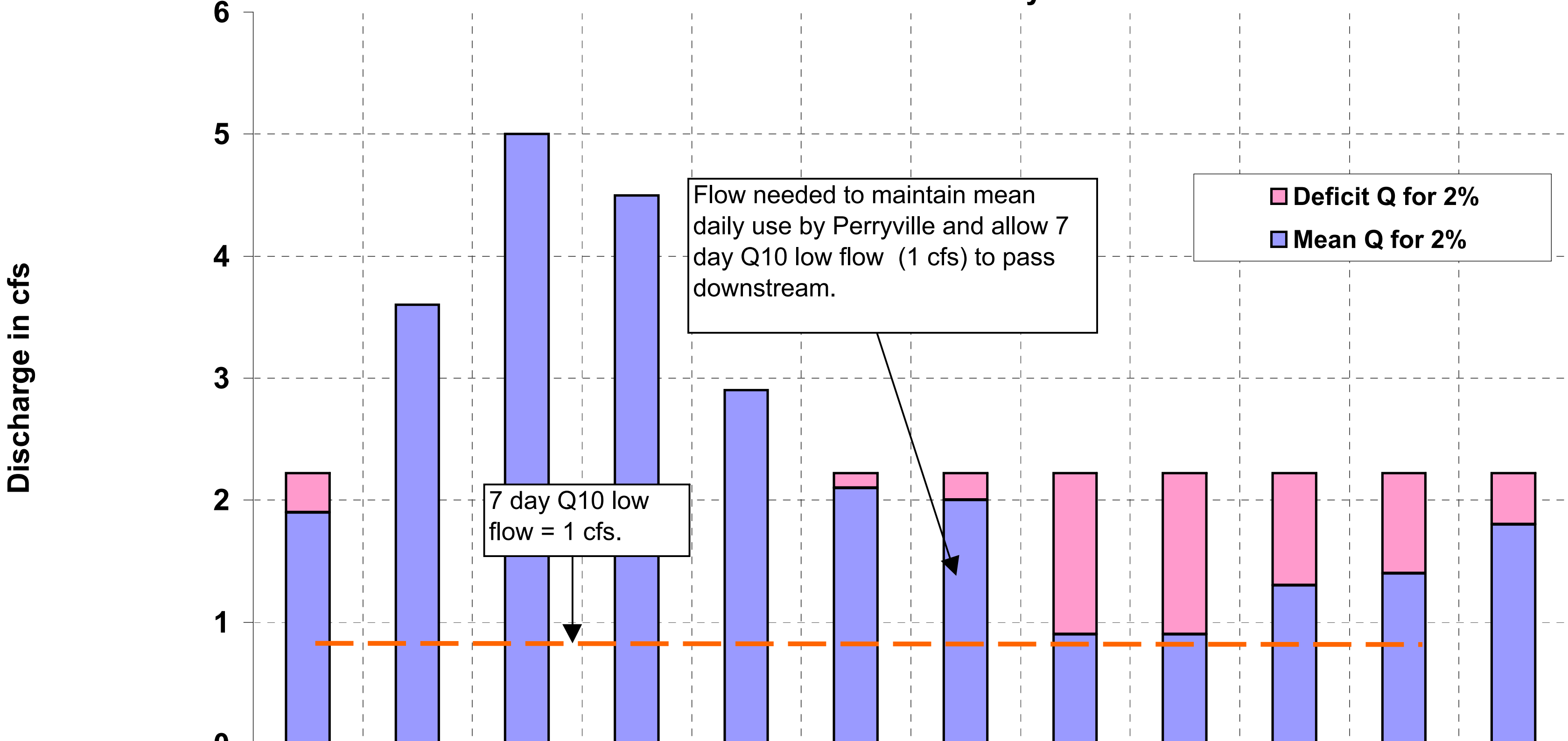
Figure 50.8.a

Perryville, Missouri

Water Supply Study

Saline Creek

2% chance of non-exceedent flow or 1 year in 50

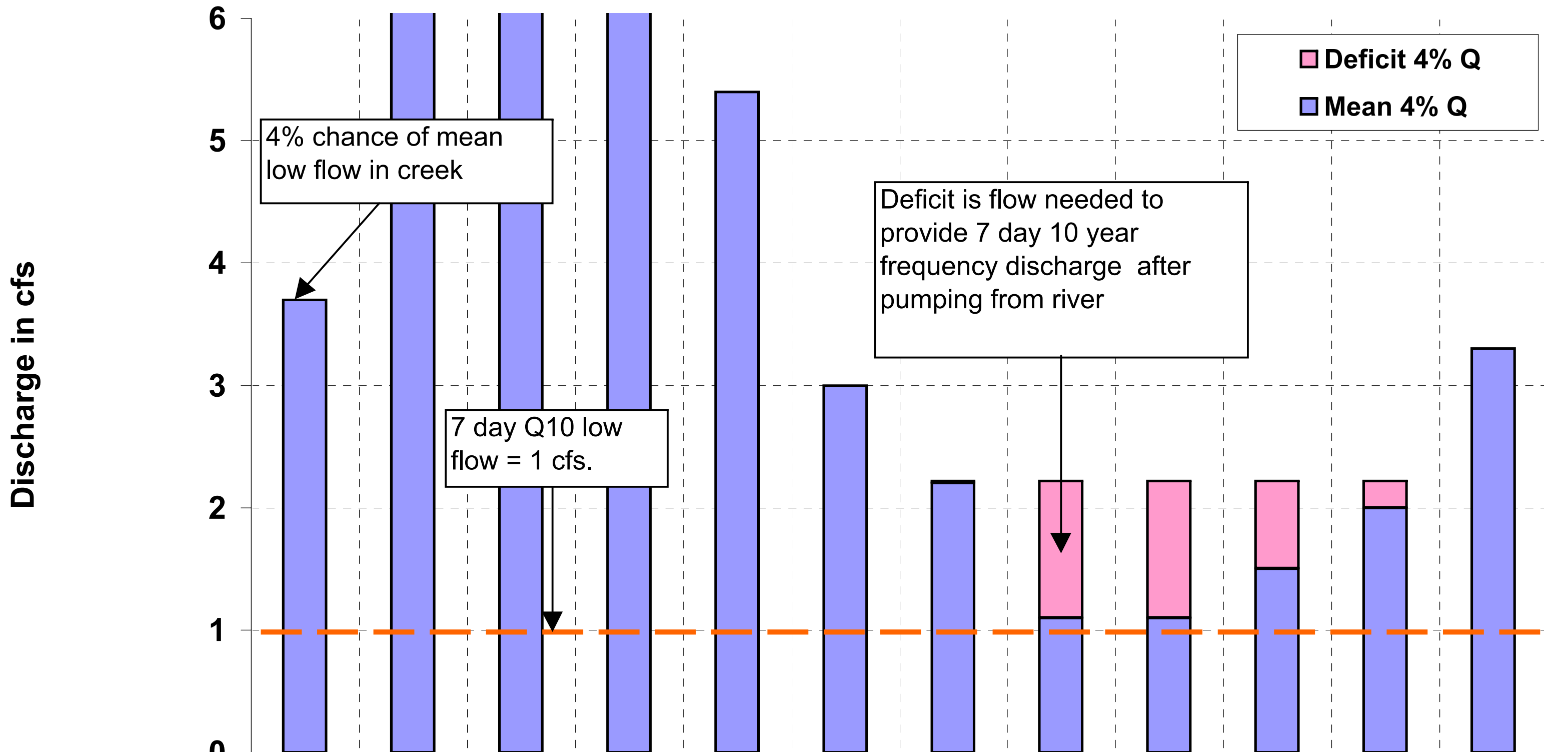


	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Deficit Q for 2%	0.32	0	0	0	0	0.12	0.22	1.32	1.32	0.92	0.82	0.42
Mean Q for 2%	1.9	3.6	5	4.5	2.9	2.1	2	0.9	0.9	1.3	1.4	1.8

Month

Figure 50.8.b

Perryville, Missouri
Low Flow
4% chance of non-exceedence
or 1 year in 25 years
Period of Record 1950 through 2000



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Deficit 4% Q	0	0	0	0	0	0	0.02	1.12	1.12	0.72	0.22	0
Mean 4% Q	3.7	7.4	11.9	9.6	5.4	3	2.2	1.1	1.1	1.5	2	3.3

Month

Figure 50.8.c

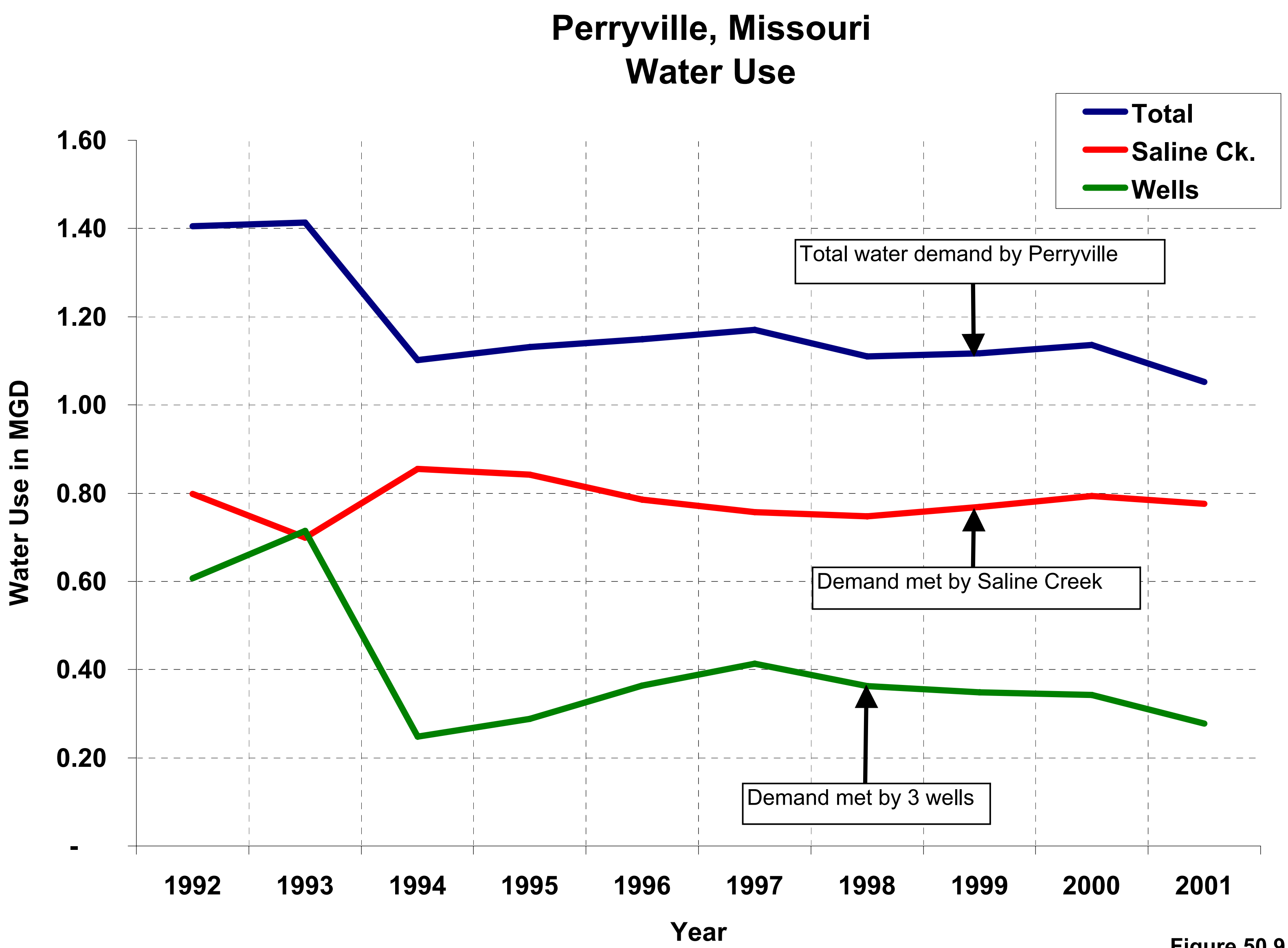
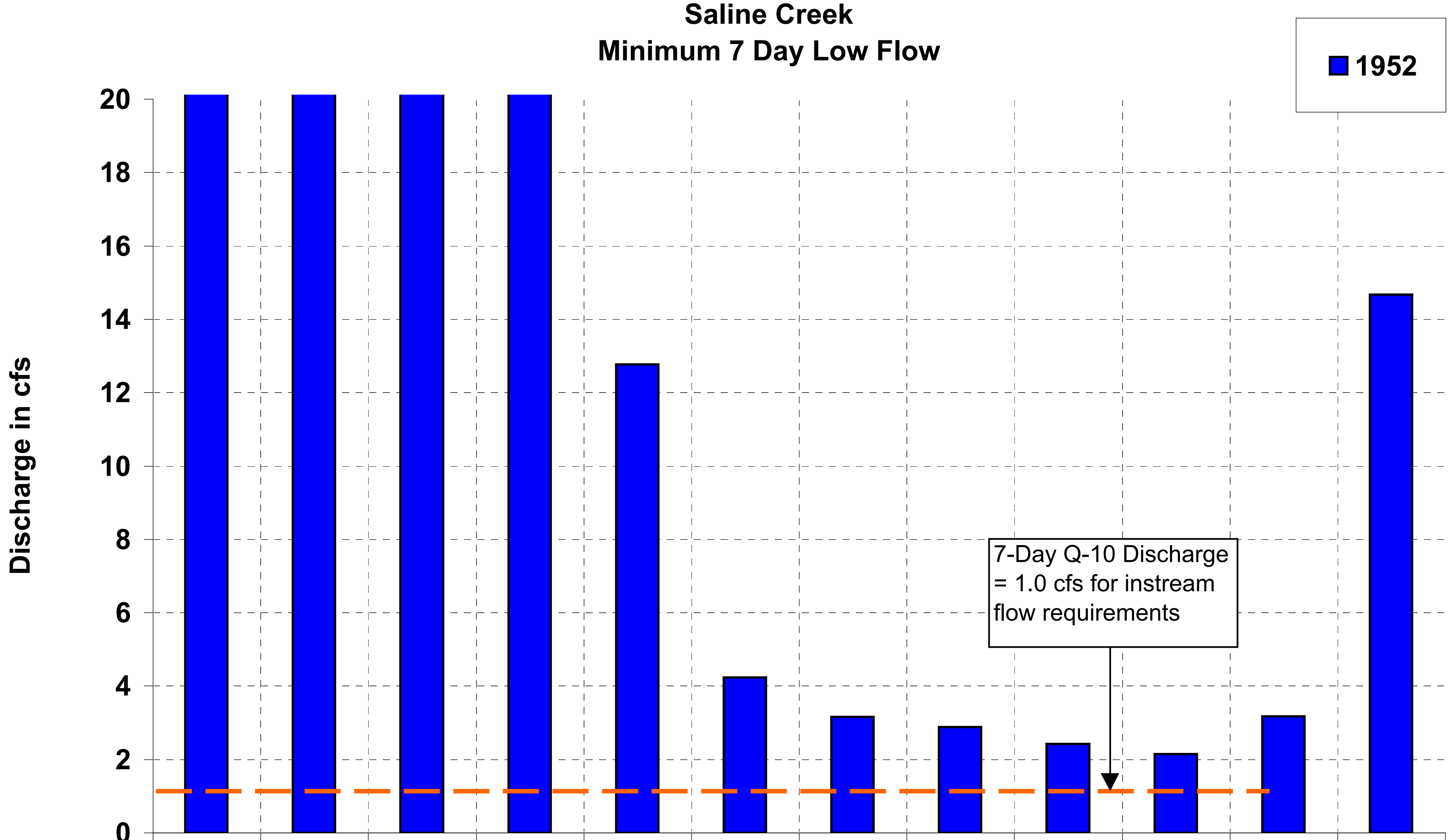

Perryville, Missouri
Water Use
Total
Saline Ck.
Wells
Total water demand by Perryville
Demand met by Saline Creek
Demand met by 3 wells
Water Use in MGD
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
-
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
Year

Figure 50.9

Perryville, Missouri

Saline Creek

Minimum 7 Day Low Flow

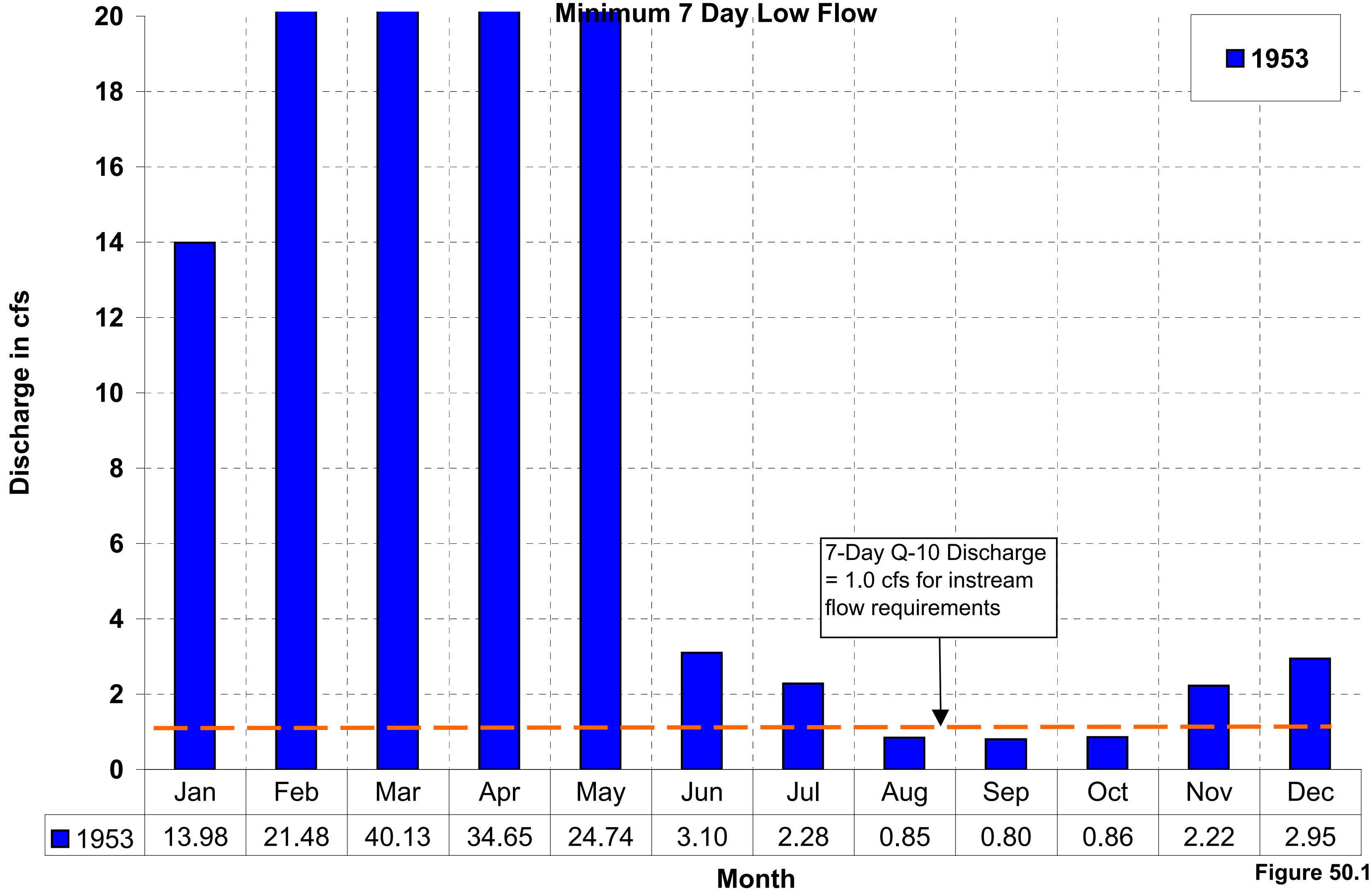


	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1952	38.25	37.46	37.65	72.27	12.77	4.23	3.16	2.89	2.42	2.15	3.17	14.67

Month

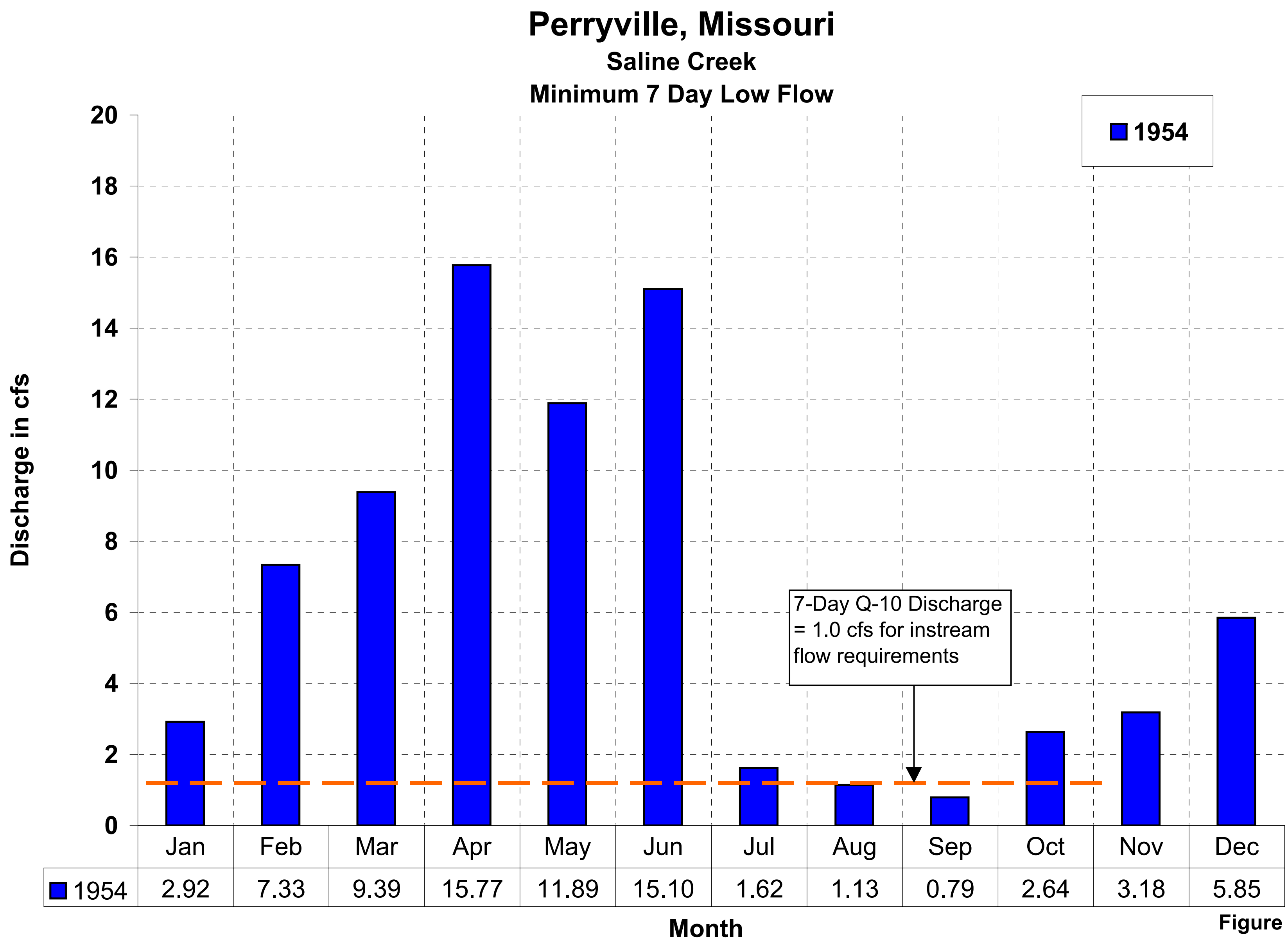
Figure 50.10.a

Perryville, Missouri
Saline Creek
Minimum 7 Day Low Flow



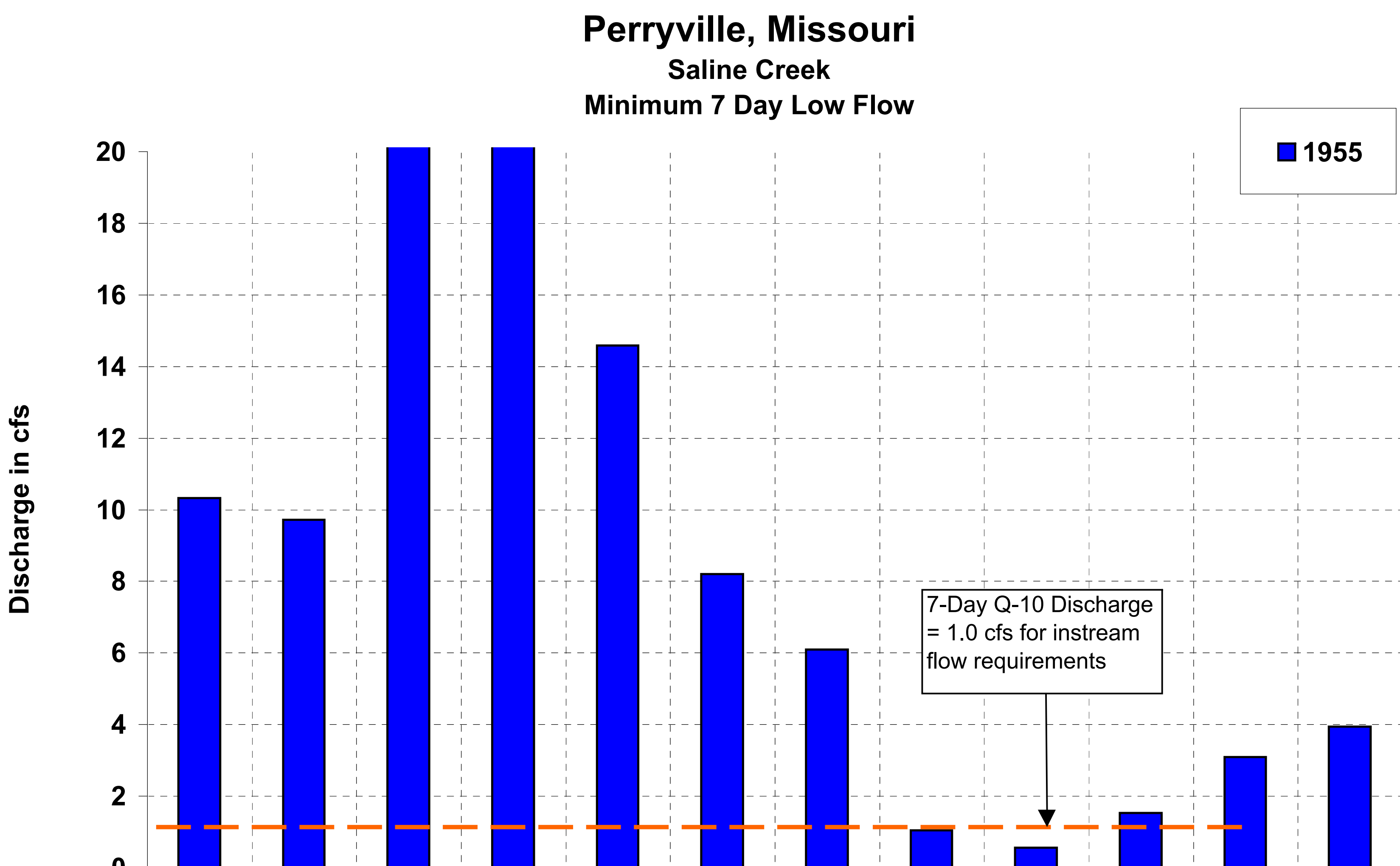
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1953	13.98	21.48	40.13	34.65	24.74	3.10	2.28	0.85	0.80	0.86	2.22	2.95

Figure 50.10.b



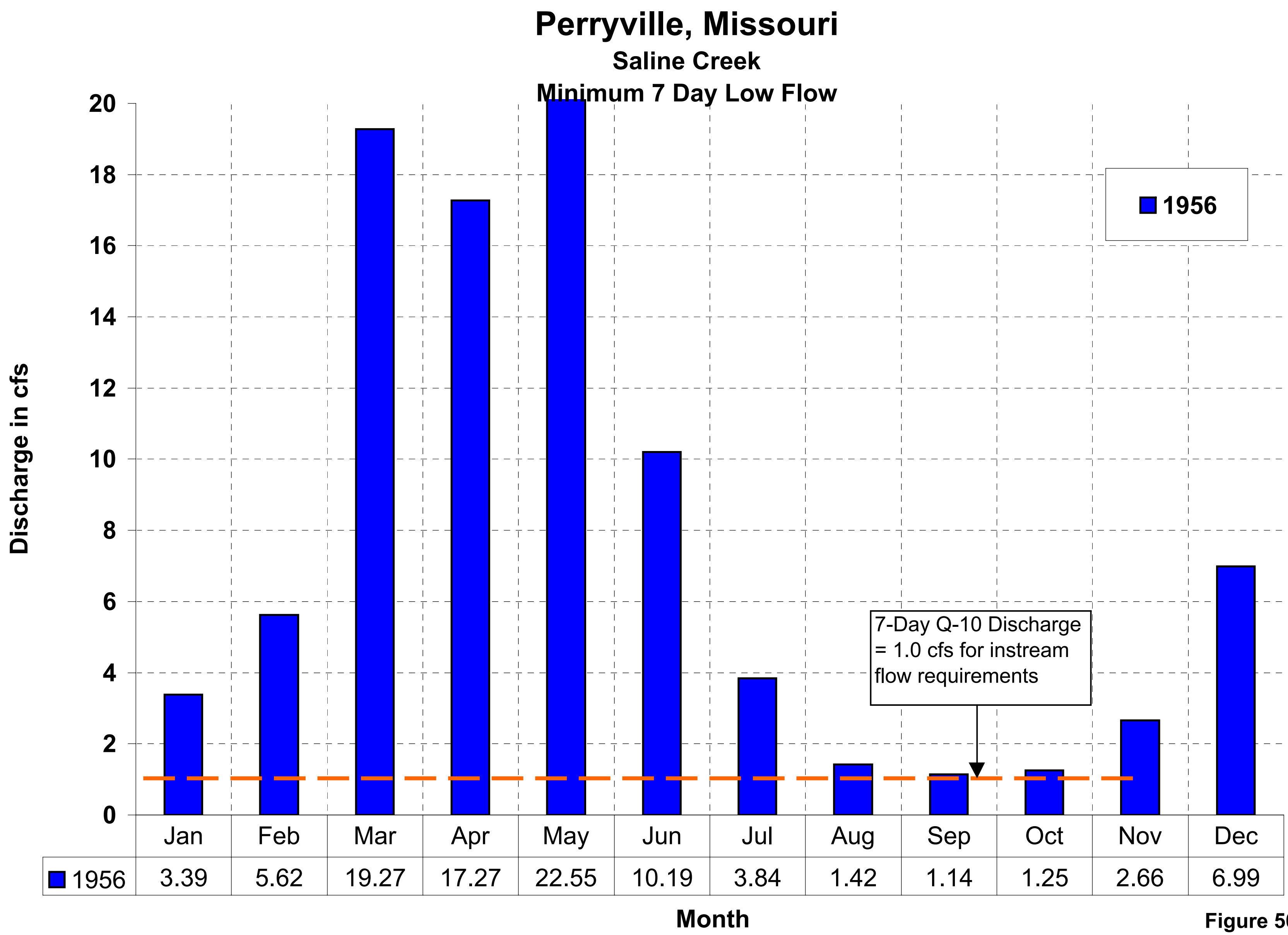
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1954	2.92	7.33	9.39	15.77	11.89	15.10	1.62	1.13	0.79	2.64	3.18	5.85

Figure 50.10.c



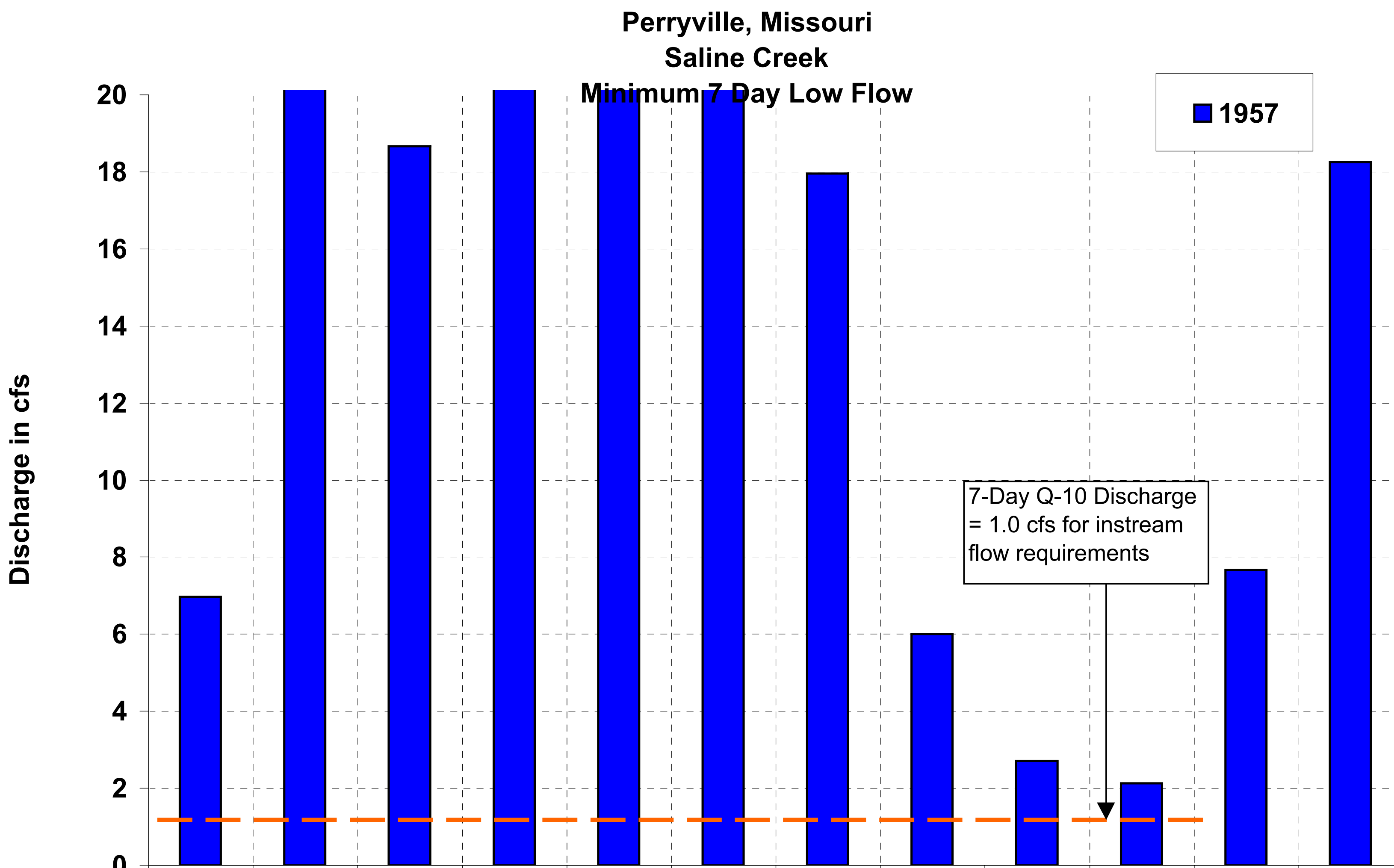
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1955	10.32	9.72	47.85	20.46	14.59	8.21	6.10	1.04	0.55	1.54	3.09	3.94

Figure 50.10.d



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1956	3.39	5.62	19.27	17.27	22.55	10.19	3.84	1.42	1.14	1.25	2.66	6.99

Figure 50.10.e



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1957	6.97	34.01	18.67	111.29	59.82	24.63	17.95	6.00	2.71	2.13	7.66	18.25

Month

Figure 50.10.f

POPLAR BLUFF, MISSOURI
Water Supply Study
Black River

INTRODUCTION:

This analysis was made to assess the availability of Poplar Bluff's water supply. Poplar Bluff obtains their water supply from The Black River. In 2001 there was an average of 3.075 million gallons per day (4.76 cfs) pumped from Black River, which is fed by numerous springs throughout its drainage area and a continuous release from Clearwater Reservoir.

DISCUSSION:

Poplar Bluff obtains their municipal water from Black River. There is no off channel storage to draw upon during periods of low flow. The drainage area at the intake for Poplar Bluff is 1245 square miles. There are two stream gages on Black River, one at Poplar Bluff with a drainage area of 1245 square miles and the other at Annapolis, drainage area is 484 square miles. Upstream of Poplar Bluff is Clearwater Lake at drainage area 898 square miles. Completion of the lake was in 1948. A minimum continuous release rate from the lake of 150 cfs is maintained at the dam. This was the estimated minimum continuous flow at the dam site prior to construction. Below the dam, Piedmont and Poplar Bluff use stream flow for their municipal water supplies. Clearwater dam was designed for flood control and has no storage for municipal supplies. In the year 2001 Poplar Bluff used 1,123 million gallons of water, or 3.075 MGD. In addition, Piedmont uses water from Black River and takes 164.25 million gallons or 0.45 MGD. Their intake is about 1 mile below Clearwater Dam.

Clearwater Reservoir is owned and operated by the Corps of Engineers and is managed for Flood Control. The most severe drought that has been recorded in the Black River Basin was for the period 1952 through 1956. Clearwater Lake was able to maintain normal Minimum releases during all drought periods.

Figure 60.1 shows the annual rainfall at Poplar Bluff for the period 1920 through 2001. This indicates the precipitation trend to be nearly uniform for the period of record.

Figure 60.2.a shows the annual runoff fin watershed inches for Black River at Poplar Bluff. The trend indicates an increase in total annual runoff from 7.5 inches to 10 inches or approximately 33% from 1955 to year 2000. **Figure 60.2.b** shows the runoff in terms of mean annual cubic feet per second.

Stream gage records on Black River at Poplar Bluff show the drought of record to be in the 1950's. The following **figures 60.3.a, 60.3.b, 60.3.c, and 60.3.d** compare the 1-%, 2% and 4% chance mean monthly non-exceedence flows (low flow) to measured flows for 1953, 1954, 1955 and 1956. All frequencies exceeded the adjusted 7-day Q-10 discharges at Poplar Bluff. In 1953, October had the lowest mean discharge of 268 cfs, which exceeded the 7-day Q-10 discharge by 52 cfs. Low flows for 1954, 1955 and 1956 exceeded 7-day Q-10 by 84, 60 and 43 cfs respectively.

Clearwater Reservoir controls all storm runoff from its drainage area of 898 square miles and releases the runoff at a minimum rate of 150 cubic feet per second. When droughts occur, low flows will be effected by releases from Clearwater to greater extent than high flows. Therefore it is necessary to make adjustments to account for controlled and uncontrolled drainage area contribution to base flow. The total drainage area at Poplar Bluff is 1245 square miles. The uncontrolled area is 347 square miles. By determining the base flow for the uncontrolled area and adding the minimum release of 150 cubic feet per second from the reservoir we were able to determine the expected base flow for dry periods.

Base flow separation was made using the USGS computer program, HYSEP. HYSEP separates the base flow hydrograph from the total hydrograph. This analysis was made to estimate sustained flow for meeting water supply needs during a drought. **Figure 60.4.a** is the base flow index defined as the ratio of base flow to total stream flow. This chart shows the yearly fluctuation in base flow indexes and indicates the trend. The trend shows a constant base flow index of approximately 67% during the period of 1950 through 2000. Base flow was calculated and is shown in **figure 60.4.b** in terms of cfs for the period of 1950 through 2000. Trend shows that mean base flow has increased from about 850 cfs to approximately 1050 cfs for that period. Total flow was also calculated and is shown in **figure 60.4.c**. The trend for total flow shows an increase from 1300 cfs to 1600 cfs for the 50-year period.

To make the base flow analysis it was necessary to adjust the flow at Poplar Bluff for the uncontrolled area nad release from Clearwater Reservoir. A correlation between base flow and also total flow at Annapolis and Poplar Bluff gages for the period of 1940 through 1948 was determined. The gates on Clearwater Reservoir were closed in 1948. **Figure 60.4.d** is the base flow correlation and **figure 60.4.e** is the total flow correlation. Following are the steps to determine minimum base flow index.

Steps to adjust base flow are:

Step 1. Determine base flow and total stream flow for the Annapolis and Poplar Bluff Gages for years 1940 through 1948 using "HYSEP".

Step 2. Plot the annual total flow and annual base flow discharges to determine the relationship of the two gages. The resulting equations are:
Base Flow at Poplar Bluff = 2.4858 x flow at Annapolis – 5.8173 (Figure 4d)
Total Flow at Poplar Bluff = 2.066 x flow at Annapolis + 55.909. Figure 4e)

Step 3 Use the above equations to determine the mean annual base flow and total flow at Poplar Bluff for the intervening drainage area between the lake and Poplar Bluff for the period 1950 through 2000.

Step 4 Add the minimum release of 150 cfs from Clearwater Reservoir to each yearly mean discharge value from step 3.

Step 5 Plot adjusted mean annual base flow in cfs vs. year. (Figure 4b)

Step 6 Plot adjusted mean total annual flow in cfs vs. year. (Figure 4c)

Step 7 Plot ratio of base flow to total flow for the base flow index. (Figure 4a)

To determine the rate of flow needed to maintain in-stream flow requirements, the 7-day Q-10 low flow was determined using the period of record, 1950 through 2000. The 7-day Q-10 frequency discharge is used to establish standards for water quality issues. A computer program named 'DURFREK' (a duration frequency computer program developed by Hydrosphere) was used to make a frequency analysis of 7-day duration discharges. **Figure 60.5.a** shows the plot of the values for a frequency analysis. The 7-day Q-10 frequency analysis was determined to be 66 cfs for the intervening area below the Clearwater dam. 150 cfs was added for the minimum continuous release from Clearwater Lake and the minimum value for 7-day Q-10 low flow is 216 cfs.

Steps taken to make the adjustment for effects of Clearwater Reservoir on the minimum in-stream flow requirements are:

Step 1 Determine frequency of 7-day duration mean flow for Annapolis and Poplar Bluff Gages for years 1940 through 1948, which is the period when data was available for both gages and before Clearwater Reservoir was constructed. Run Durfrek on Annapolis and Poplar Bluff gages for that time period.

Step 2 Convert the 7-day duration discharges in step 1 to a per square mile of drainage area for each gage.

Step 3 Plot data in step 2, Poplar Bluff data vs. Annapolis data for 1940 through 1948, as shown in figure 60.5.b.

Step 4 Determine equation for relationship between the two gages from step 3. The following equation for the 7-day duration 10-year frequency low flow discharge was determined to be:

7-day duration low flow frequency =
1.6982 x (Discharge at Annapolis gage per square mile)^2 +
0.5885* (Discharge at Annapolis gage per square mile) + 0.597.

Step 5 Run duration frequency analysis, using Durfrek computer program, On Black River at Annapolis stream gage data for years 1950 through 2000 for 7-day duration.

Step 6 Convert results in step 5 to a per square mile basis by dividing by drainage area at the Annapolis gage.

Step 7 Multiply results in step 6 by the 346 square miles drainage area below Clearwater Reservoir.

Step 8 Add 150 cfs to each frequency value in step 7 to account for minimum release from Clearwater Reservoir.

Step 9 Plot results of 7-day Q-10 discharge in step 7 for the intervening area. Also plot step 8 results for the total 7-day Q-10 total discharge with constant release from Clearwater Reservoir.

Step 10 Minimum 7-day Q-10 discharge was determined to be 66 cfs from the intervening area plus 150 cfs constant release from Clearwater Reservoir established flow requirement for in-stream needs of 216 cfs.

Seven-day annual low flows for 1941 through 2000 were calculated and are shown **figure 60.6**. Visual observation shows that the trend for 7-day annual low flows has increased during the 60 years of record by about 40 percent.

Monthly non-excedence probabilities (low flows) for 1% chance of occurrence (1 time in 100 years), 2% chance (1 time in 50 years) and 4% chance (1 time in 25 years) were established from stream flow data for the years 1950 through 2000. **Figure 60.7** displays these results. Mean monthly low flow probabilities exceed the 7-day Q-10 discharge of 216 cfs for all frequencies. For this report, all statistical determinations were made using the Log Pearson Type 3 method as described in Water Resource Council bulletin 17B.

Because all mean monthly flows exceed the 7-day Q-10 in-stream flow requirements plus withdrawal rates by the city, it is not necessary to show shortages of water for Poplar Bluff. Any deficits that may occur would be of very short duration.

Figure 60.9 is the daily demand by Poplar Bluff, in million gallons per year. During the period of 1985 through 2001 their demand has increased from 1.937 MGD in 1985 to 3.075 MGD in 2001. The trend is increasing at the rate of 75,000 gallon per year.

Additional comparisons for the 1950's drought were made using the mean 7-day low flow for examining a shorter duration. These comparisons are shown in **figures 60.10.a, 60.10.b, 60.10.c and 60.10.d**. These figures compare mean seven-day low flows to 7 day Q10 flow, and indicate short-term critical periods. In the 4 years period of 1953 through 1956 there were 12 months that had mean seven-day flows below 7 day Q10 discharge.

They were:
1953 – 2 months October (255 cfs), November (245 cfs).
1954 - 2 months September (250cfs), October (259 cfs).
1955 - 2 months September (254 cfs), October (253 cfs).

1956 - 2 months September (253cfs), October (259 cfs).

Clearwater Lake is a Corps of Engineers project and was constructed in 1948 to provide flood control for the downstream drainage districts. Water supply was not included in the design of this lake. During planning, it was determined that base flow at the dam site was 150 cfs. The operating plan for the lake requires a minimum of 150-cfs continuous release. Their water control plan requires alerting the residents of Poplar Bluff if the stage drops below 0.3 feet. To date this has never happened and is not likely to occur. During the 1950's, the drought of record occurred from 1952 through 1956, release of 150 cfs from Clearwater Lake was maintained through the drought. There are several springs between the lake and Poplar Bluff that have continuous flow. **Figure 60.11** shows the storage in Clearwater Reservoir from its closure to year 2000.

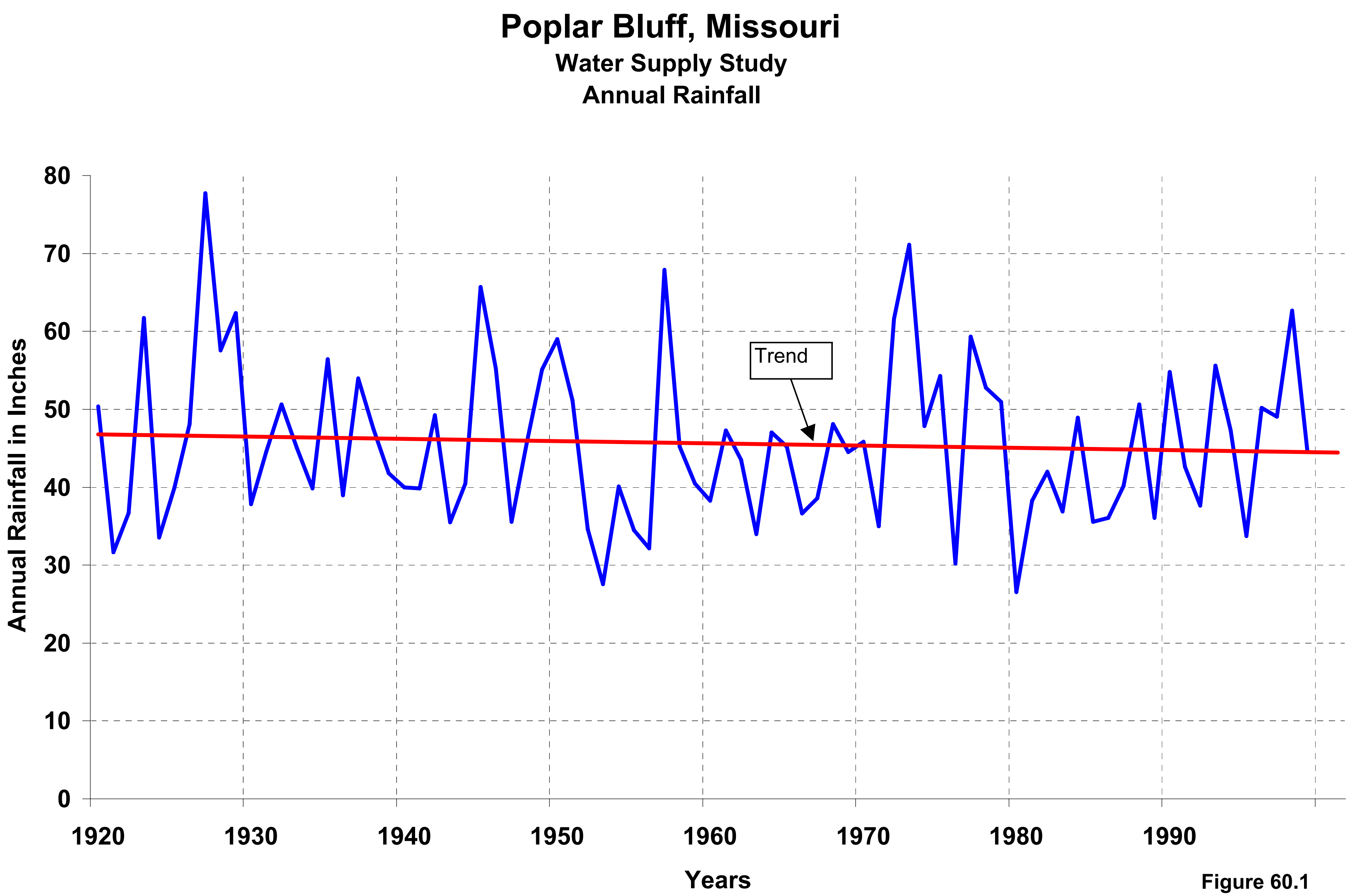

Poplar Bluff, Missouri
Water Supply Study
Annual Rainfall
Annual Rainfall in Inches
0
10
20
30
40
50
60
70
80
1920
1930
1940
1950
1960
1970
1980
1990
Years
Trend

Figure 60.1

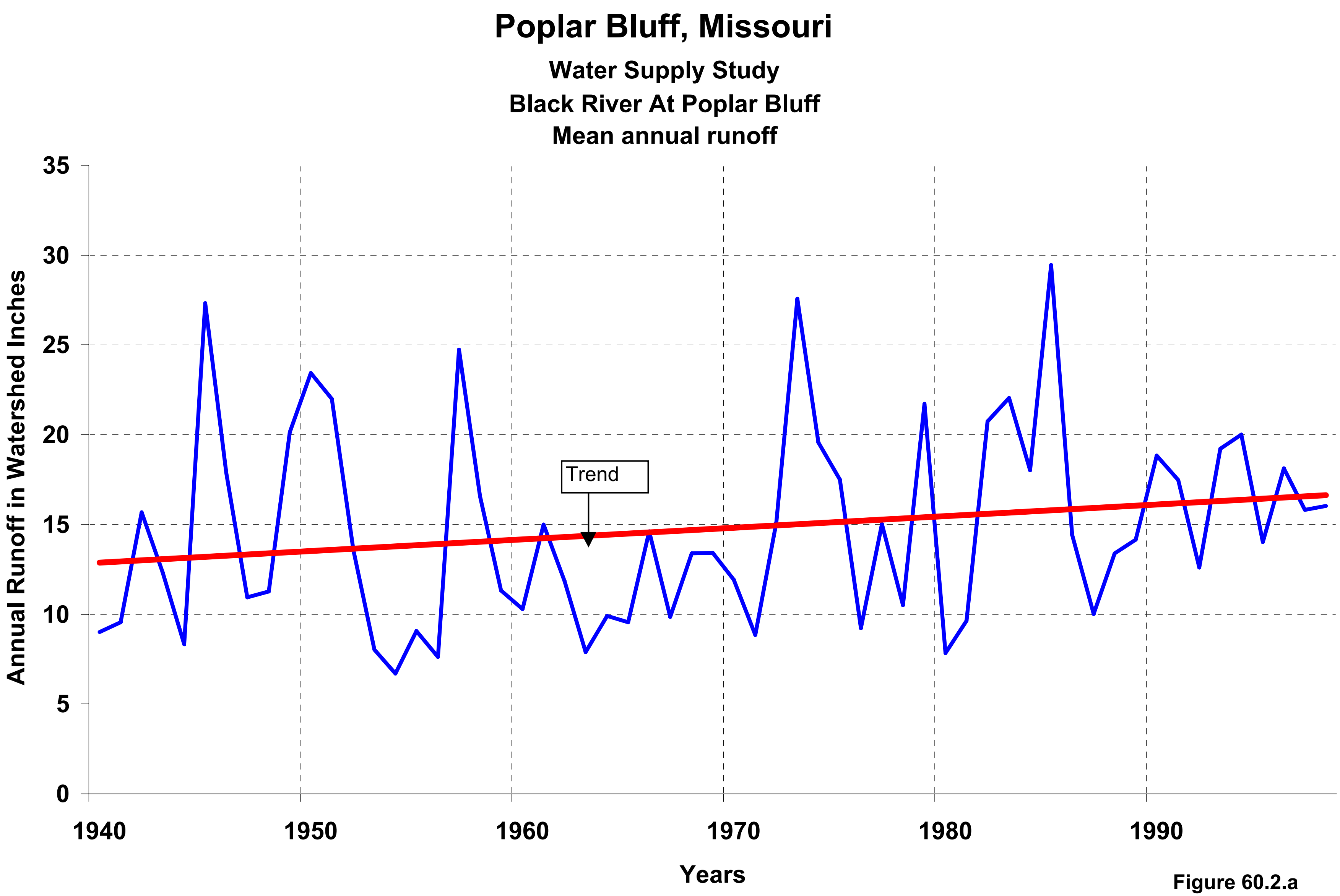
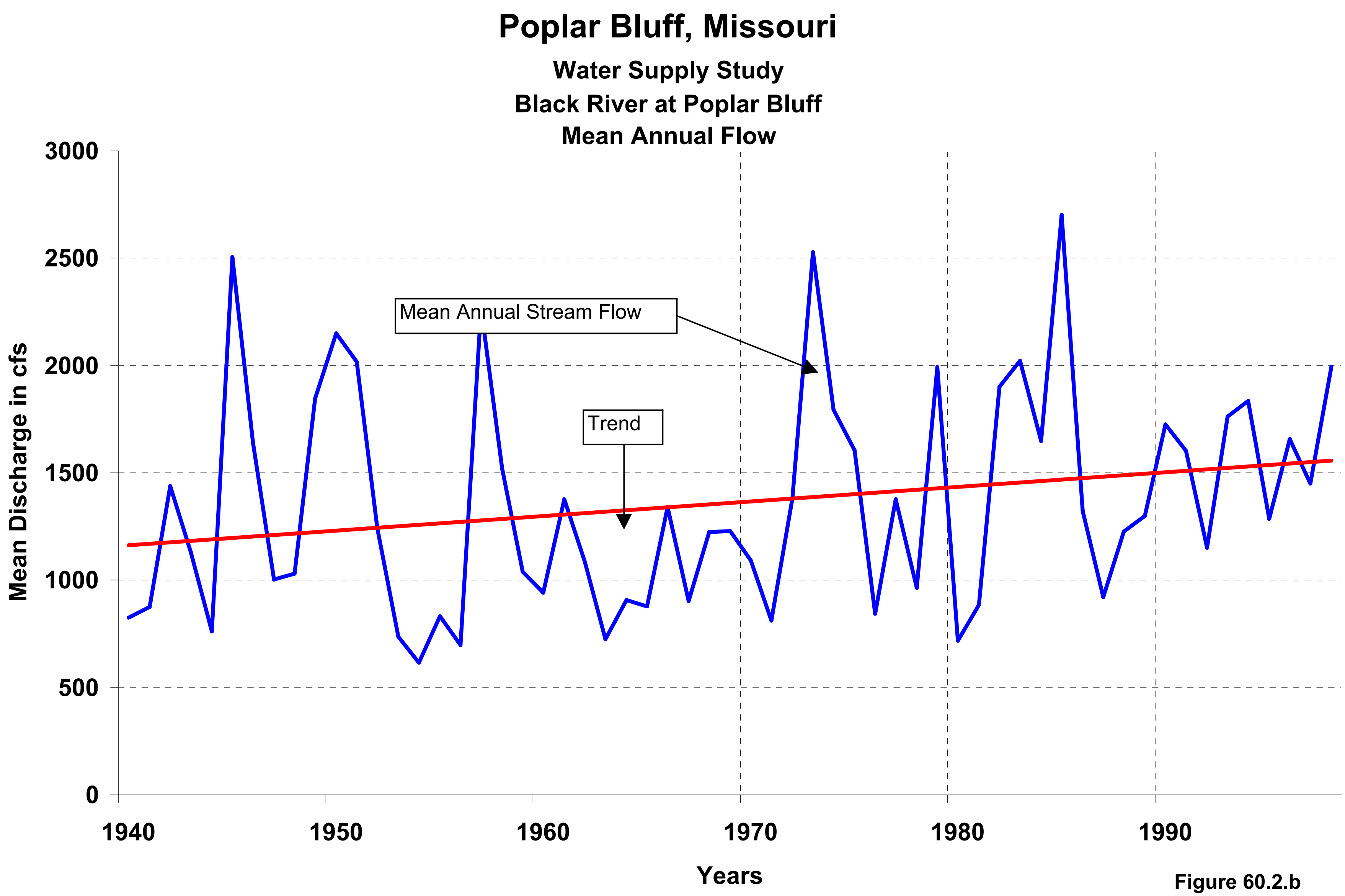
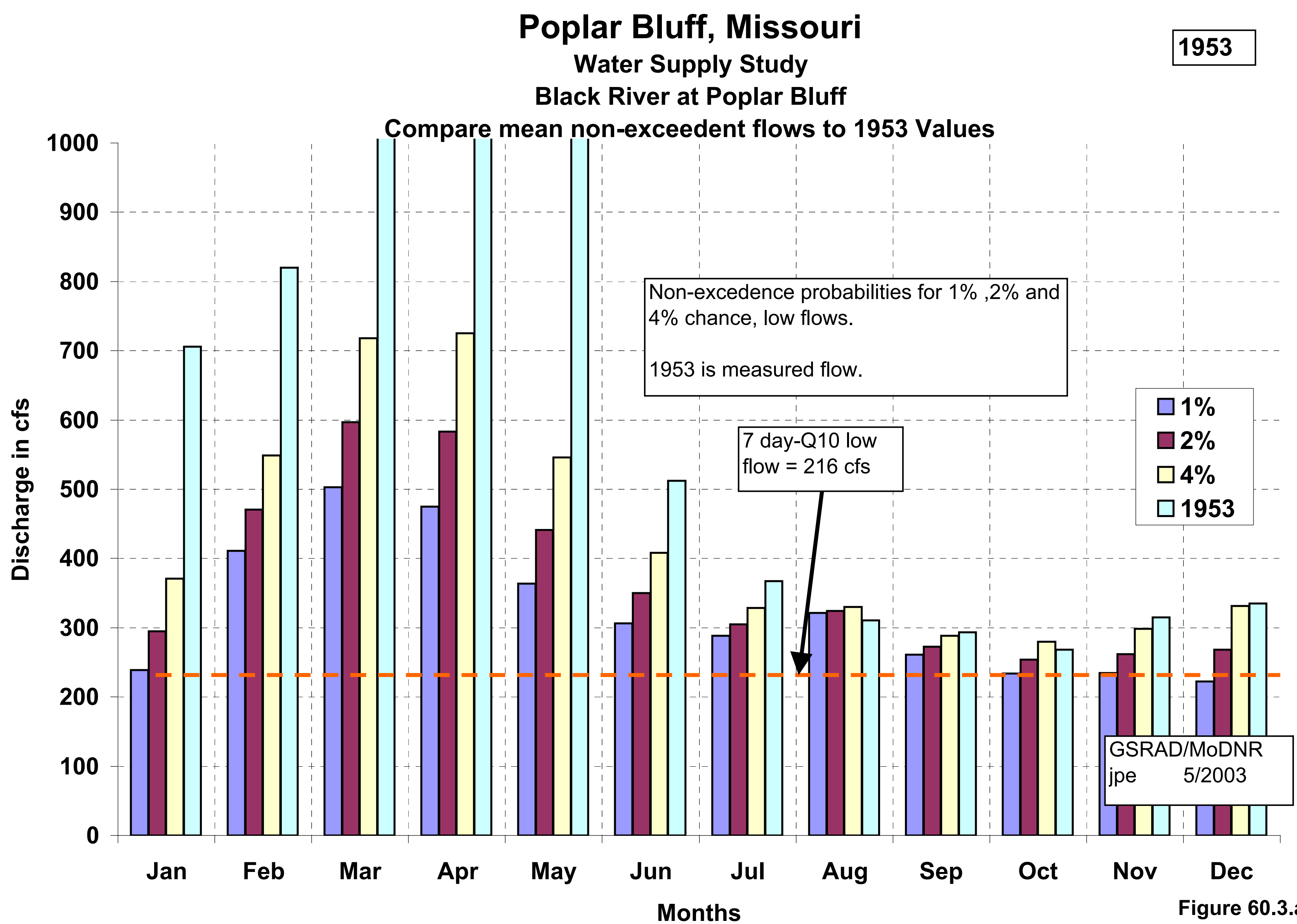

Poplar Bluff, Missouri
Water Supply Study
Black River At Poplar Bluff
Mean annual runoff
Annual Runoff in Watershed Inches
35
30
25
20
15
10
5
0
Trend
1940
1950
1960
1970
1980
1990
Years

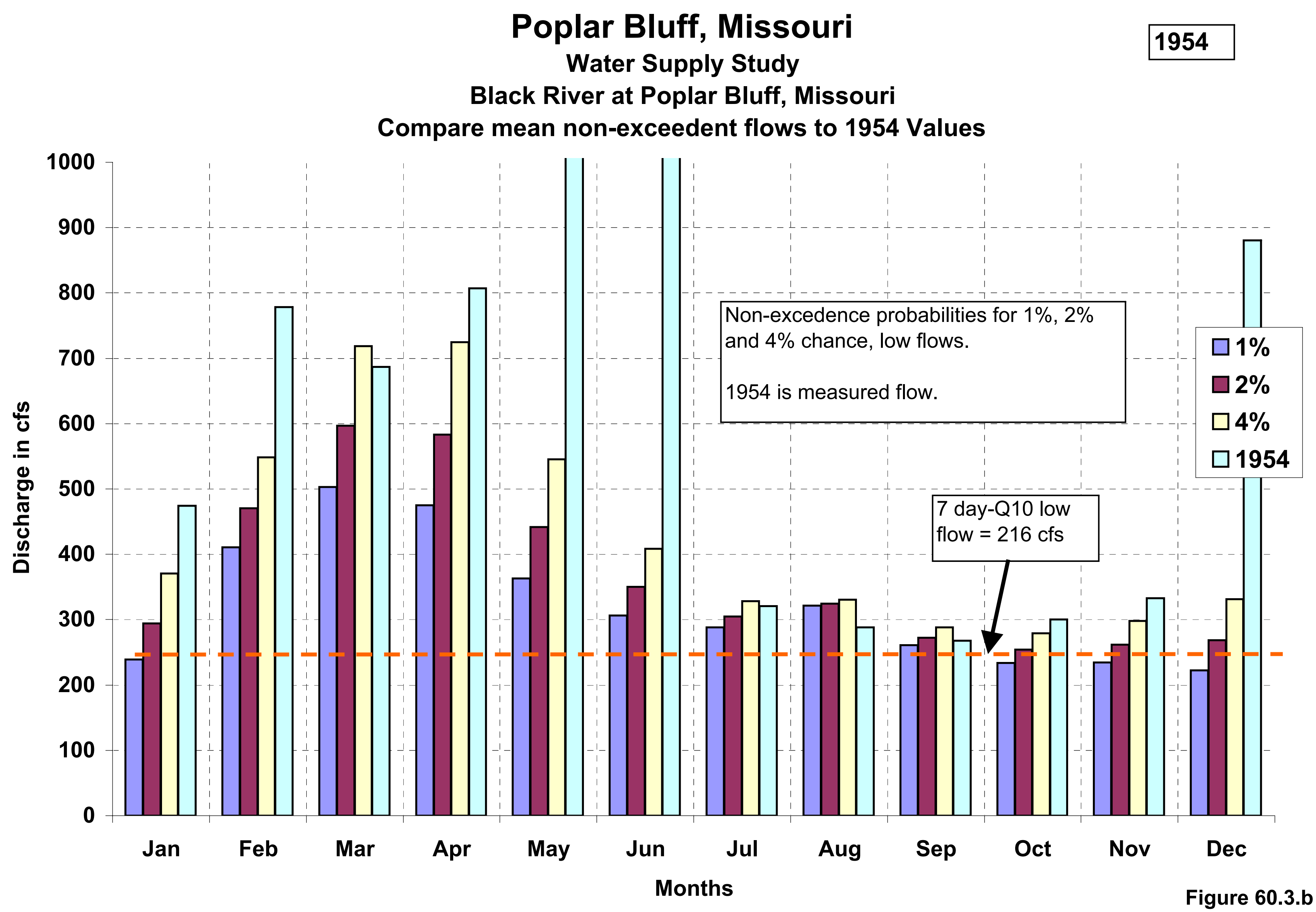
Figure 60.2.a



Poplar Bluff, Missouri
Water Supply Study
Black River at Poplar Bluff
Mean Annual Flow
Mean Discharge in cfs
3000
2500
2000
1500
1000
500
0
Mean Annual Stream Flow
Trend
1940
1950
1960
1970
1980
1990
Years

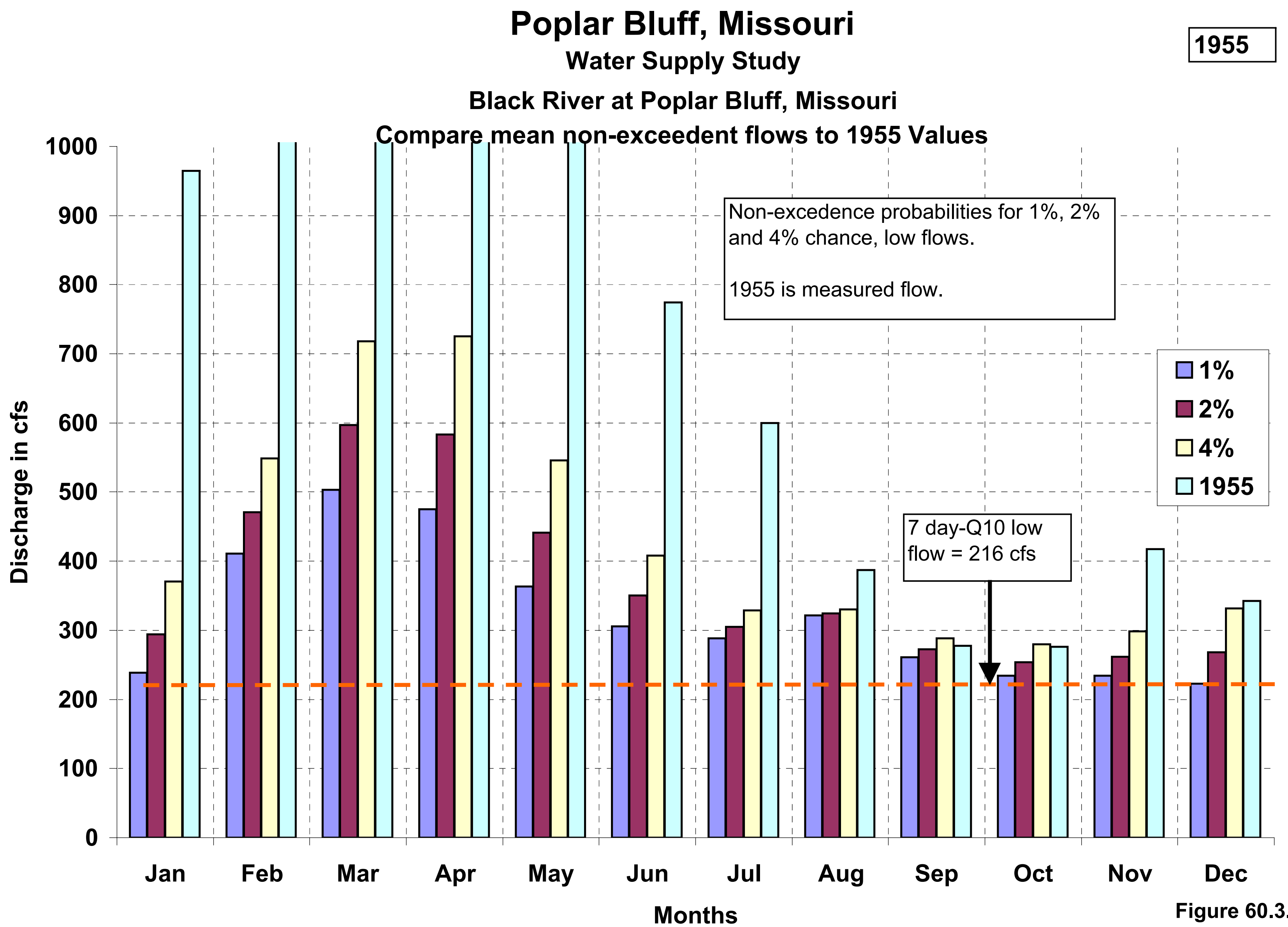
Figure 60.2.b


Poplar Bluff, Missouri
Water Supply Study
Black River at Poplar Bluff
Compare mean non-exceedent flows to 1953 Values
1953
Discharge in cfs
1000
900
800
700
600
500
400
300
200
100
0
Non-excedence probabilities for 1% ,2% and 4% chance, low flows.
1953 is measured flow.
7 day-Q10 low flow = 216 cfs
1%
2%
4%
1953
GSRAD/MoDNR
jpe 5/2003
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Months
Figure 60.3.a



Poplar Bluff, Missouri
Water Supply Study
Black River at Poplar Bluff, Missouri
Compare mean non-exceedent flows to 1954 Values
1954
Discharge in cfs
1000
900
800
700
600
500
400
300
200
100
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Months
Non-excedence probabilities for 1%, 2% and 4% chance, low flows.
1954 is measured flow.
7 day-Q10 low flow = 216 cfs
1%
2%
4%
1954

Figure 60.3.b



Poplar Bluff, Missouri
Water Supply Study
Black River at Poplar Bluff, Missouri
Compare mean non-exceedent flows to 1955 Values
1955
Discharge in cfs
1000
900
800
700
600
500
400
300
200
100
0
Non-excedence probabilities for 1%, 2% and 4% chance, low flows.
1955 is measured flow.
1%
2%
4%
1955
7 day-Q10 low flow = 216 cfs
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Months

Figure 60.3.c

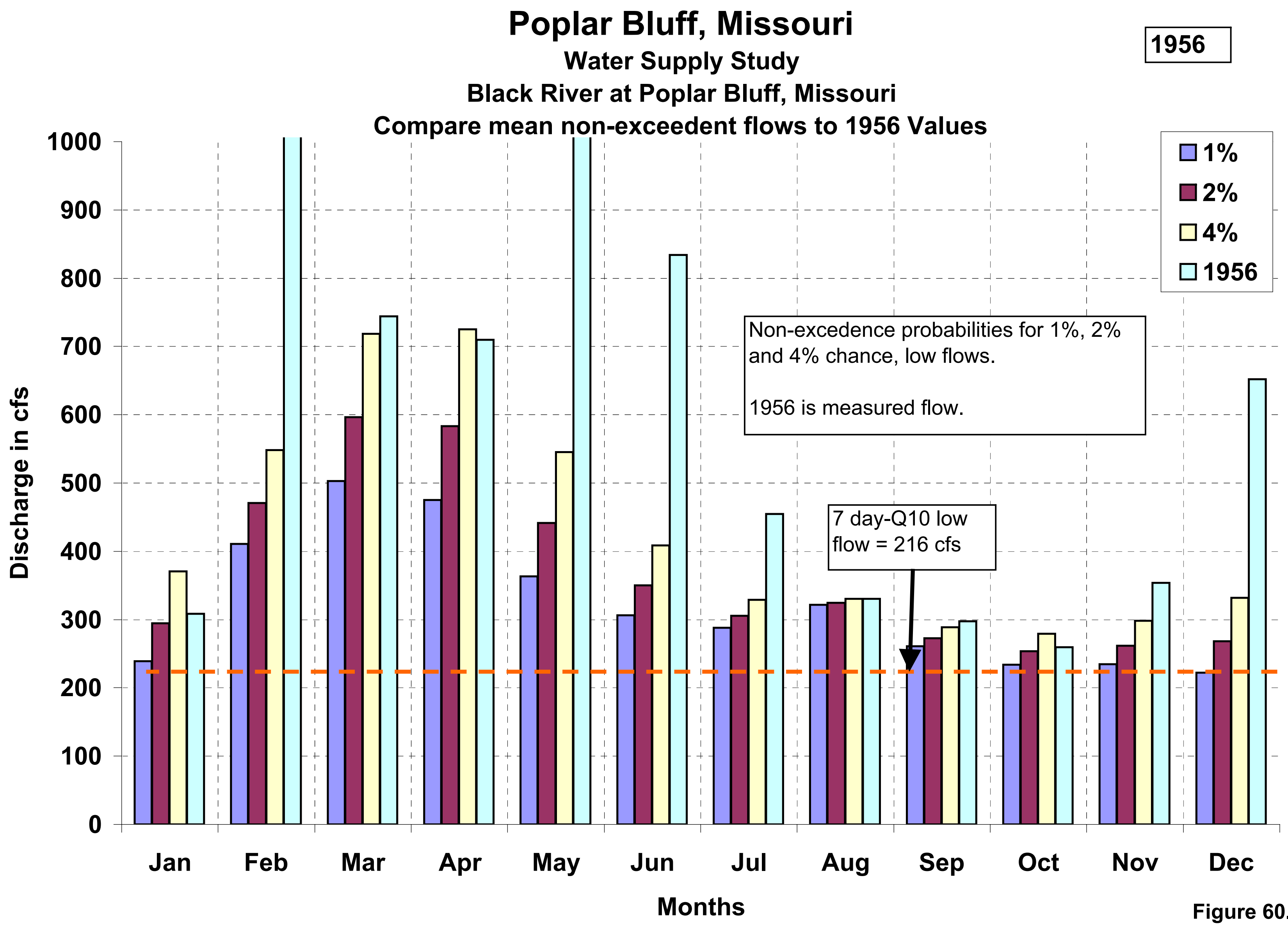

Poplar Bluff, Missouri
Water Supply Study
Black River at Poplar Bluff, Missouri
Compare mean non-exceedent flows to 1956 Values
1956
1%
2%
4%
1956
Non-excedence probabilities for 1%, 2% and 4% chance, low flows.
1956 is measured flow.
7 day-Q10 low flow = 216 cfs
Discharge in cfs
1000
900
800
700
600
500
400
300
200
100
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Months

Figure 60.3.d

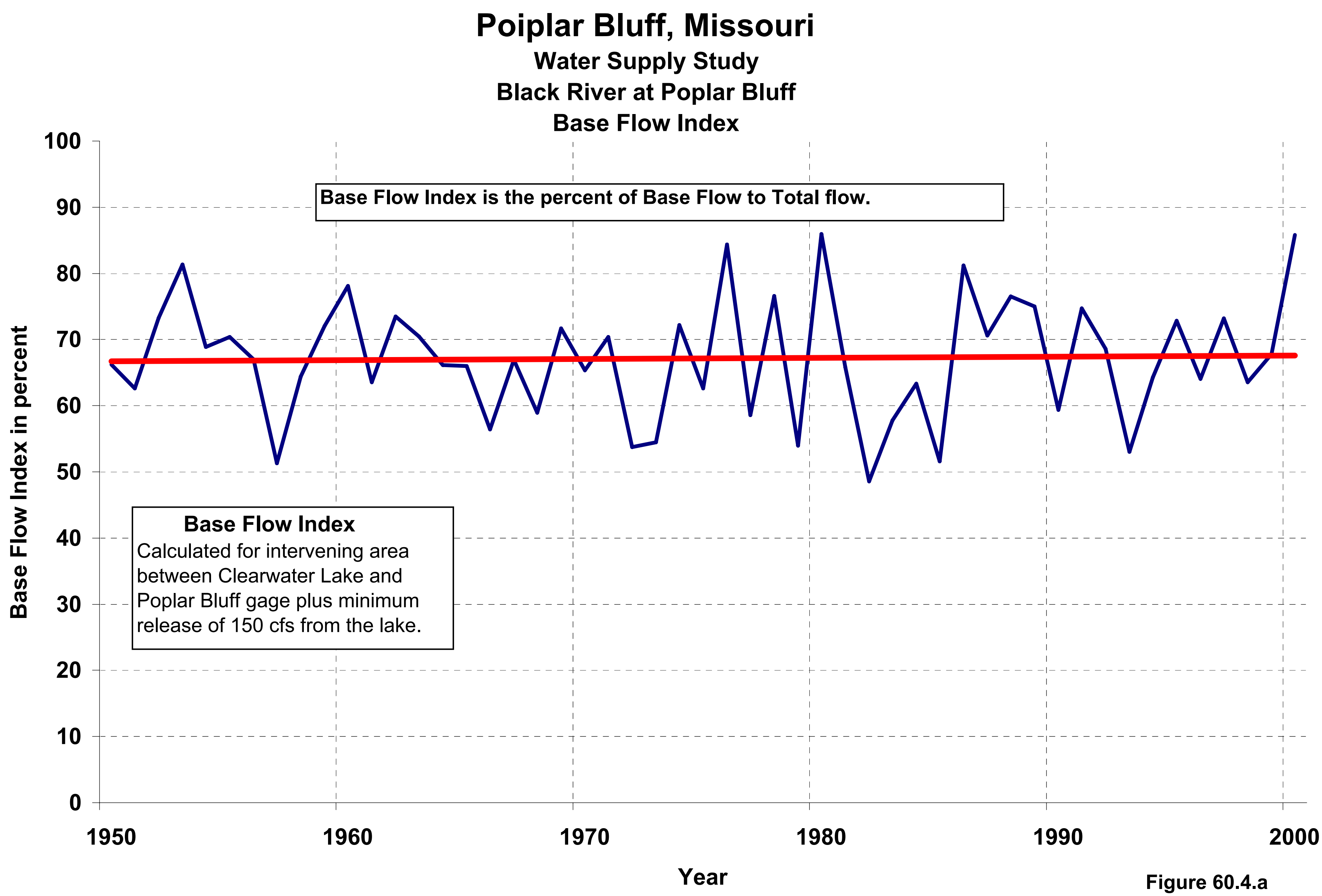

Poiplar Bluff, Missouri
Water Supply Study
Black River at Poplar Bluff
Base Flow Index
Base Flow Index is the percent of Base Flow to Total flow.
Base Flow Index
Calculated for intervening area
between Clearwater Lake and
Poplar Bluff gage plus minimum
release of 150 cfs from the lake.
Base Flow Index in percent
100
90
80
70
60
50
40
30
20
10
0
1950
1960
1970
1980
1990
2000
Year

Figure 60.4.a

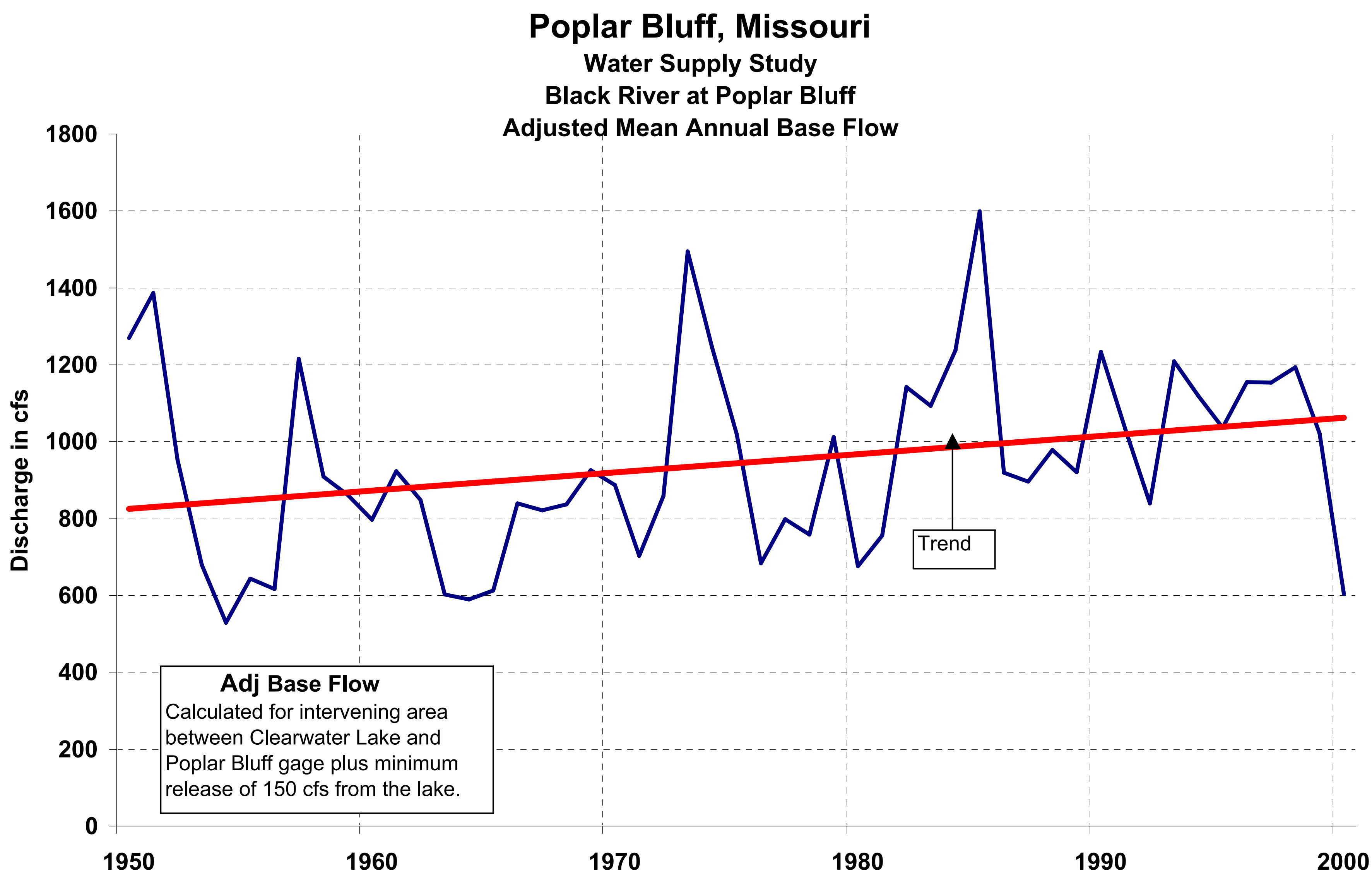

Poplar Bluff, Missouri
Water Supply Study
Black River at Poplar Bluff
Adjusted Mean Annual Base Flow
Discharge in cfs
1800
1600
1400
1200
1000
800
600
400
200
0
1950
1960
1970
1980
1990
2000
Year
Trend
Adj Base Flow
Calculated for intervening area
between Clearwater Lake and
Poplar Bluff gage plus minimum
release of 150 cfs from the lake.

Figure 60.4.b

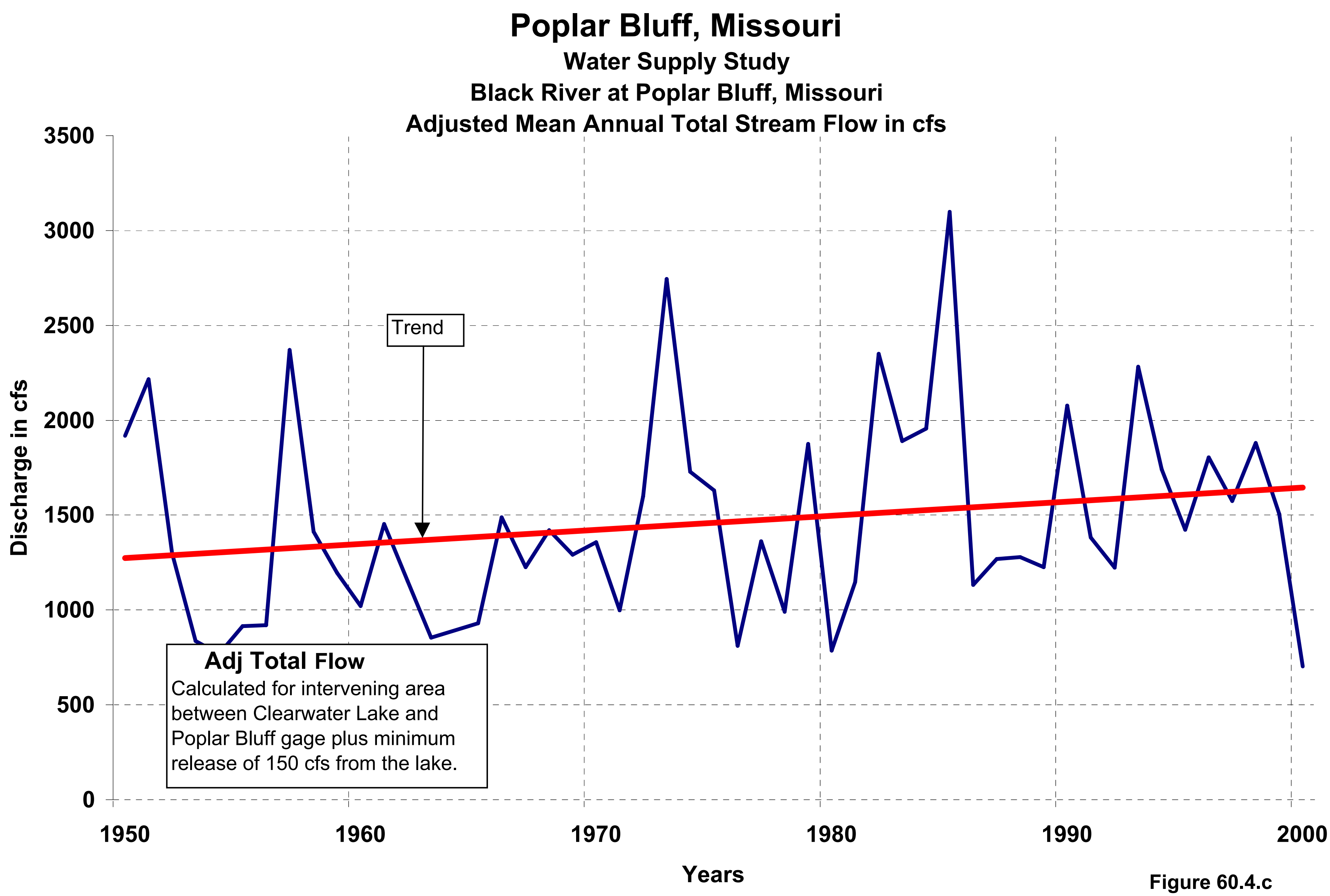
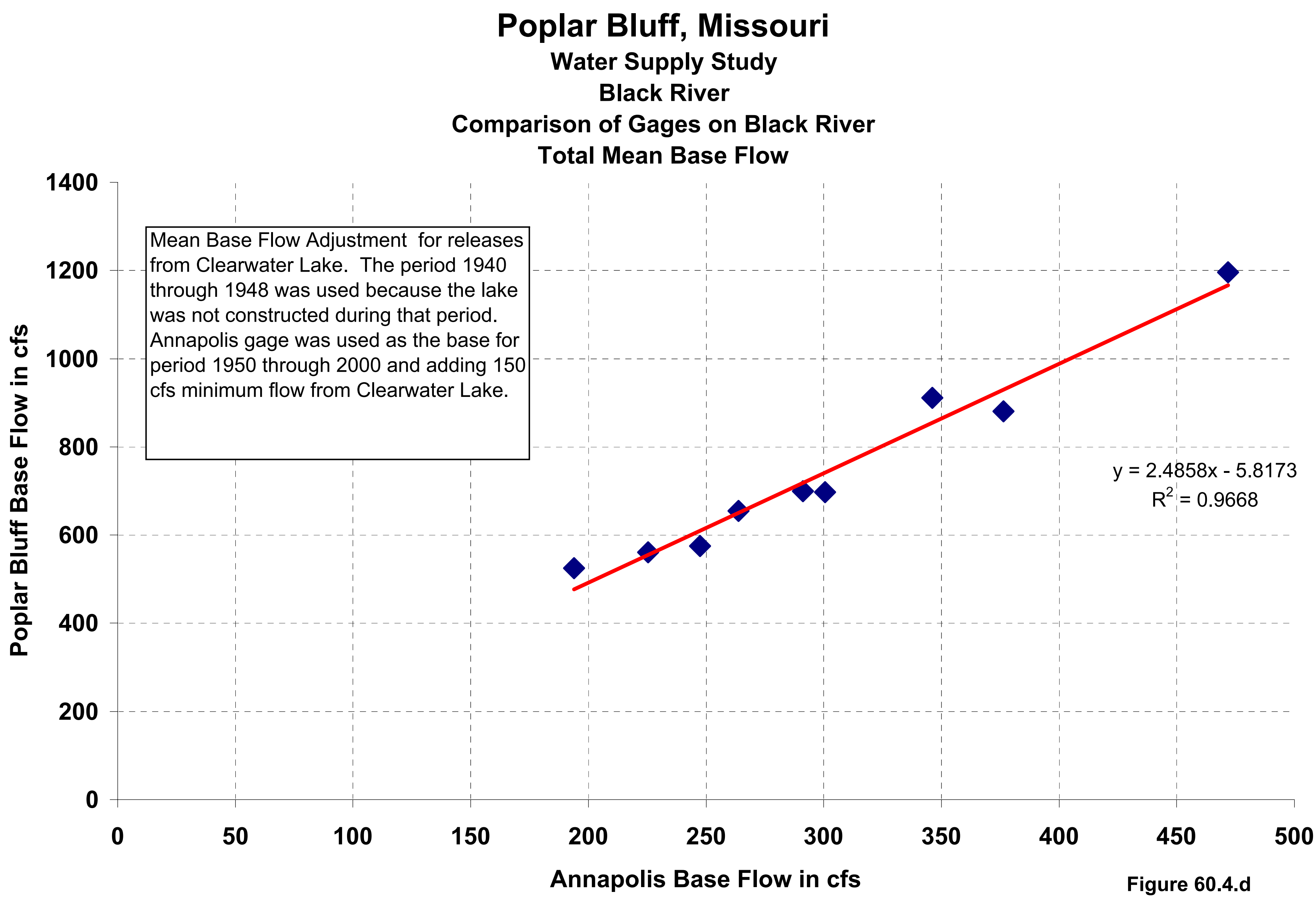

Poplar Bluff, Missouri
Water Supply Study
Black River at Poplar Bluff, Missouri
Adjusted Mean Annual Total Stream Flow in cfs
Discharge in cfs
3500
3000
2500
2000
1500
1000
500
0
1950
1960
1970
1980
1990
2000
Years
Trend
Adj Total Flow
Calculated for intervening area between Clearwater Lake and Poplar Bluff gage plus minimum release of 150 cfs from the lake.

Figure 60.4.c



Poplar Bluff, Missouri
Water Supply Study
Black River
Comparison of Gages on Black River
Total Mean Base Flow
Mean Base Flow Adjustment for releases from Clearwater Lake. The period 1940 through 1948 was used because the lake was not constructed during that period. Annapolis gage was used as the base for period 1950 through 2000 and adding 150 cfs minimum flow from Clearwater Lake.
y = 2.4858x - 5.8173
R2 = 0.9668
Poplar Bluff Base Flow in cfs
Annapolis Base Flow in cfs
0
200
400
600
800
1000
1200
1400
0
50
100
150
200
250
300
350
400
450
500

Figure 60.4.d

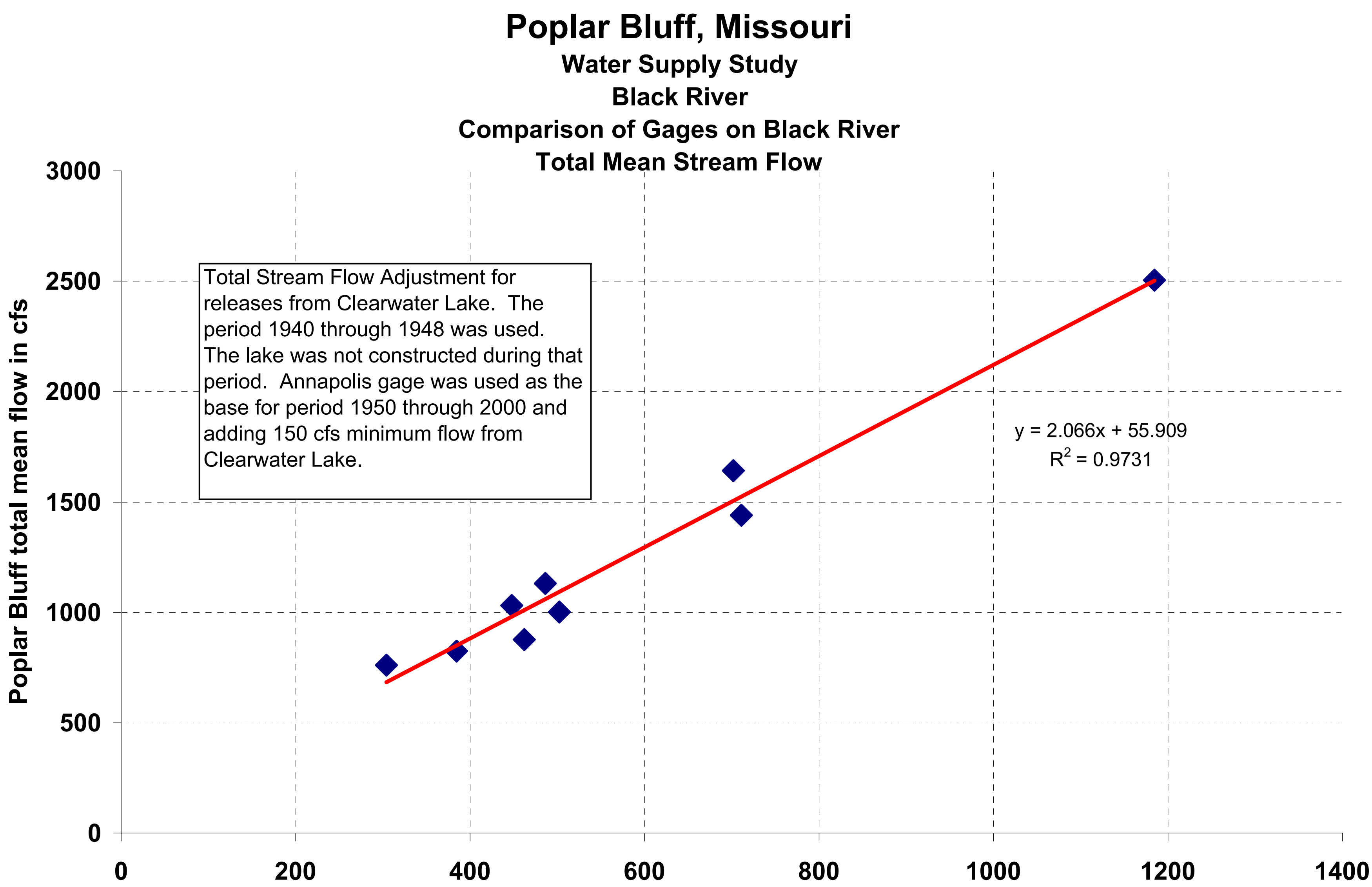

Poplar Bluff, Missouri
Water Supply Study
Black River
Comparison of Gages on Black River
Total Mean Stream Flow
Total Stream Flow Adjustment for releases from Clearwater Lake. The period 1940 through 1948 was used. The lake was not constructed during that period. Annapolis gage was used as the base for period 1950 through 2000 and adding 150 cfs minimum flow from Clearwater Lake.
y = 2.066x + 55.909
R^2 = 0.9731
Poplar Bluff total mean flow in cfs
Annapolis total mean flow in cfs
0
500
1000
1500
2000
2500
3000
0
200
400
600
800
1000
1200
1400

Figure 60.4.e

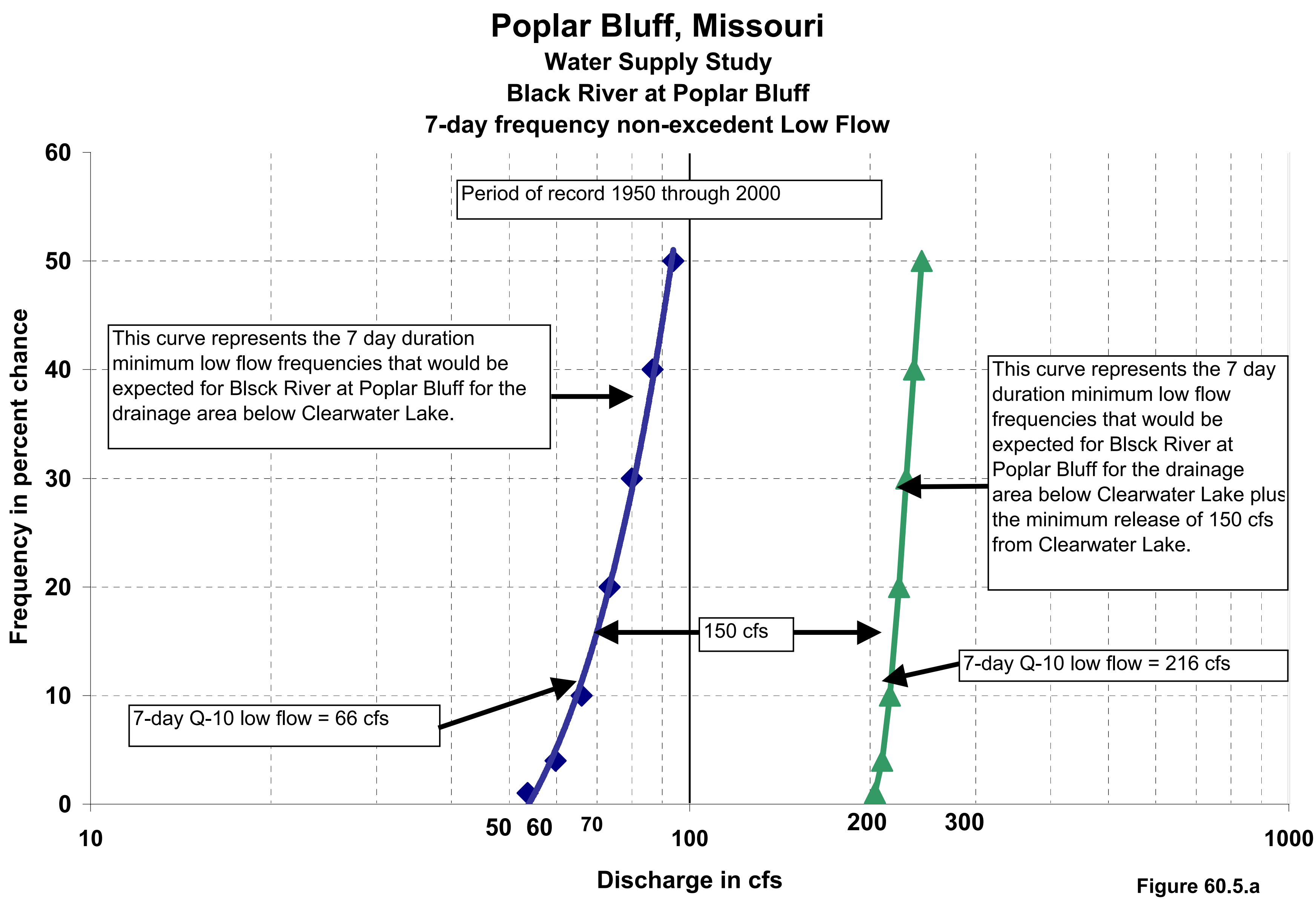

Poplar Bluff, Missouri
Water Supply Study
Black River at Poplar Bluff
7-day frequency non-excedent Low Flow
Period of record 1950 through 2000
This curve represents the 7 day duration minimum low flow frequencies that would be expected for Blsck River at Poplar Bluff for the drainage area below Clearwater Lake.
This curve represents the 7 day duration minimum low flow frequencies that would be expected for Blsck River at Poplar Bluff for the drainage area below Clearwater Lake plus the minimum release of 150 cfs from Clearwater Lake.
150 cfs
7-day Q-10 low flow = 66 cfs
7-day Q-10 low flow = 216 cfs
Frequency in percent chance
60
50
40
30
20
10
0
10
50
60
70
100
200
300
1000
Discharge in cfs

Figure 60.5.a

Poplar Bluff, Missouri

Water Supply Study

Black River

Compare 7-day frequency discharges
Annapolsis and Poplar Bluff before Clearwater Dam

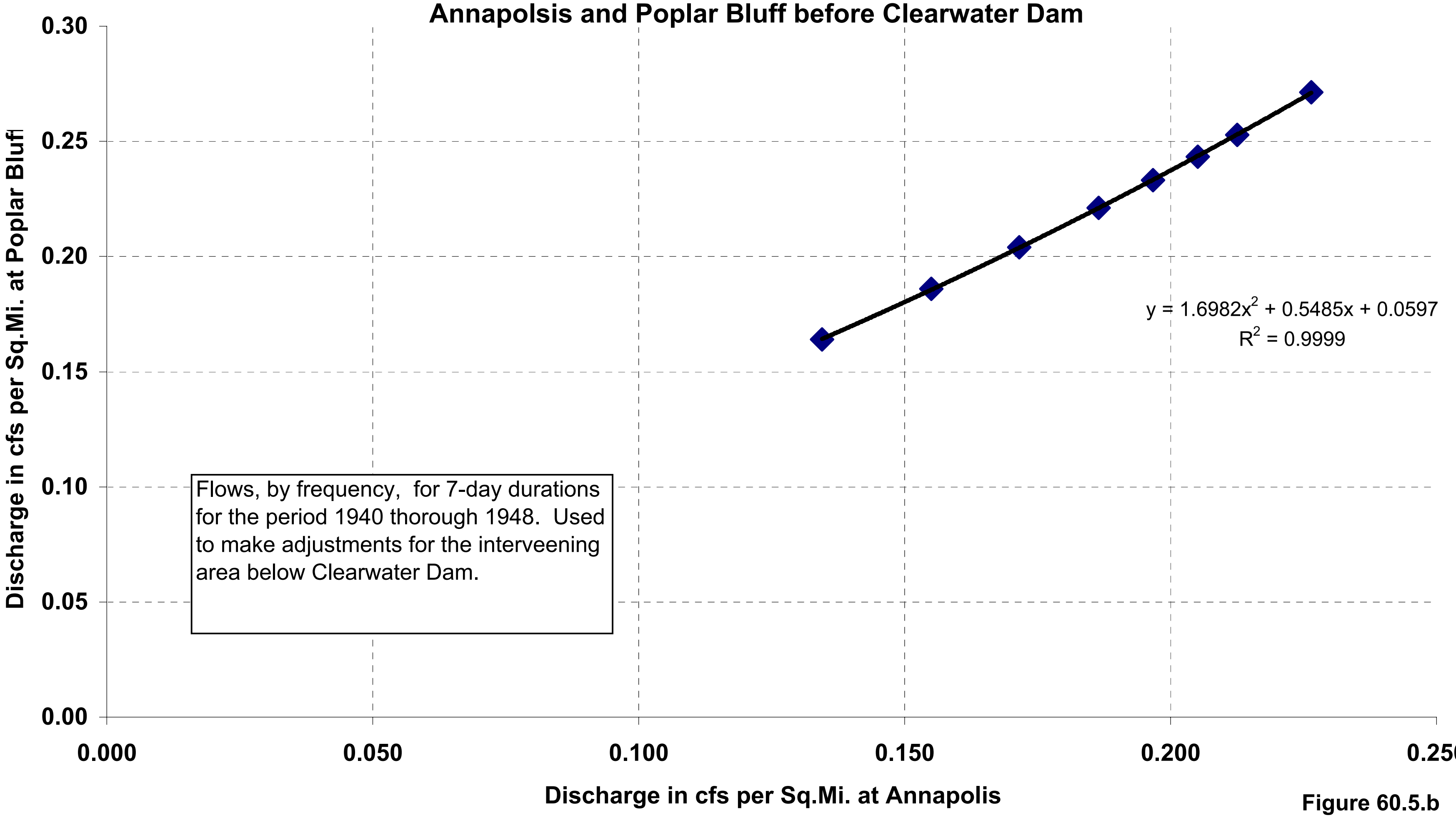


Figure 60.5.b

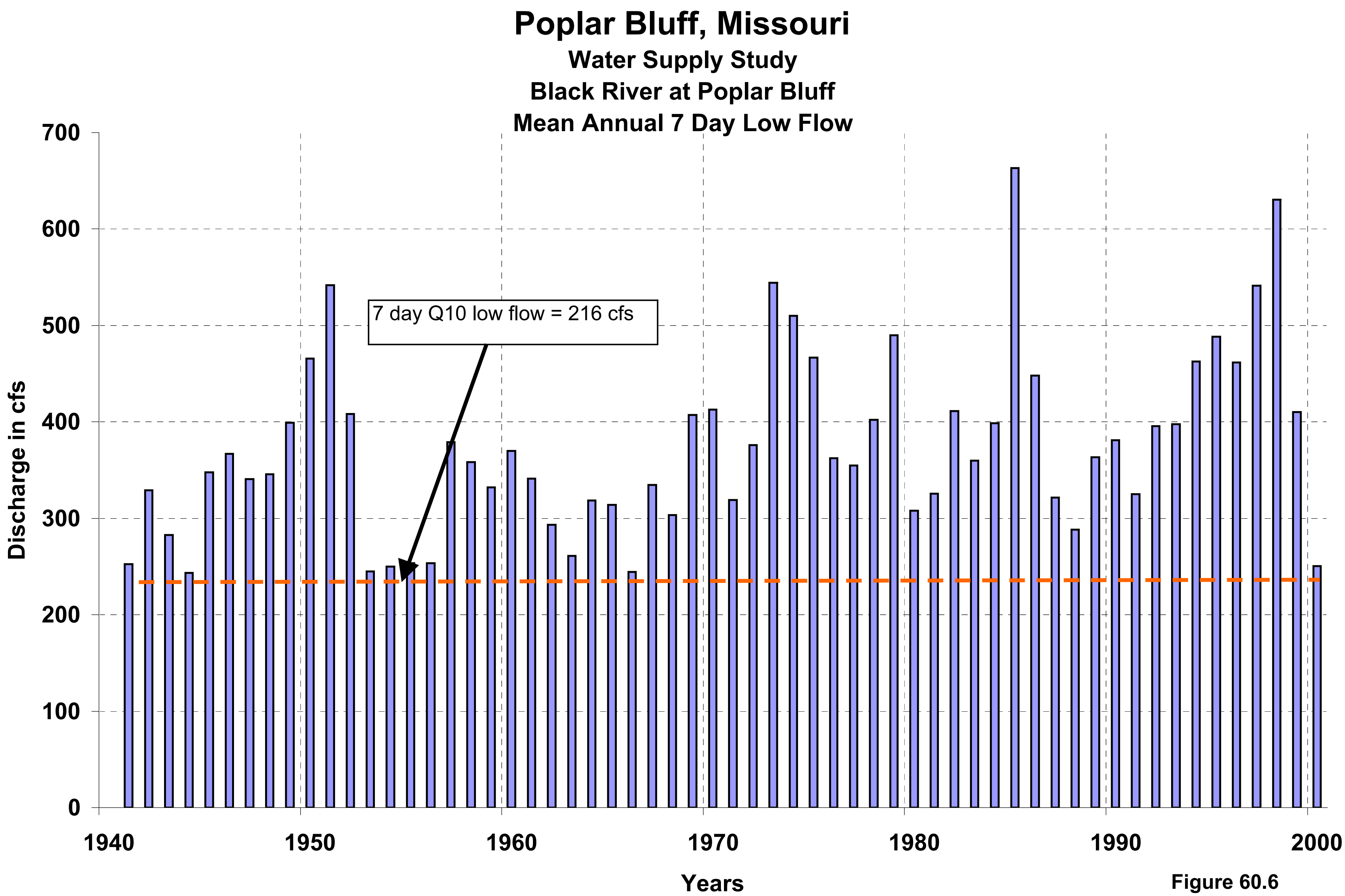
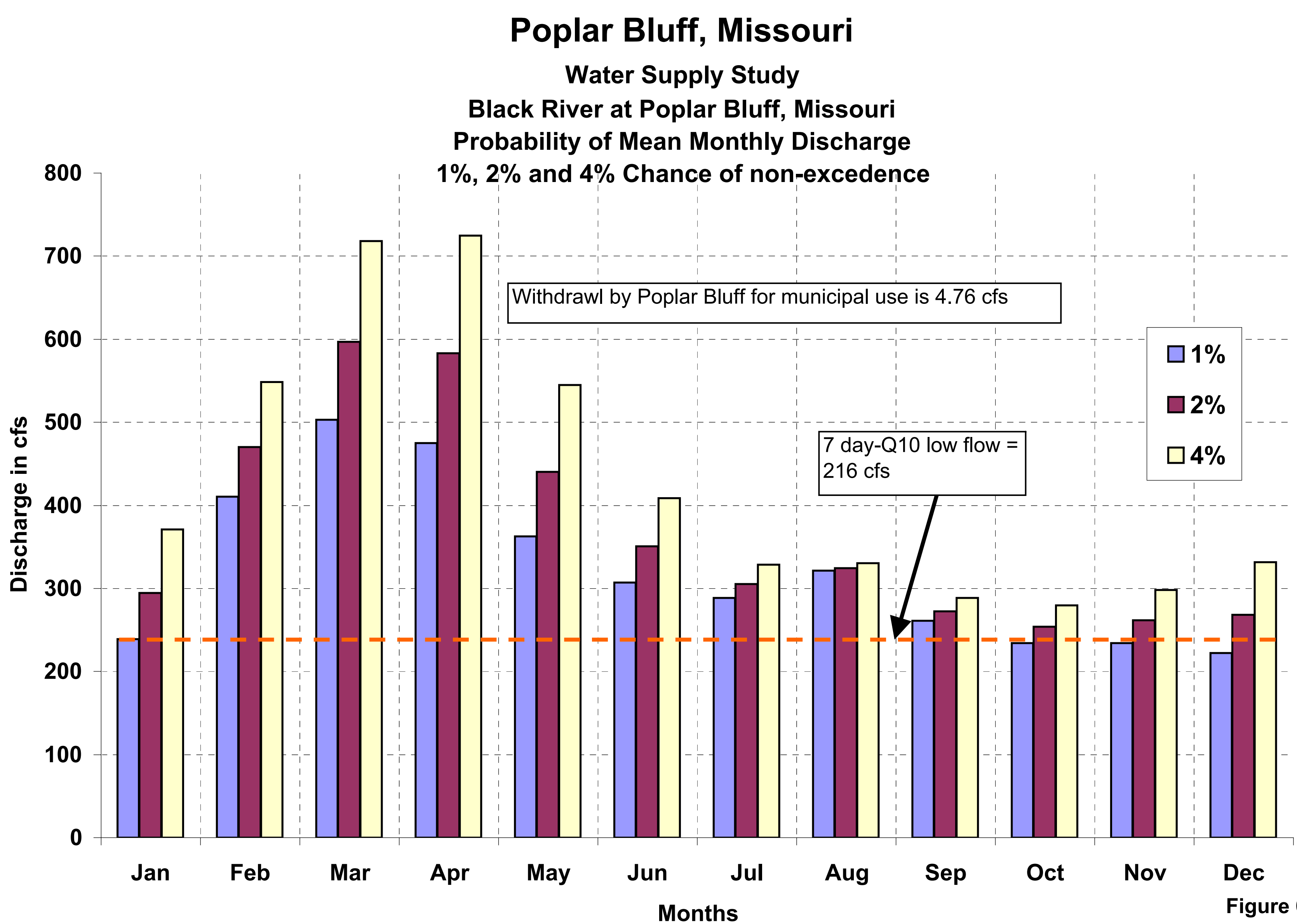

Poplar Bluff, Missouri
Water Supply Study
Black River at Poplar Bluff
Mean Annual 7 Day Low Flow
7 day Q10 low flow = 216 cfs
Discharge in cfs
0
100
200
300
400
500
600
700
1940
1950
1960
1970
1980
1990
2000
Years

Figure 60.6



Poplar Bluff, Missouri
Water Supply Study
Black River at Poplar Bluff, Missouri
Probability of Mean Monthly Discharge
1%, 2% and 4% Chance of non-excedence
Withdrawl by Poplar Bluff for municipal use is 4.76 cfs
7 day-Q10 low flow =
216 cfs
1%
2%
4%
Discharge in cfs
0
100
200
300
400
500
600
700
800
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Months

Figure 60.7

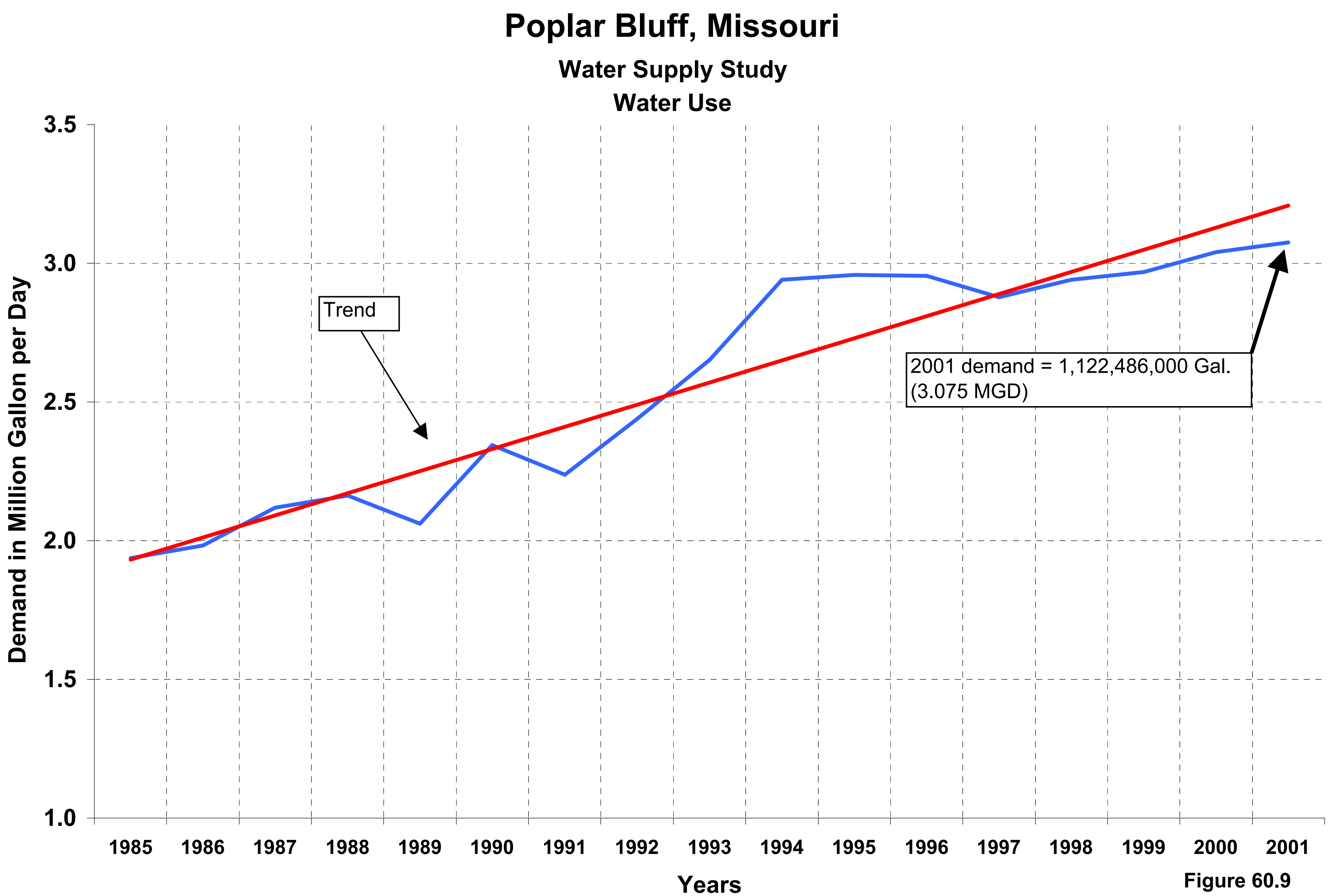

Poplar Bluff, Missouri
Water Supply Study
Water Use
Demand in Million Gallon per Day
3.5
3.0
2.5
2.0
1.5
1.0
Trend
2001 demand = 1,122,486,000 Gal.
(3.075 MGD)
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
Years

Figure 60.9

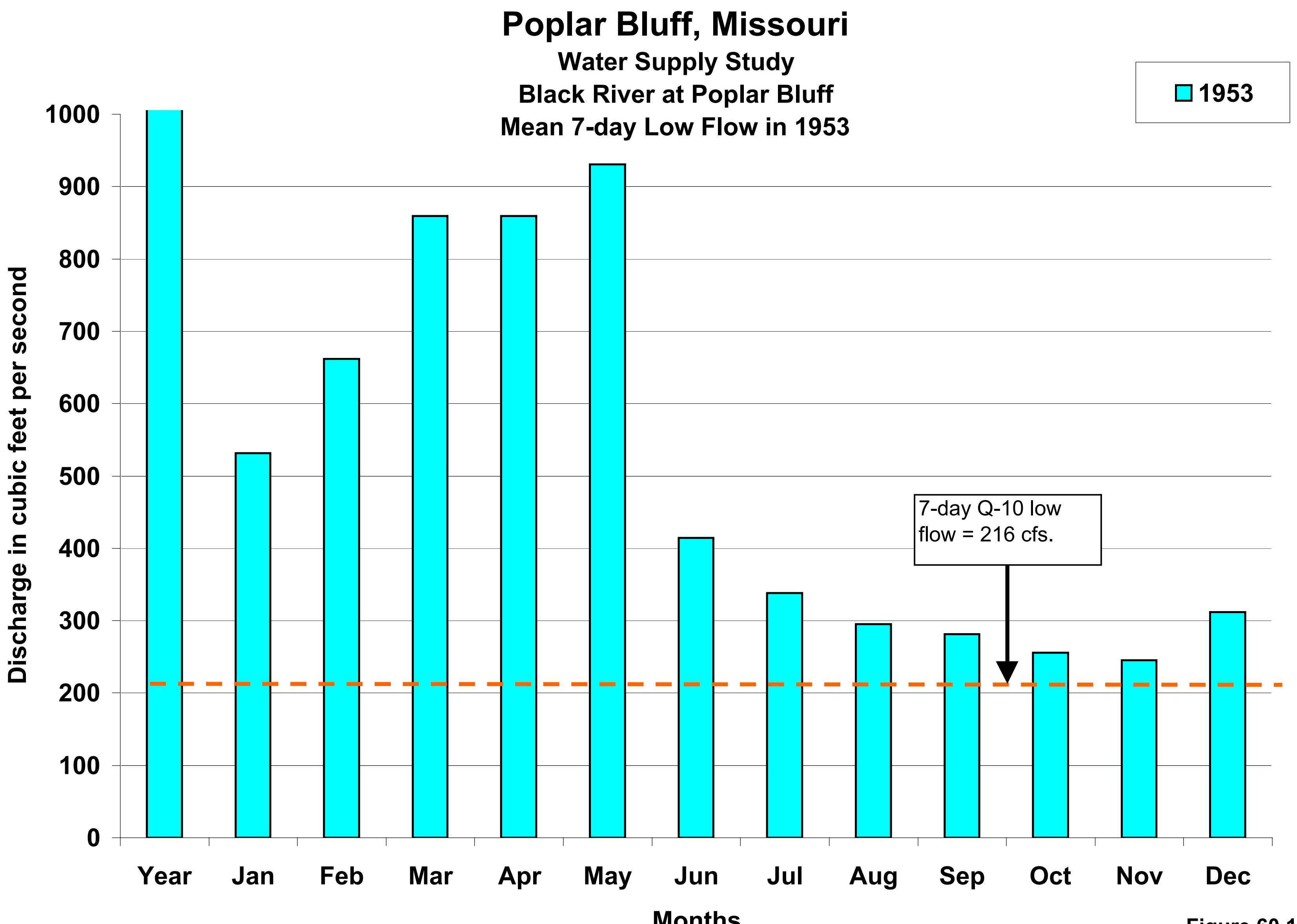


Figure 60.10.a

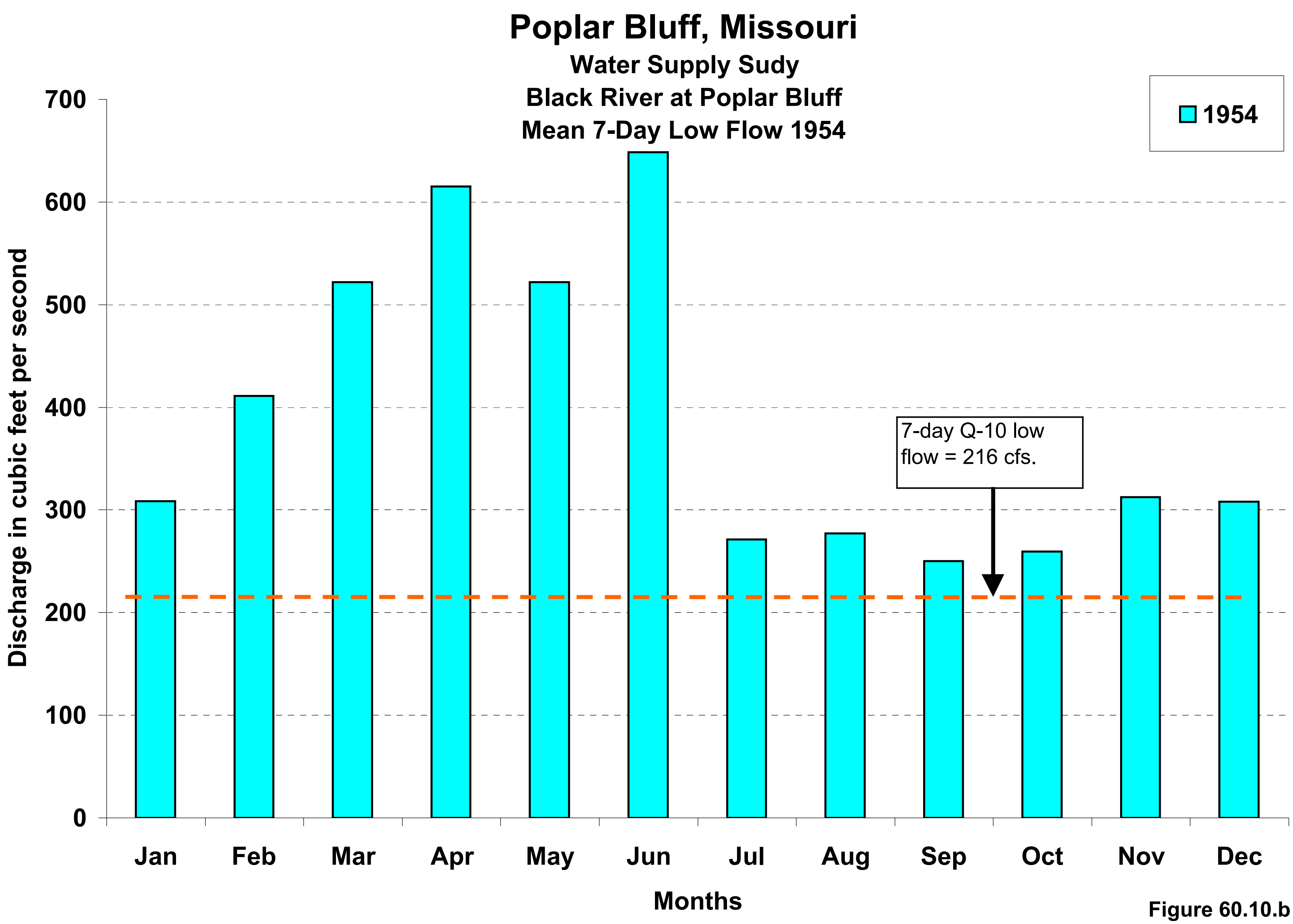


Figure 60.10.b

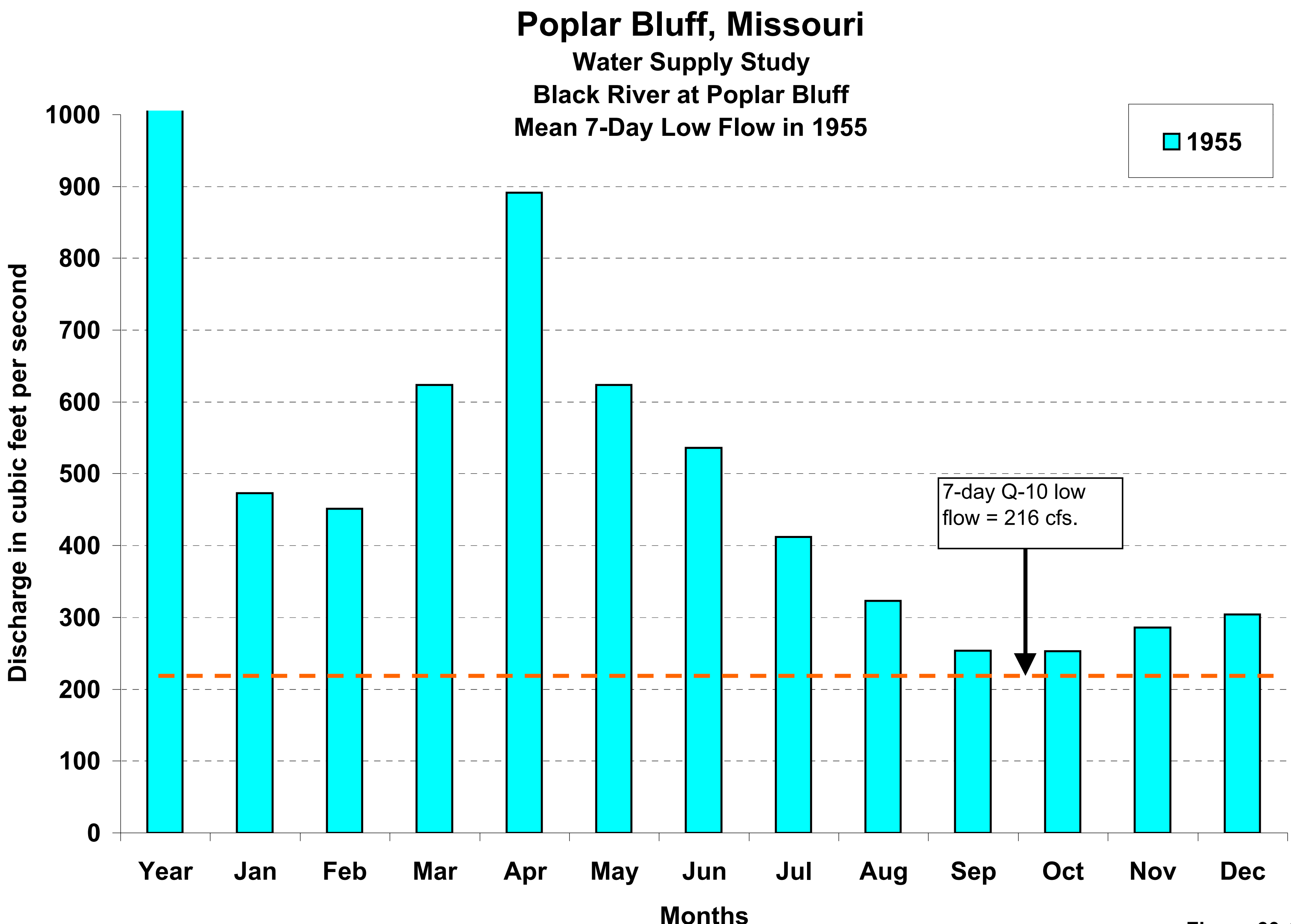


Figure 60.10.c

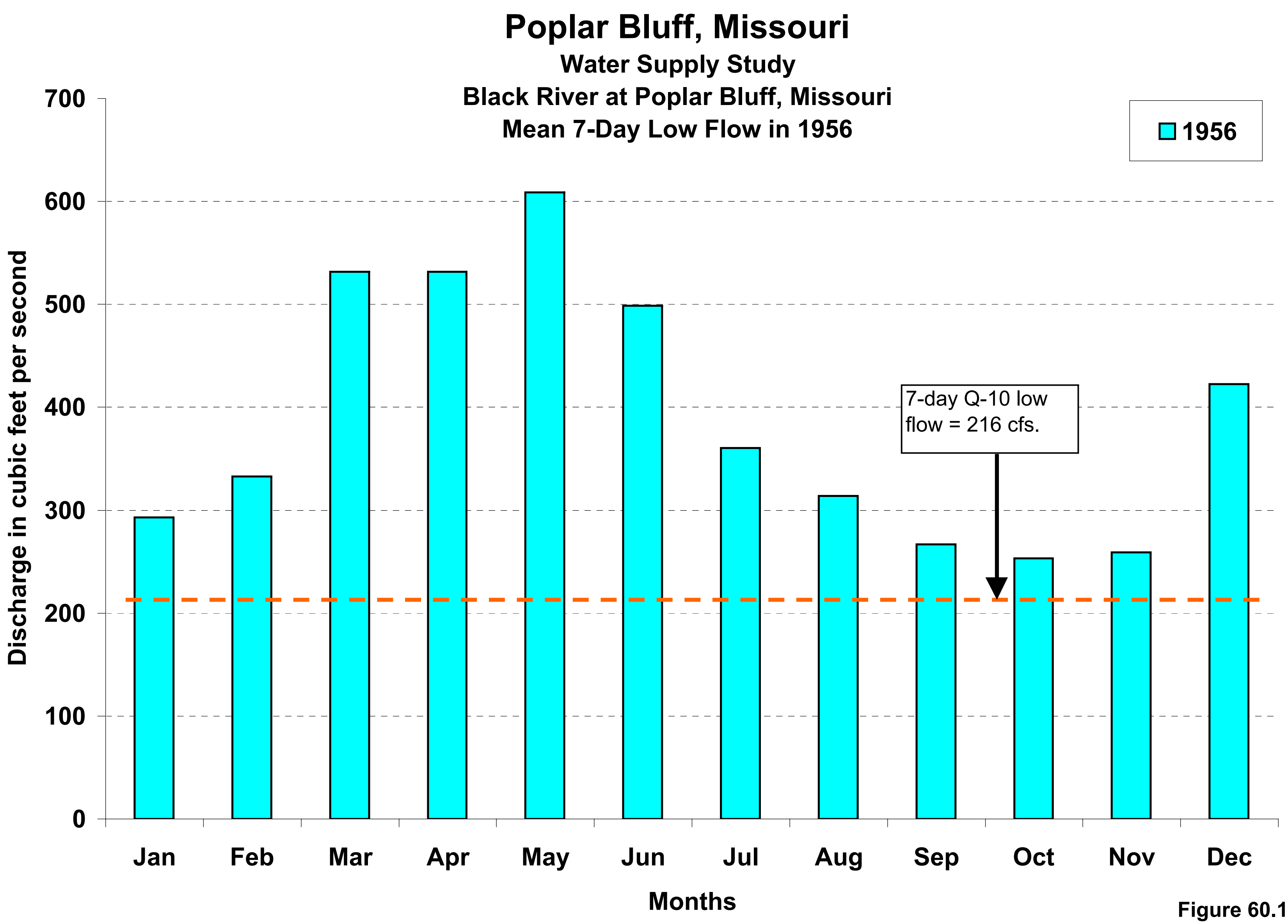


Figure 60.10.d

Poplar Bluff, Missouri

Water Supply Study
Clearwater Lake
Mean Annual Storage

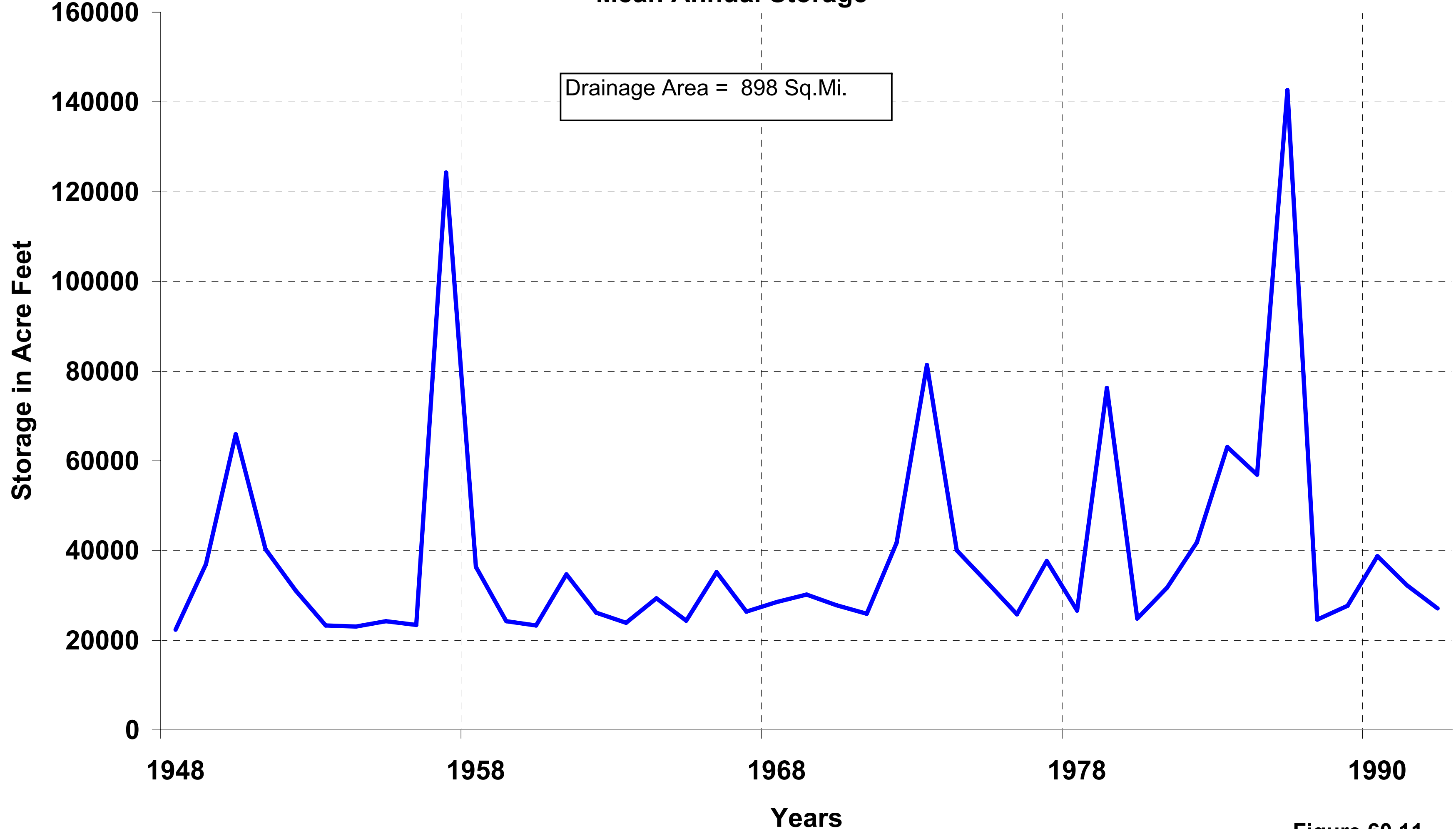


Figure 60.11

Trenton, Missouri
Water Supply Study

Introduction

This analysis was made to assess the availability of Trenton's water supply. Trenton obtains their water supply from Thompson River. Thompson River stream gage at Trenton, drainage area 1670 square miles is located approximately one mile downstream of the pump intake. Analysis indicates insufficient instream supply to meet demand during an extended multi-year drought such as the 1950's

Discussion:

Two pumps, pump from Thompson River to the storage basins, each pump is rated at 3125 GPM. They use one at a time and keep the other in reserve. 3125 GPM is near treatment plant capacity of 4.5 MGD. 3125 GPM = 6.96 cfs.

Stream flow data was obtained from USGS water supply data. Mean daily discharges were used to analyze stream flow volumes and frequencies. Continuous records have been kept from 1928 through 2002.

There are two raw water storage basins. The south basin has a surface area if 13.5 acres with storage capacity of 75.3 acre feet (24.5 million gallon). The maximum depth is 20 feet. The north basin has a surface area of 34.9 acres with storage capacity of 430 acre-feet (140 million-gallon). The maximum depth is 17 feet. The operating procedure is to keep the basins as near full as possible. When using water at treatment plant capacity of 4.5 MGD the supply in the basins would be used up in 36 days with no additional inflow. Figure 9a shows that the maximum water usage of 2.055 MGD occurred in 1993. At this demand there would be 80 days of water stored in the basins.

Annual precipitation amounts for most of Missouri has been increasing during the last 50 years. This is shown in the state water plan. The study was recently made for the state by Steve Hu (former state climatologist at University of Missouri) to update climate data. **Figures 70.1.a and 70.1.b** illustrate the precipitation trend for two gages near the center of the Thompson River drainage area. One gage is at Princeton, Missouri and the other at Lamoni, Iowa. These stations trends, show 50 year precipitation increase of 23% at Princeton to 32% at Lamoni for years 1950 through 2000. **Figure 70.2** shows the effect of increased annual rainfall on runoff. The trend indicates an increase in total annual runoff from 7.5 watershed inches to 10 inches or approximately 33% from 1955 to year 2000. The drought of record was in the 1950's. Non-excedence probabilities for the 1%, 2% and 4% chance flows in figure 7 are compared to actual stream flow records in **figures 70.3.a through 70.3.d** for the drought of record (1954 through 1957). These monthly runoff volumes for 1954, 1955, 1956 and 1957 were obtained from USGS stream flow records. These figures show that mean monthly discharge in Thompson River falls below the 7 day Q10 low flow (9 cfs) for 3 months. These occur in January 1954 when discharge = 7.1 cfs, December 1955 discharge = 6.5 cfs and January 1956 discharge = 4.7 cfs.

Figure 70.3.a compares 1954 mean monthly flow to monthly probability shown in figure 7.
Figure 70.3.b compares 1955 mean monthly flow to monthly probability shown in figure 7.
Figure 70.3.c compares 1956 mean monthly flow to monthly probability shown in figure 7.
Figure 70.3.d compares 1957 mean monthly flow to monthly probability shown in figure 7.

Base flow separation was made using the USGS computer program, HYSEP. This analysis was made to estimate sustained flow, in order to establish availability of continuous stream flow. **Figure 70.4.a** is the base flow index and is the ratio of base flow to total stream flow. This chart shows the yearly fluctuation in base flow indexes and indicates the trend. The trend has increased from 26% of total annual runoff in 1955 to 38% in 2000. The increase in annual base flow volume is shown in **figure 70.4.b and 70.4.c**. Figure 4b illustrates the runoff in watershed inches. Figure 4c shows the same runoff in terms of cubic feet per second at the intake. Annual base flow volume has doubled from 1.9 inches to 3.8 inches in the last 50 years.

To determine the rate of flow needed to meet in-stream flow requirements, the 7 day Q10 low flow was determined using the period of record, 1950 through 2000. **Figure 70.5** shows the results of the frequency analysis to be 9 cfs. For purposes of pumping from the river to fill the storage basins, discharge needed to exceed 9 cfs.

Mean seven-day annual low flows for 1928 through 1999 were calculated and are shown in **figure 70.6.**
The lowest 7-day discharge occurred in 1956 with a mean value of 2 cfs.

Monthly non-excedence probabilities for 1%, 2% and 4% chance of occurring were established from stream flow data for the years 1950 through 2000. **Figure 70.7** displays the 1% and 2% mean monthly low flow. The 4% chance indicates discharge to be more than 7day Q10 discharge for all months. For this report, all statistical determinations were made using the Log Pearson type III method as described in Water Resource Council bulletin 17B.

Deficits shown in the following displays are the volume shortages necessary to meet the 7-day Q-10 in-stream flow requirements. **Figure 70.8.a** shows non-excedence probability flows of the 1% chance of occurrence and indicates that half of the months, March through August exceed the 7-day Q-10 flow rate, The remaining months were below the 7-day Q-10 flow rate. **Figure 70.8.b** is the 2 percent chance low flows and indicates only three months are close to 7 day Q 10 discharge, and they would have enough carry over storage in the reservoirs to provide adequate water. **Figure 70.8.c** shows the 4% chance of occurrence is able to provide enough flow so that there would be no deficit. **Figures 70.8.d and 70.8.e** display the deficits in bar charts, one showing the deficit in acre-feet and the other in terms of cfs.

Water usage for the last seven years of record are:

1995	1.38 MGD
1996	1.62 MGD
1997	1.47 MGD
1998	1.51 MGD
1999	1.64 MGD
2000	1.84 MGD
2001	1.90 MGD

Figure 70.9.a shows that the long-term trend (1983 through 2001) daily water usage has increased from approximately 1.5 MGD in 1983 to 1.75 MGD in 2001. Resulting in a daily increase in demand of 17 %. Historical use from 1995 through 2001 increased from 1.38 MGD to 1.90MGD, and increase of 38%. **Figure 70.9.b** shows total annual usage in million gallons per year.

Additional comparisons for the 1950's drought were made using the mean 7-day low flow for examining a shorter duration. These comparisons are shown in **figures 70.10.a, 70.10.b, 70.10.c and 70.10.d**. These figures compare mean seven-day low flows to 7 day Q10 flow, and indicate short-term critical periods. In the 4 years period of 1954 through 1957 there were 12 months that had mean seven-day flows below 7 day Q10 discharge.
They were:
1954 – 3 months January (4 cfs), February (4 cfs), September (8 cfs).
1955 - 3 months September (6cfs), November (8 cfs), December (5 cfs).
1956 - 5 months January (4 cfs), February (5 cfs), April (4 cfs), May (3 cfs) and June (2cfs).
1957 - 1 month October (6 cfs).

Conclusions:

Mean monthly Thompson River discharges will be less than the 7-day 10-year frequency discharge of 9 cfs for the 1% chance or 1 year in 100 years low flows for six months of January, February, and September through December. For the 2% chance or 1 year in 50 years, these same months were very close to the 7 day Q10 flow with January and December being slightly less and 4 months had flows approximately equal to the minimum 9 cfs.

During the 1950's there were no months that flow in Thompson River would not allow pumping at the rated pump capacity of 3125 gallon per minute (6.96 cfs) for at least some of the month. However there would be longer periods of time flows would be too low for pumping. This is indicated by the 7-day low mean discharge values for 1954, 1955, 1956 and 1957. Each year had mean 7-day duration flows below pump ratings.

Trenton's demand is increasing at a long-term rate of 0.013 MGD. The present system is meeting their needs. The treatment plant is able to treat 4.5 MGD and the current demand is less than 2 MGD. Between years 1928, when the stream gage on Thompson River was installed, to year 2001 there were five 30 day periods when pumping from the river to the reservoirs could not occur. These were all in 1956 or earlier. They are: July 1954, January 1940, December 1955 and January 1956, as well as May 1956. With the storage in the reservoirs, City demand could be met during the 30-day dry periods.

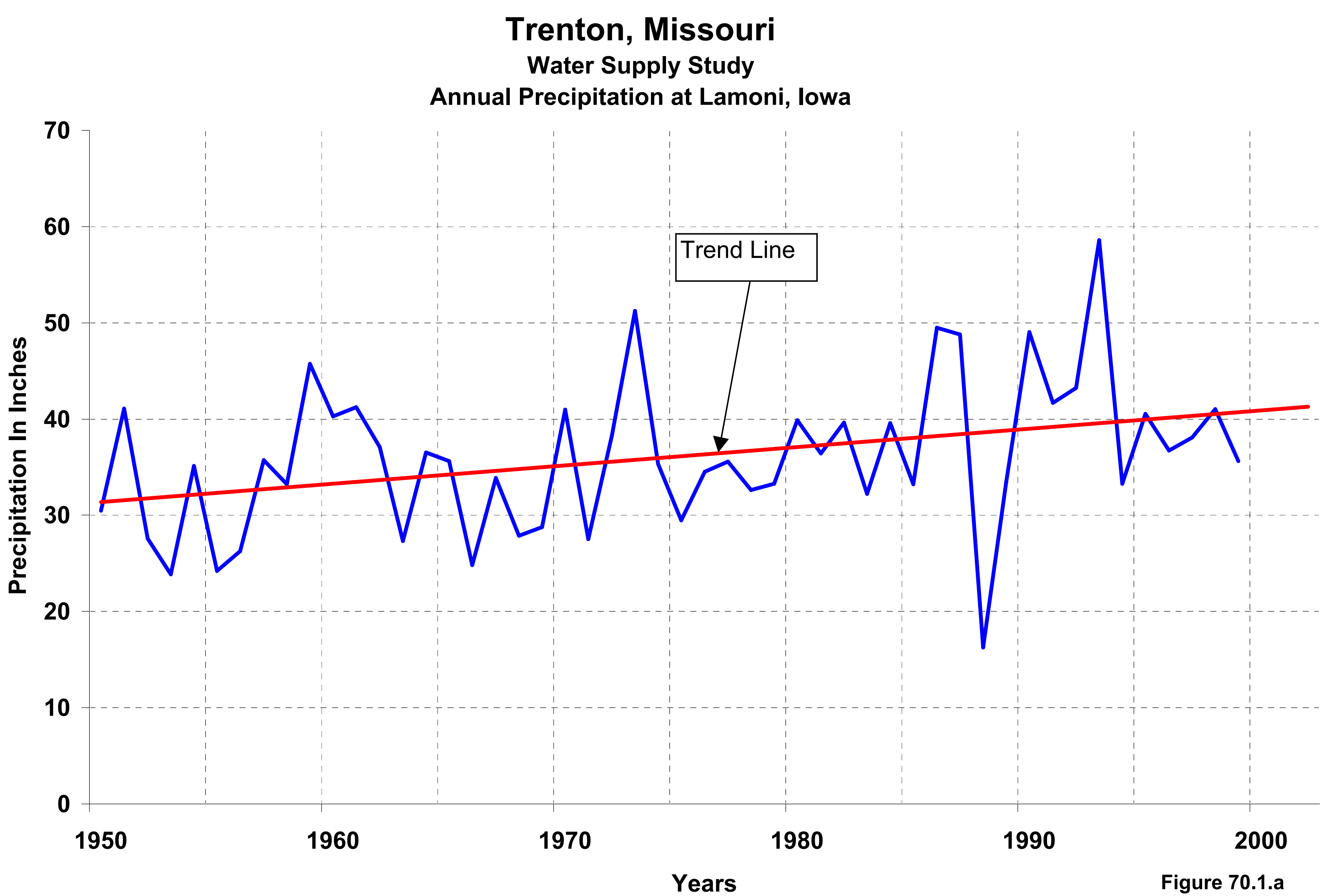

Trenton, Missouri
Water Supply Study
Annual Precipitation at Lamoni, Iowa
Trend Line
Precipitation In Inches
0
10
20
30
40
50
60
70
1950
1960
1970
1980
1990
2000
Years

Figure 70.1.a

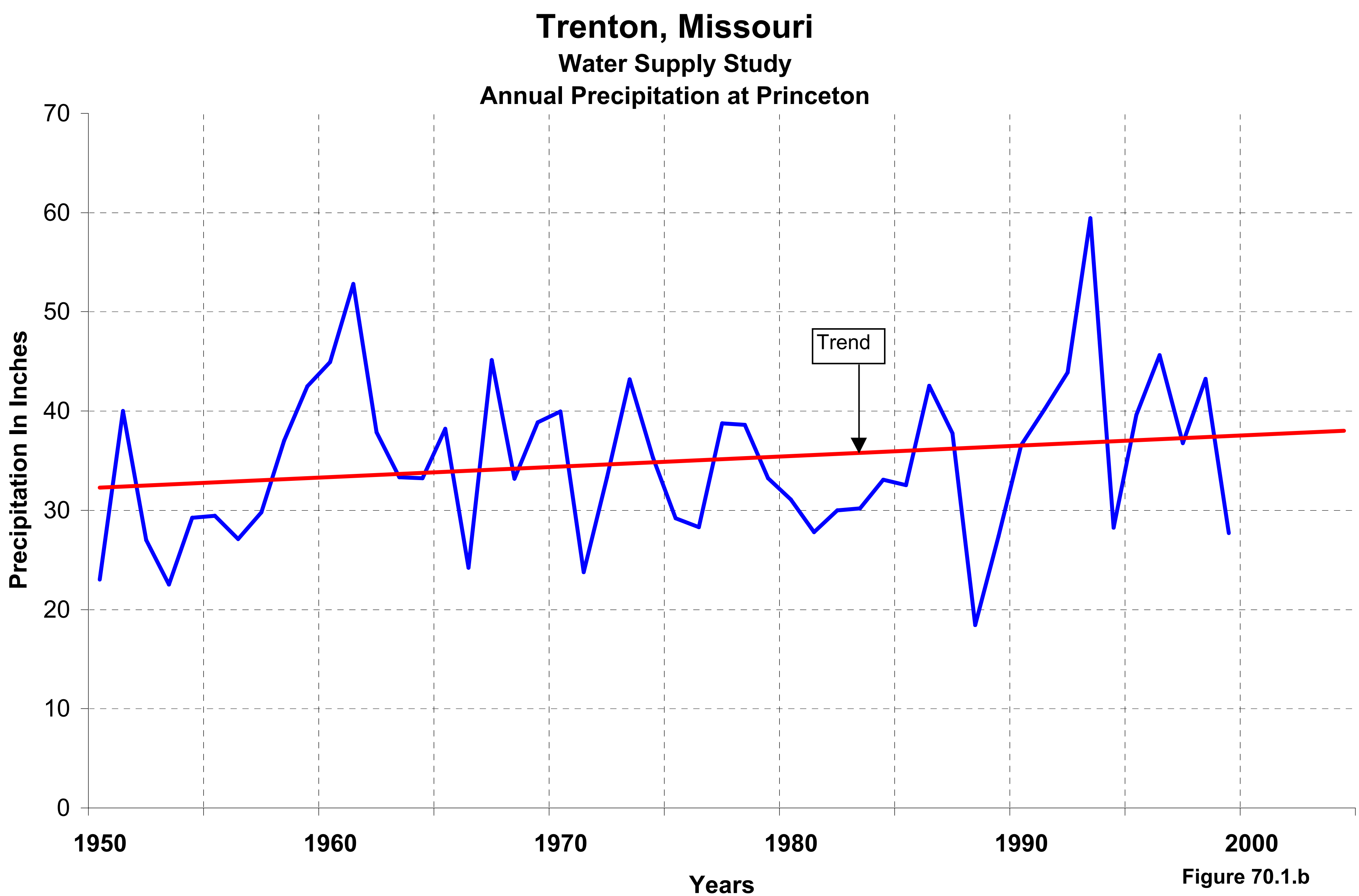

Trenton, Missouri
Water Supply Study
Annual Precipitation at Princeton
Precipitation In Inches
70
60
50
40
30
20
10
0
1950
1960
1970
1980
1990
2000
Years
Trend

Figure 70.1.b

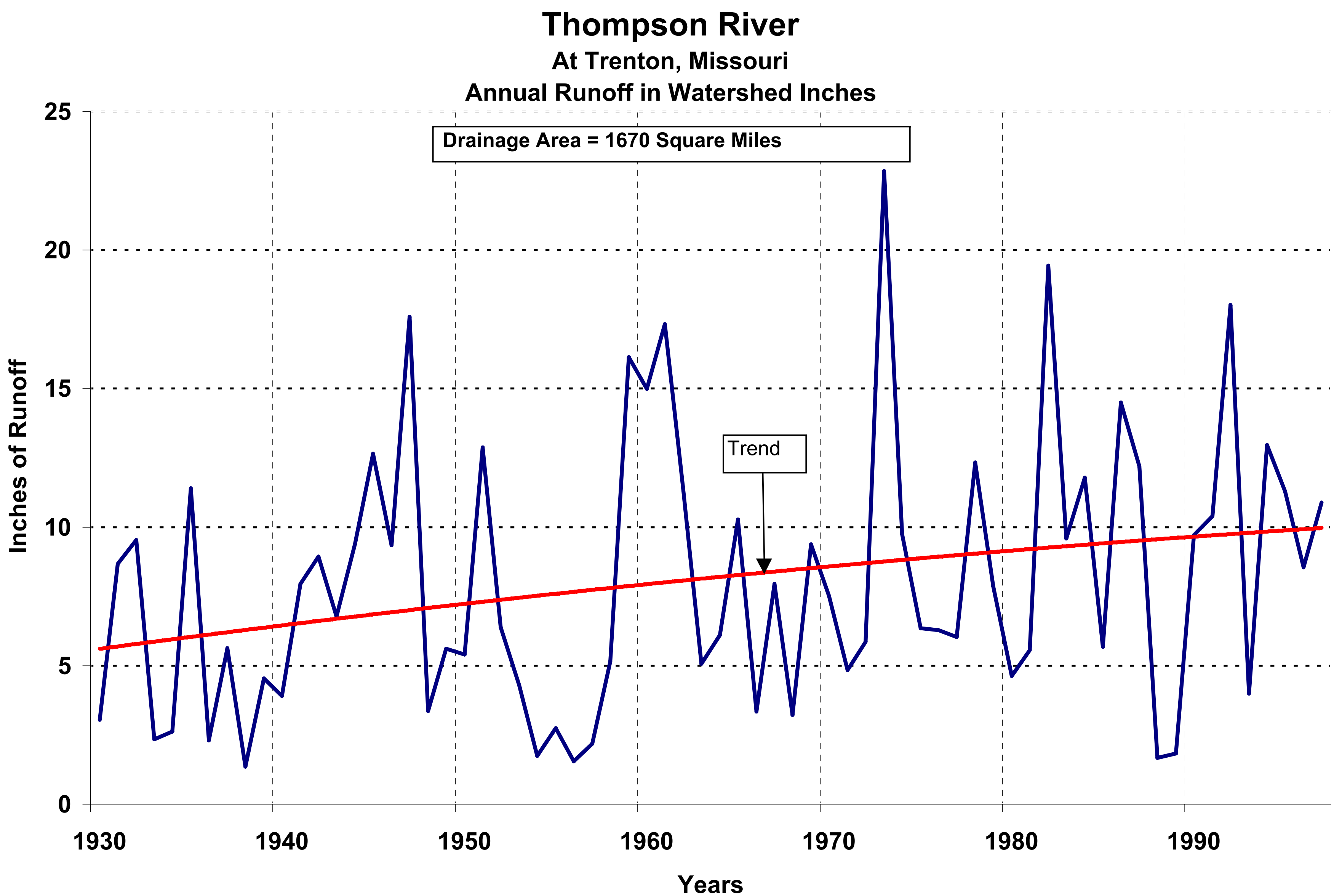

Thompson River
At Trenton, Missouri
Annual Runoff in Watershed Inches
Drainage Area = 1670 Square Miles
Trend
Inches of Runoff
Years
0
5
10
15
20
25
1930
1940
1950
1960
1970
1980
1990

Figure 70.2

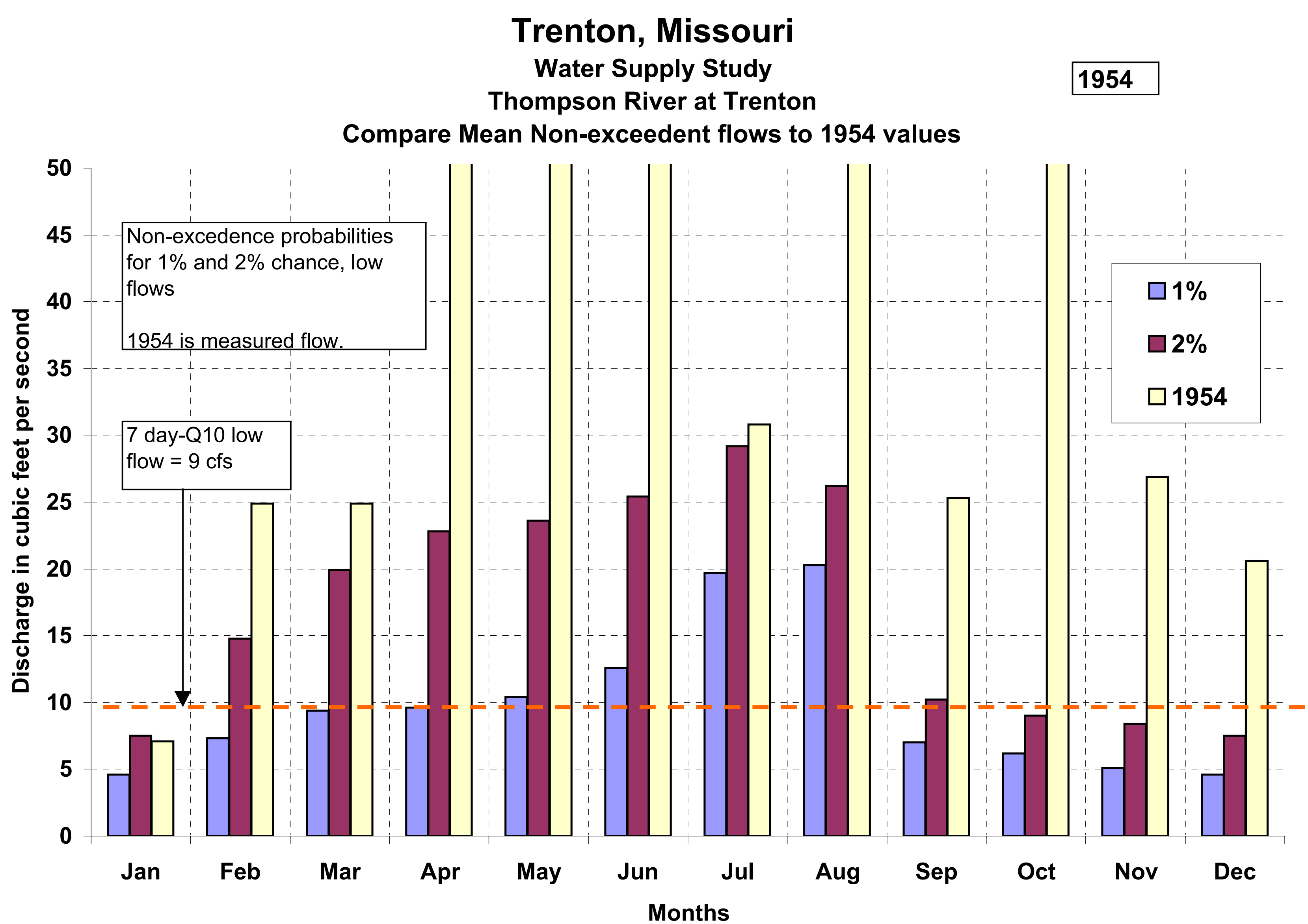
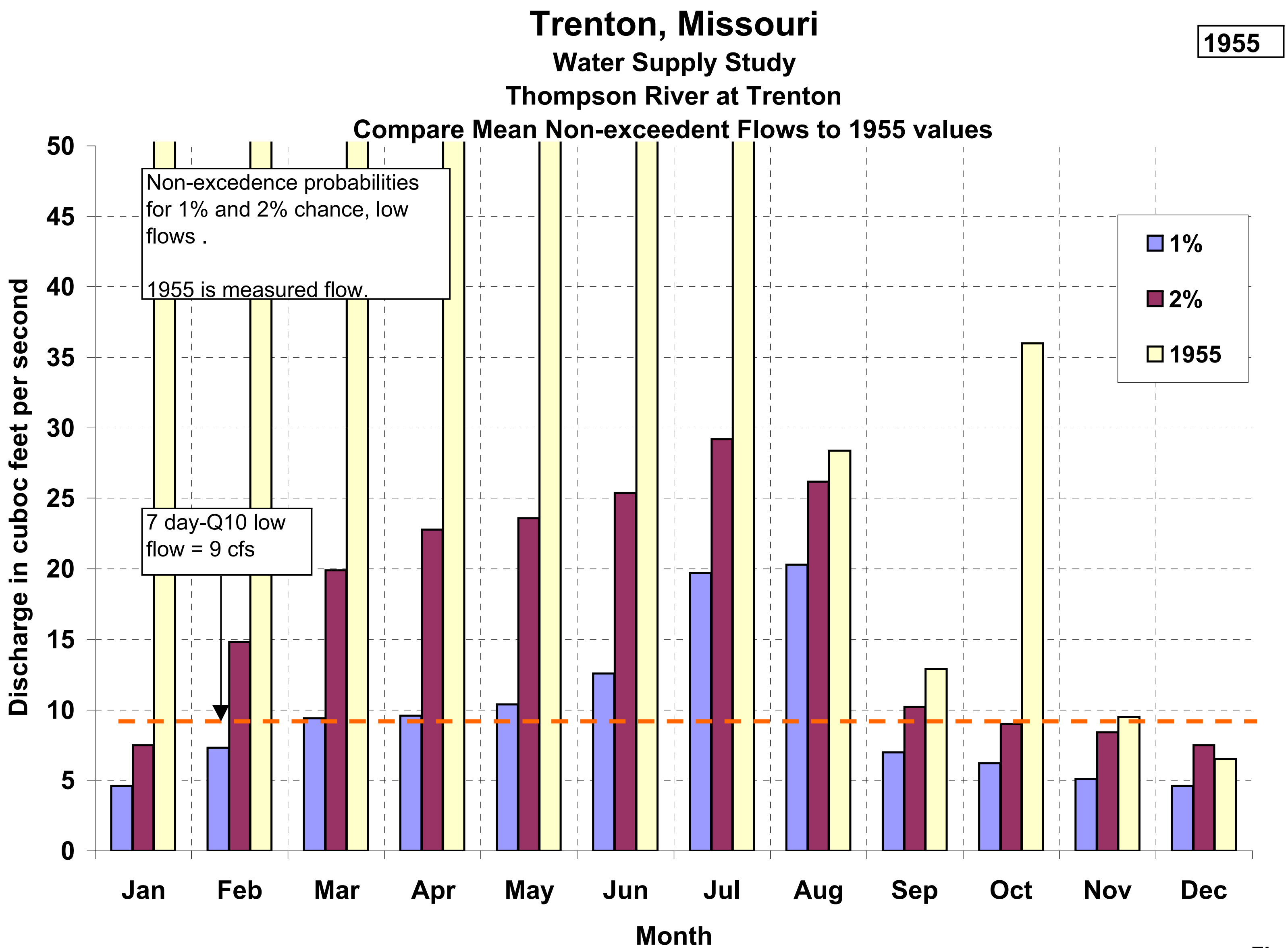

Trenton, Missouri
Water Supply Study
Thompson River at Trenton
Compare Mean Non-exceedent flows to 1954 values
1954
Non-excedence probabilities for 1% and 2% chance, low flows
1954 is measured flow.
7 day-Q10 low flow = 9 cfs
1%
2%
1954
Discharge in cubic feet per second
0
5
10
15
20
25
30
35
40
45
50
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Months

Figure 70.3.a



Trenton, Missouri
Water Supply Study
Thompson River at Trenton
Compare Mean Non-exceedent Flows to 1955 values
1955
Non-excedence probabilities for 1% and 2% chance, low flows .
1955 is measured flow.
7 day-Q10 low flow = 9 cfs
1%
2%
1955
Discharge in cuboc feet per second
50
45
40
35
30
25
20
15
10
5
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

Figure 70.3.b

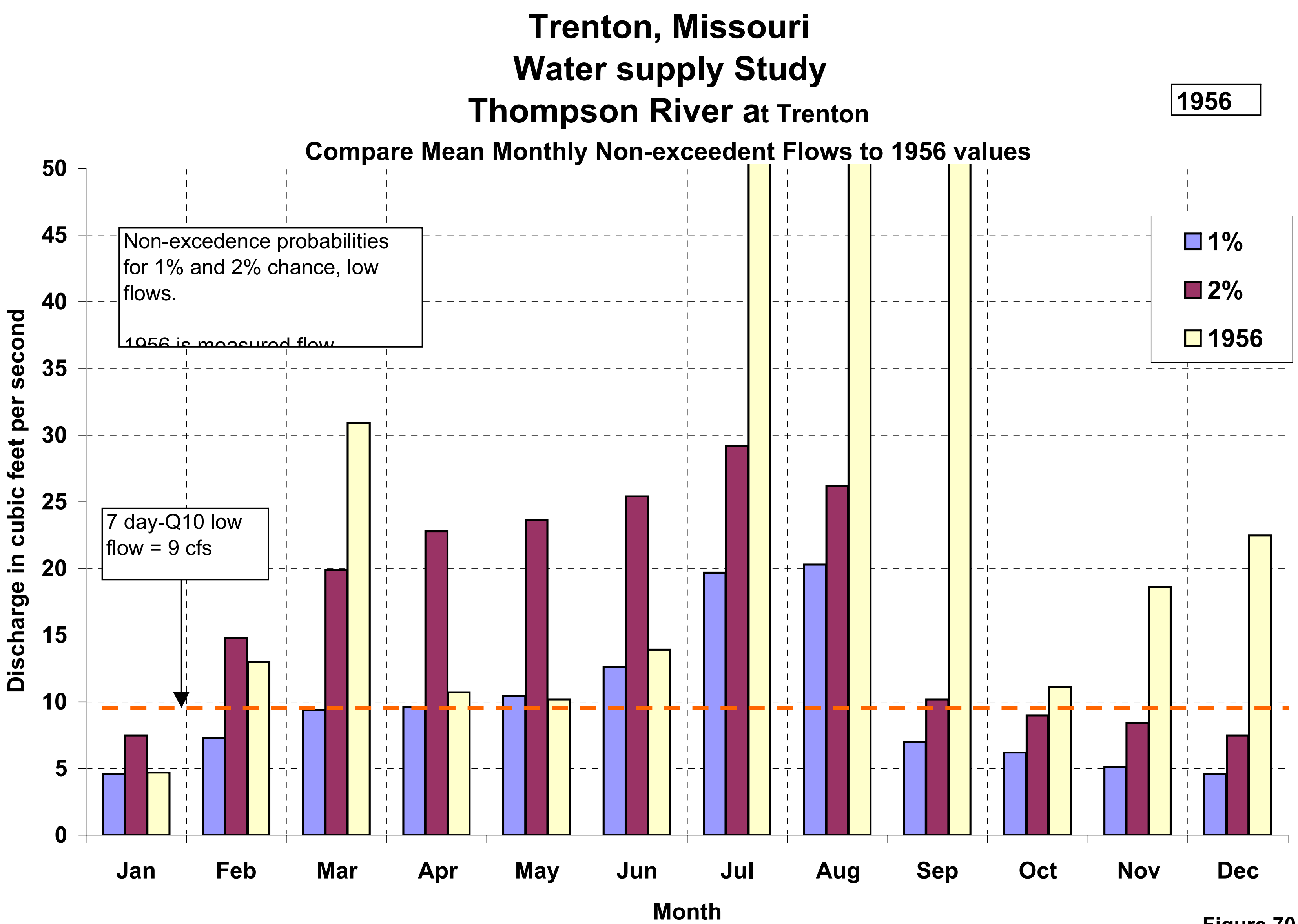

Trenton, Missouri
Water supply Study
Thompson River at Trenton
Compare Mean Monthly Non-exceedent Flows to 1956 values
1956
Non-excedence probabilities for 1% and 2% chance, low flows.
7 day-Q10 low flow = 9 cfs
1%
2%
1956
Discharge in cubic feet per second
50
45
40
35
30
25
20
15
10
5
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

Figure 70.3.c

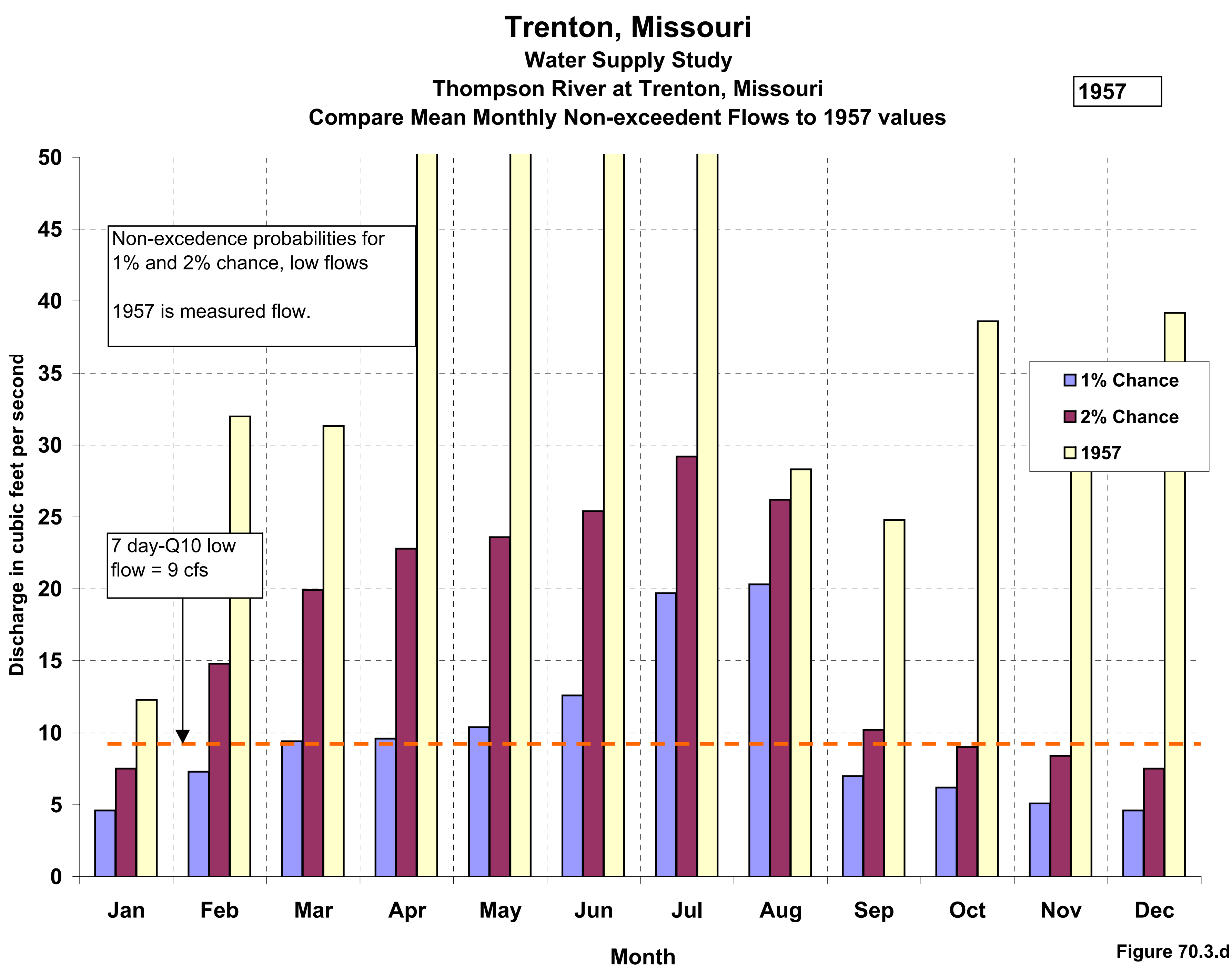

Trenton, Missouri
Water Supply Study
Thompson River at Trenton, Missouri
Compare Mean Monthly Non-exceedent Flows to 1957 values
1957
Non-excedence probabilities for
1% and 2% chance, low flows
1957 is measured flow.
7 day-Q10 low
flow = 9 cfs
1% Chance
2% Chance
1957
Discharge in cubic feet per second
50
45
40
35
30
25
20
15
10
5
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

Figure 70.3.d

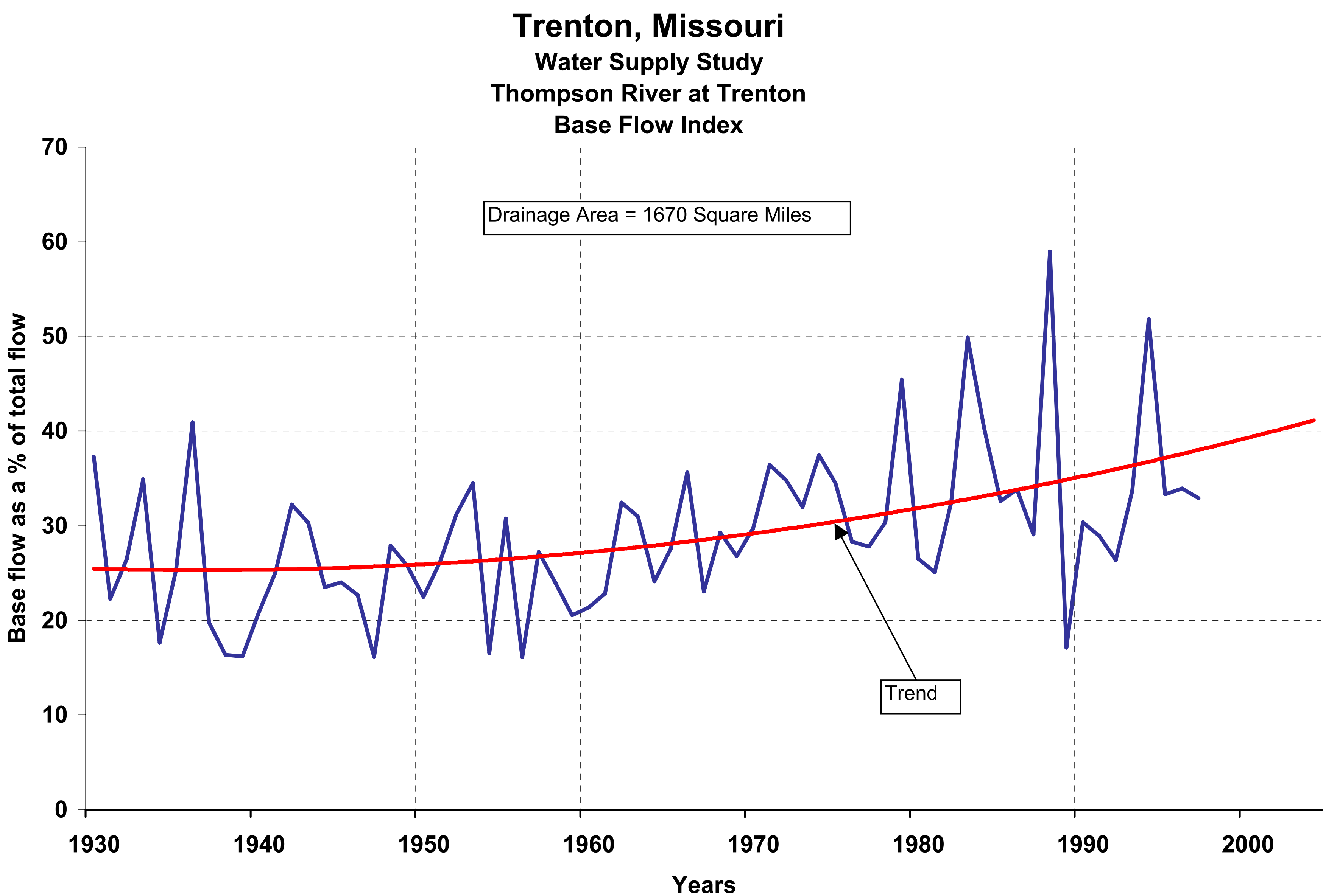
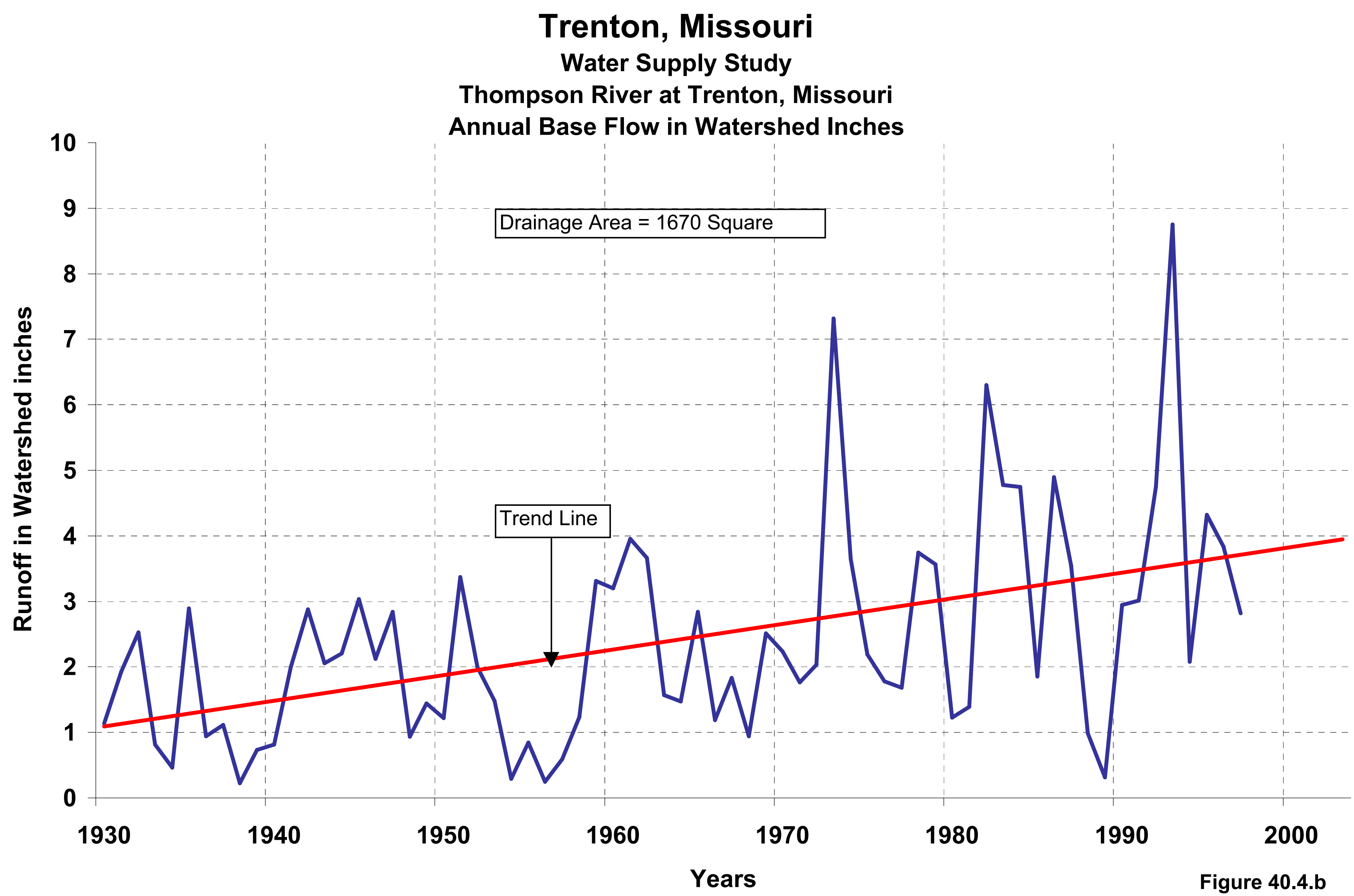

Trenton, Missouri
Water Supply Study
Thompson River at Trenton
Base Flow Index
Drainage Area = 1670 Square Miles
Trend
Base flow as a % of total flow
Years
0
10
20
30
40
50
60
70
1930
1940
1950
1960
1970
1980
1990
2000

Figure 70.4.a


Trenton, Missouri
Water Supply Study
Thompson River at Trenton, Missouri
Annual Base Flow in Watershed Inches
Drainage Area = 1670 Square
Trend Line
Runoff in Watershed inches
0
1
2
3
4
5
6
7
8
9
10
1930
1940
1950
1960
1970
1980
1990
2000
Years
Figure 40.4.b

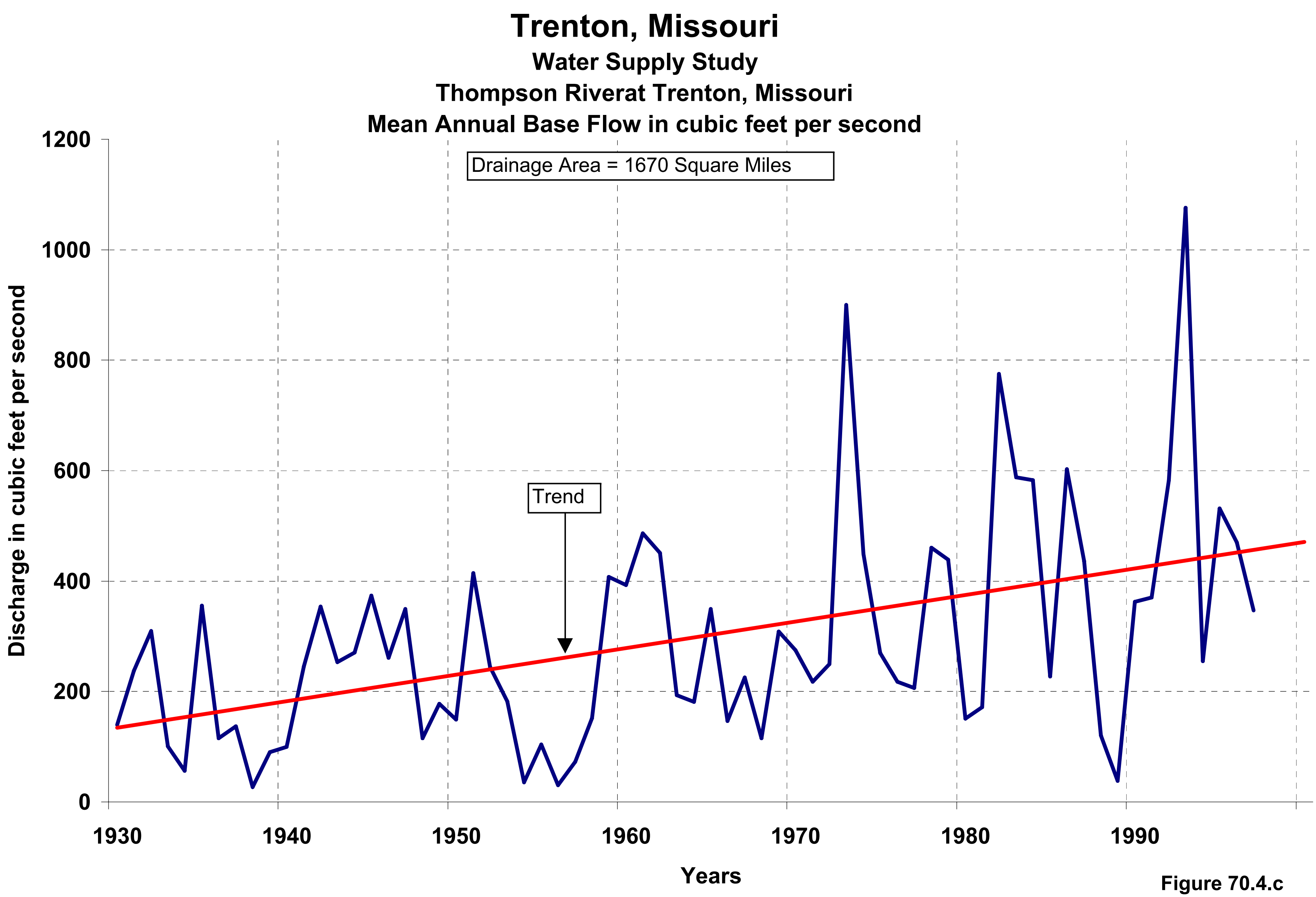
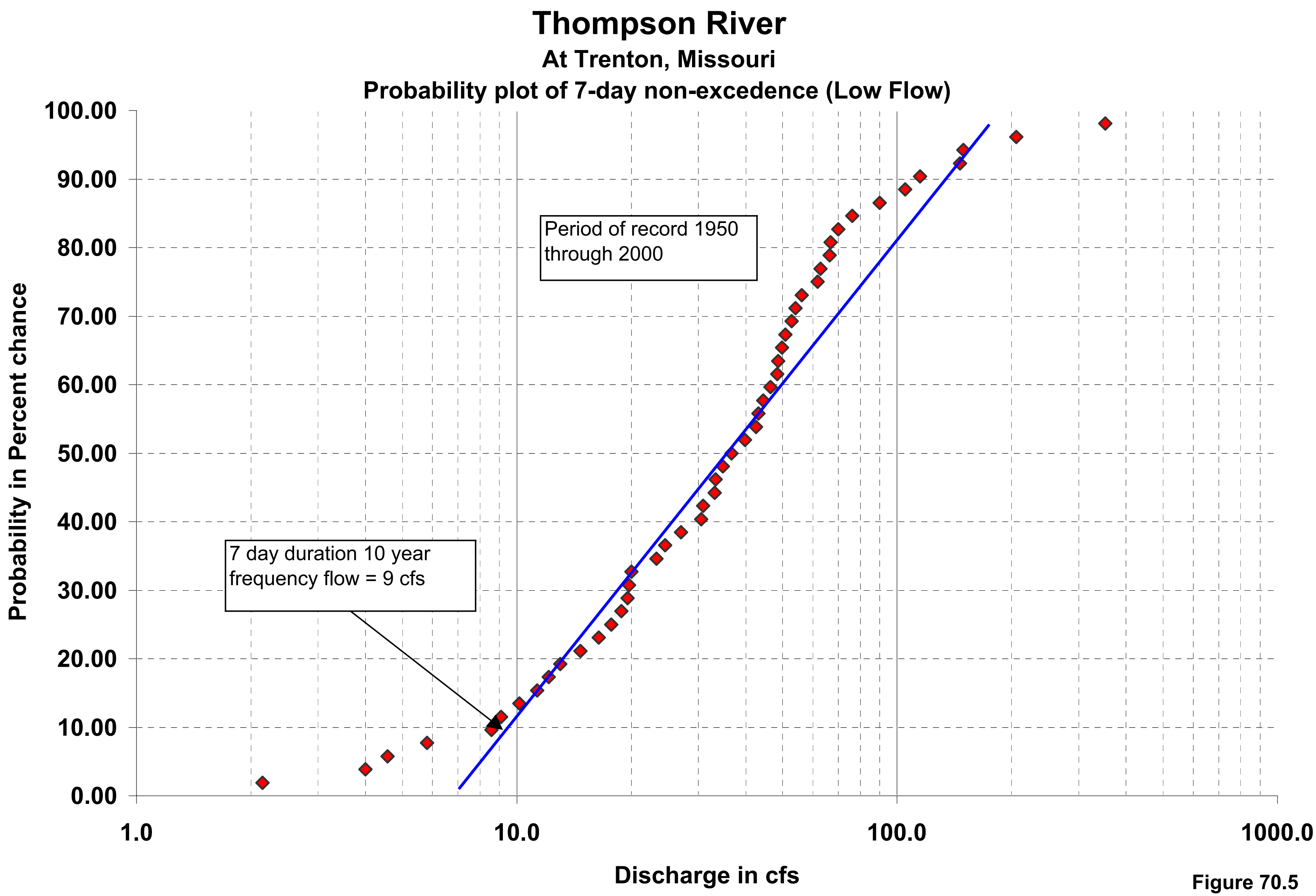

Trenton, Missouri
Water Supply Study
Thompson Riverat Trenton, Missouri
Mean Annual Base Flow in cubic feet per second
Drainage Area = 1670 Square Miles
Trend
Discharge in cubic feet per second
0
200
400
600
800
1000
1200
1930
1940
1950
1960
1970
1980
1990
Years

Figure 70.4.c



Thompson River
At Trenton, Missouri
Probability plot of 7-day non-excedence (Low Flow)
Probability in Percent chance
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
Period of record 1950 through 2000
7 day duration 10 year frequency flow = 9 cfs
1.0
10.0
100.0
1000.0
Discharge in cfs

Figure 70.5

Trenton, Missouri

Water Supply Study

Thompson River at Trenton, Missouri

Annual 7-day Mean Low Flow

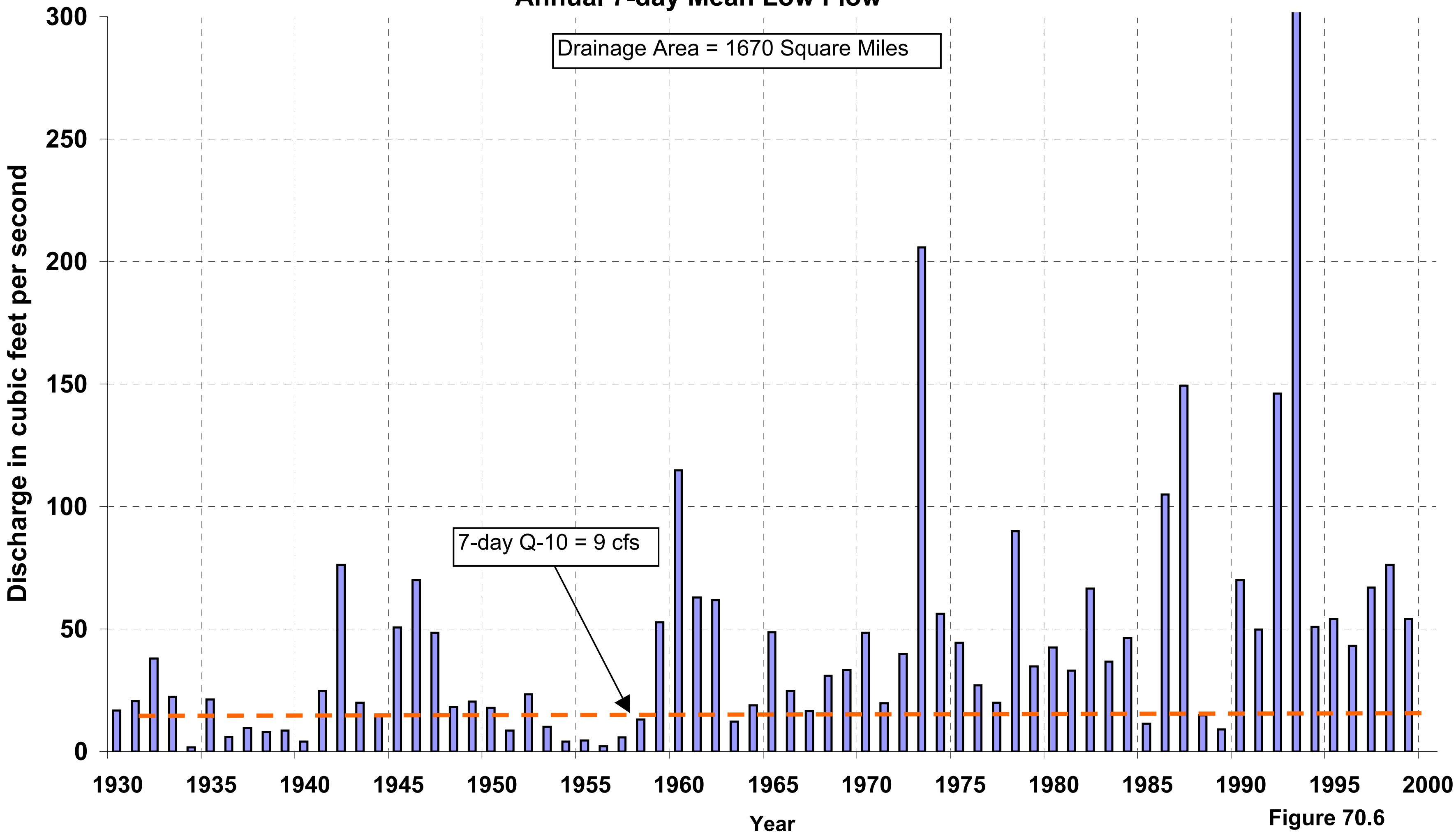


Figure 70.6

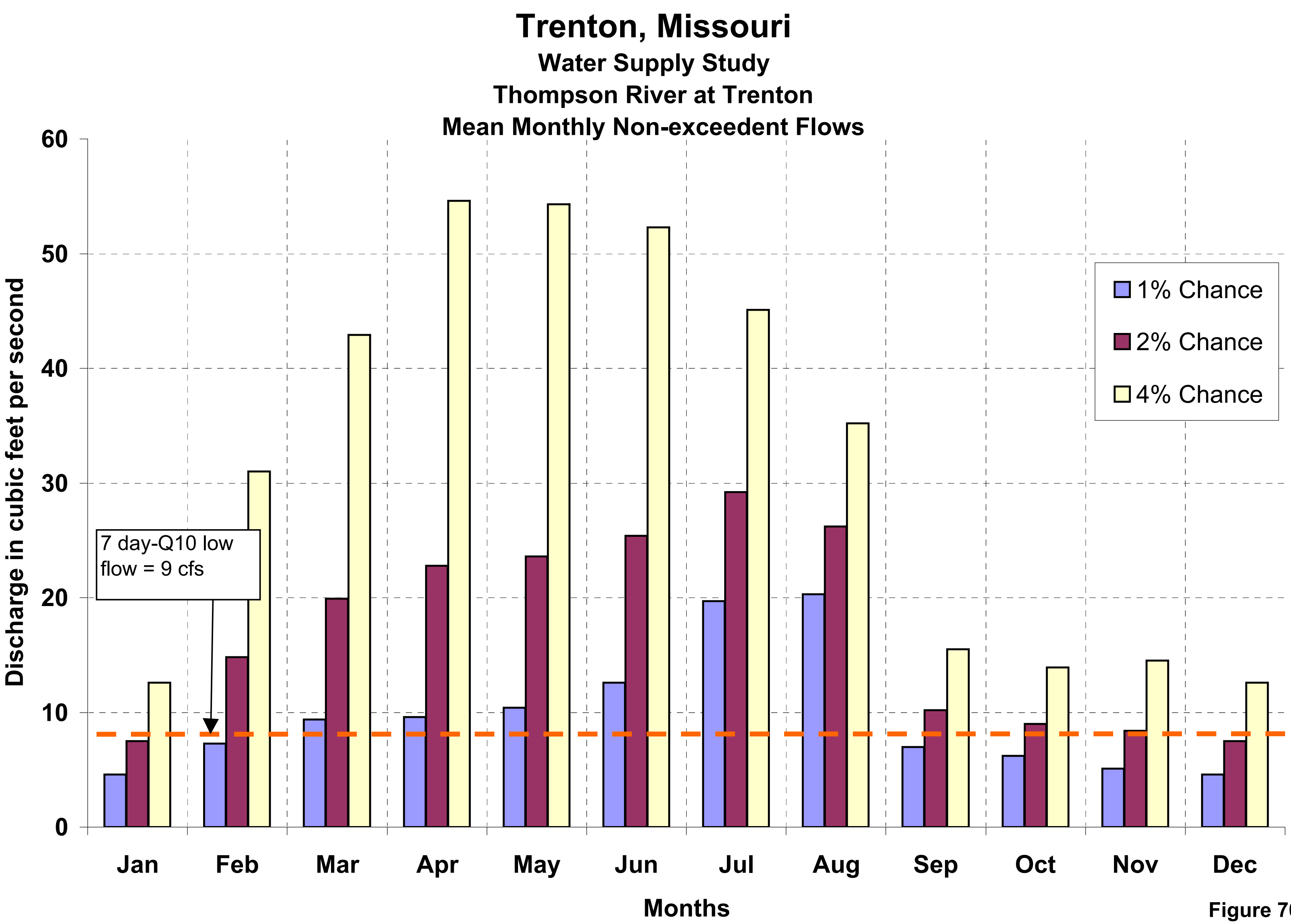
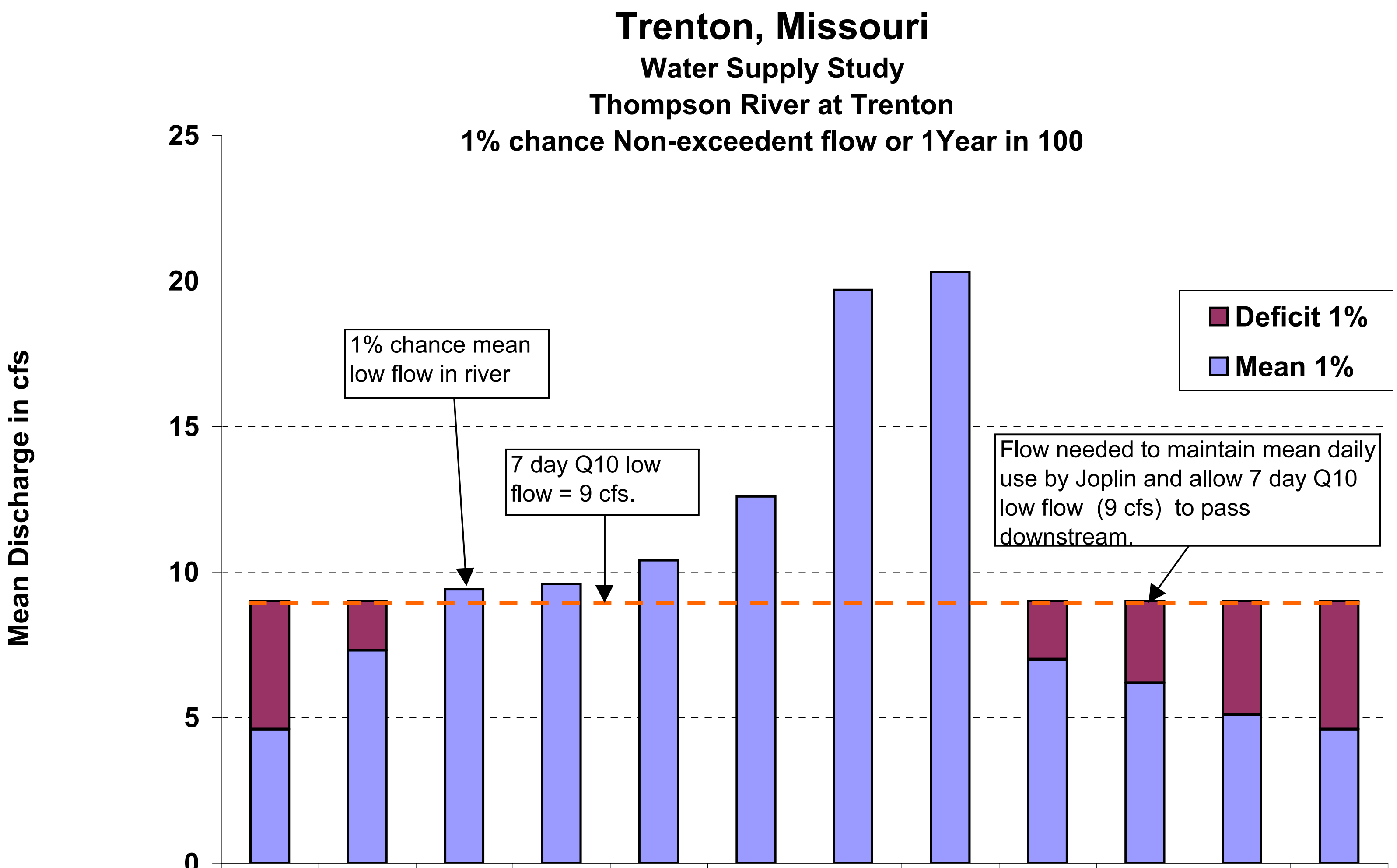

Trenton, Missouri
Water Supply Study
Thompson River at Trenton
Mean Monthly Non-exceedent Flows
Discharge in cubic feet per second
60
50
40
30
20
10
0
7 day-Q10 low
flow = 9 cfs
1% Chance
2% Chance
4% Chance
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Months

Figure 70.7

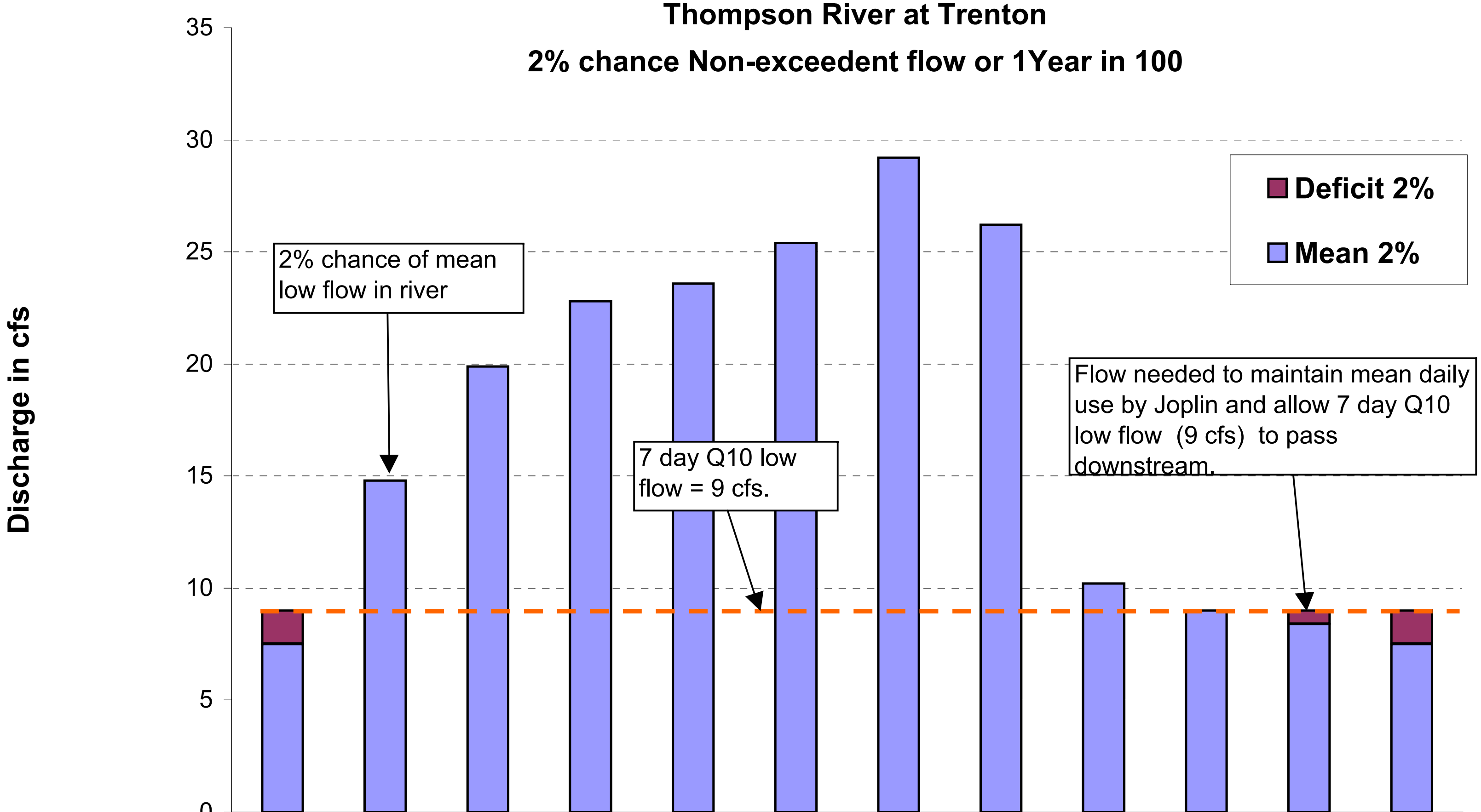


	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Deficit 1%	4.4	1.7	0	0	0	0	0	0	2	2.8	3.9	4.4
Mean 1%	4.6	7.3	9.4	9.6	10.4	12.6	19.7	20.3	7	6.2	5.1	4.6

Month

Figure 70.8.a

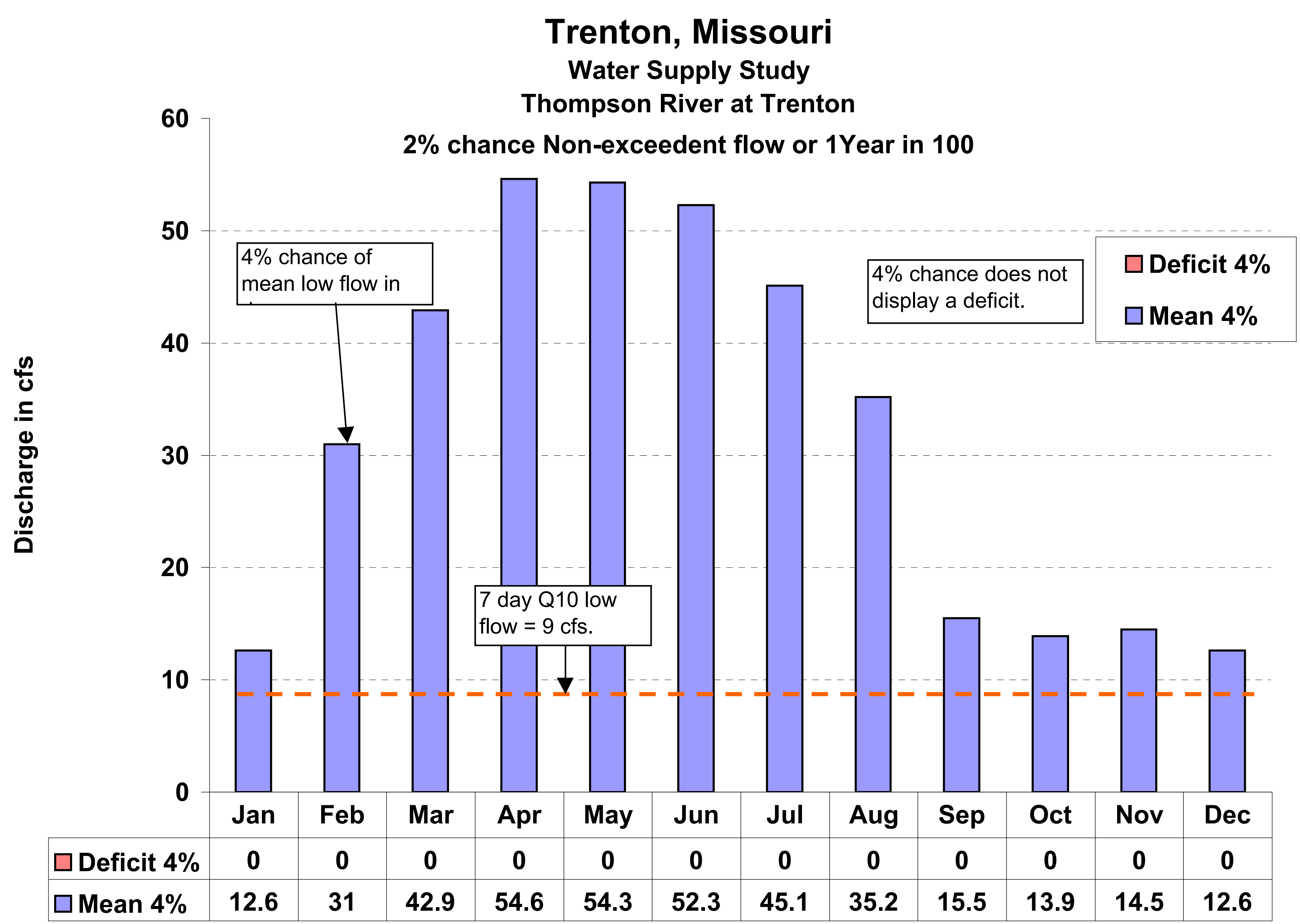
Trenton, Missouri
Water Supply Study
Thompson River at Trenton
2% chance Non-exceedent flow or 1Year in 100



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Deficit 2%	1.5	0	0	0	0	0	0	0	0	0	0.6	1.5
Mean 2%	7.5	14.8	19.9	22.8	23.6	25.4	29.2	26.2	10.2	9	8.4	7.5

Month

Figure 70.8.b



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Deficit 4%	0	0	0	0	0	0	0	0	0	0	0	0
Mean 4%	12.6	31	42.9	54.6	54.3	52.3	45.1	35.2	15.5	13.9	14.5	12.6

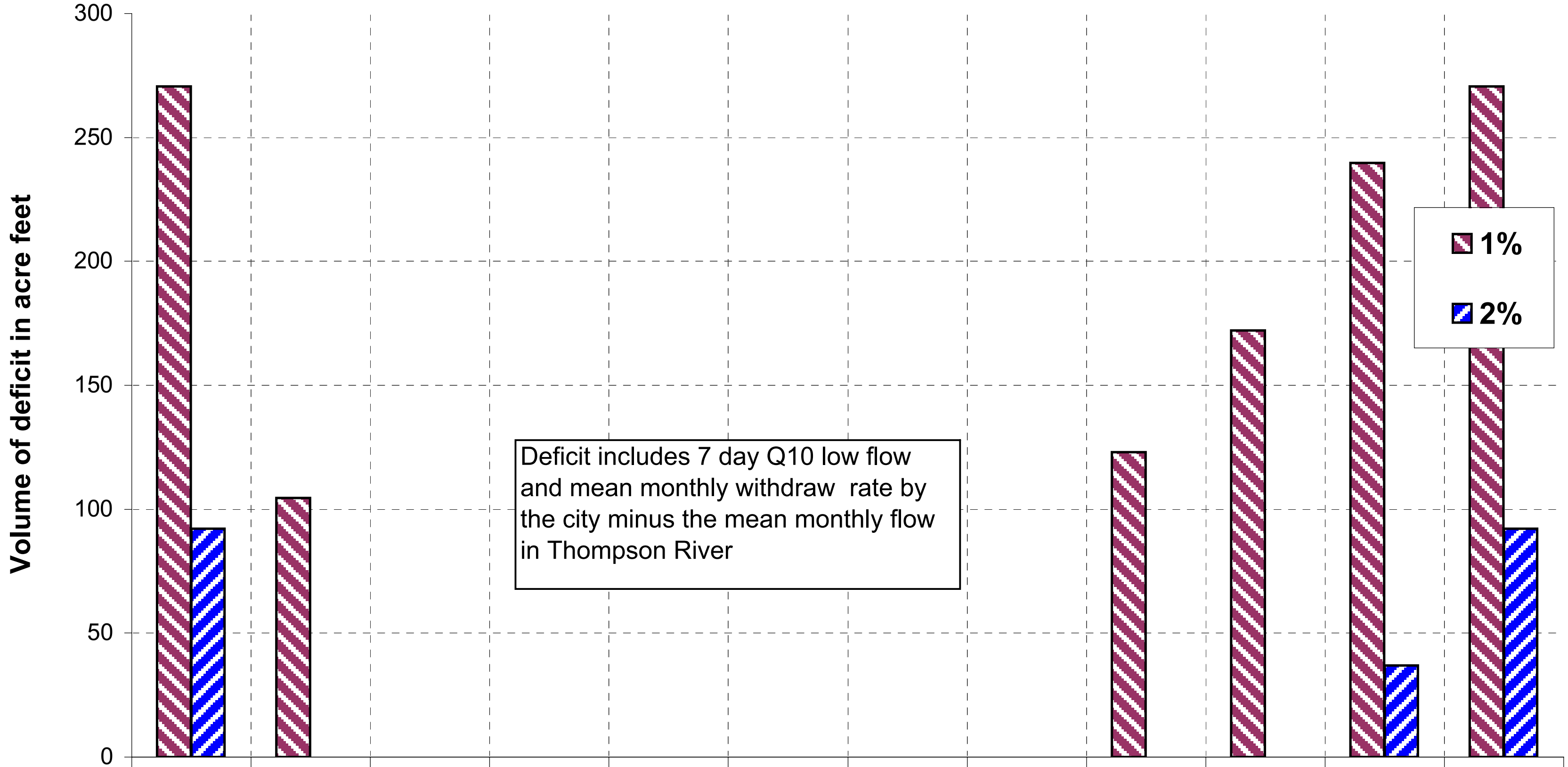
Figure 70.8.c

Trenton, Missouri

Water supply Study

Thompson River at Trenton, Missouri

Monthly Deficit in Acre Feet



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1%	271	105	0	0	0	0	0	0	123	172	240	271
2%	92	0	0	0	0	0	0	0	0	0	37	92

Month

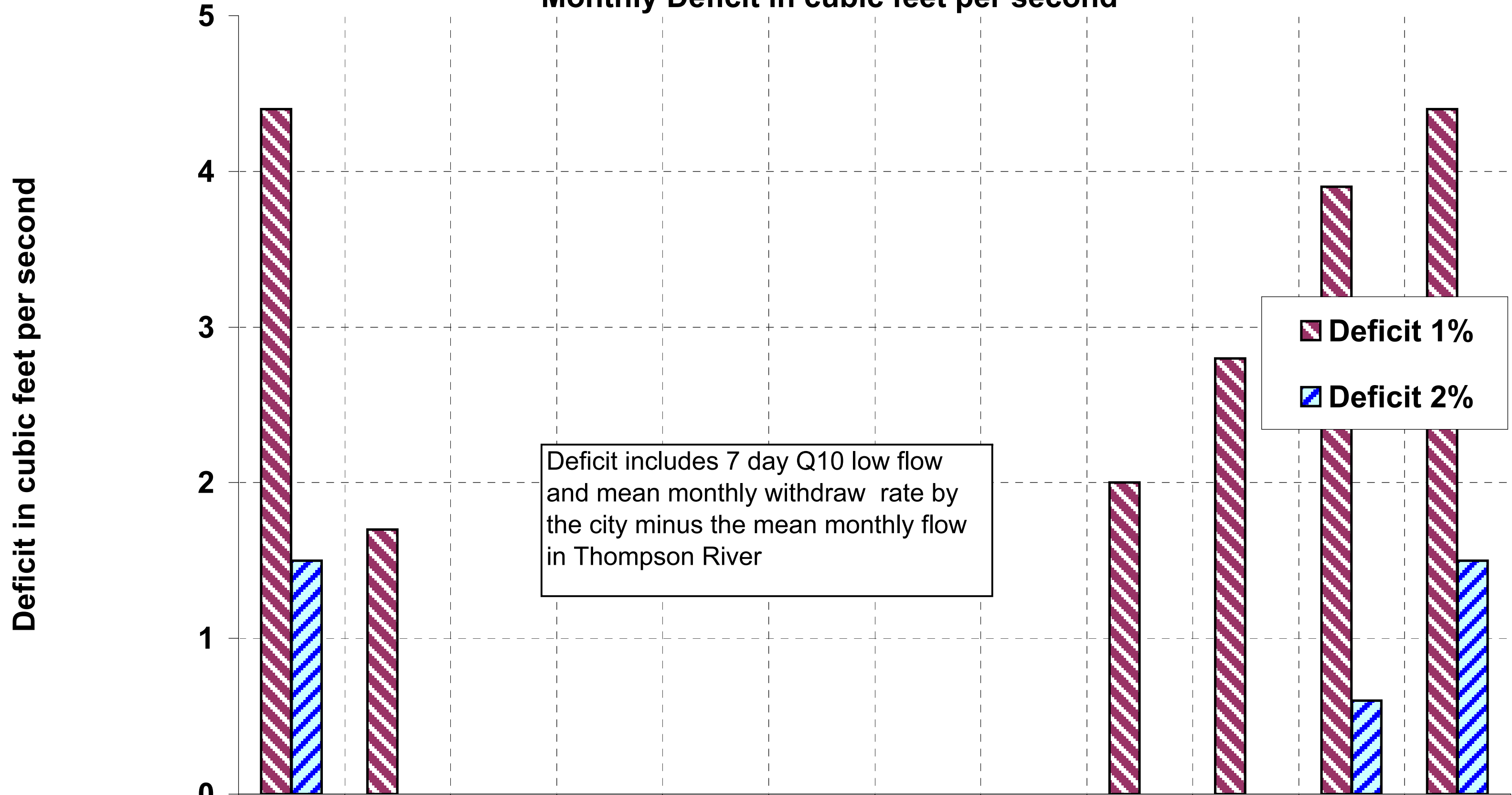
Figure 70.8.d

Trenton, Missouri

Water supply Study

Thompson River at Trenton, Missouri

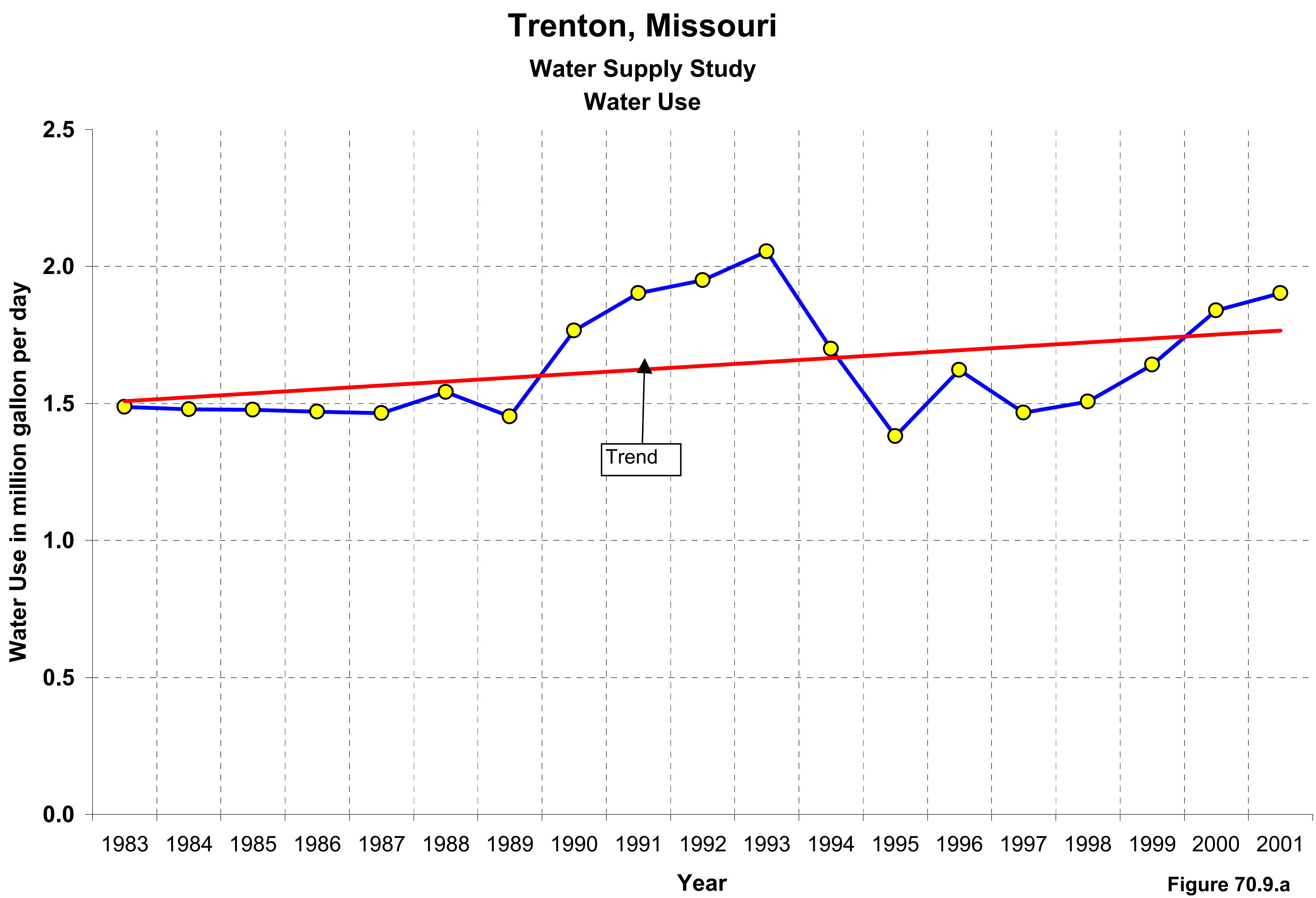
Monthly Deficit in cubic feet per second

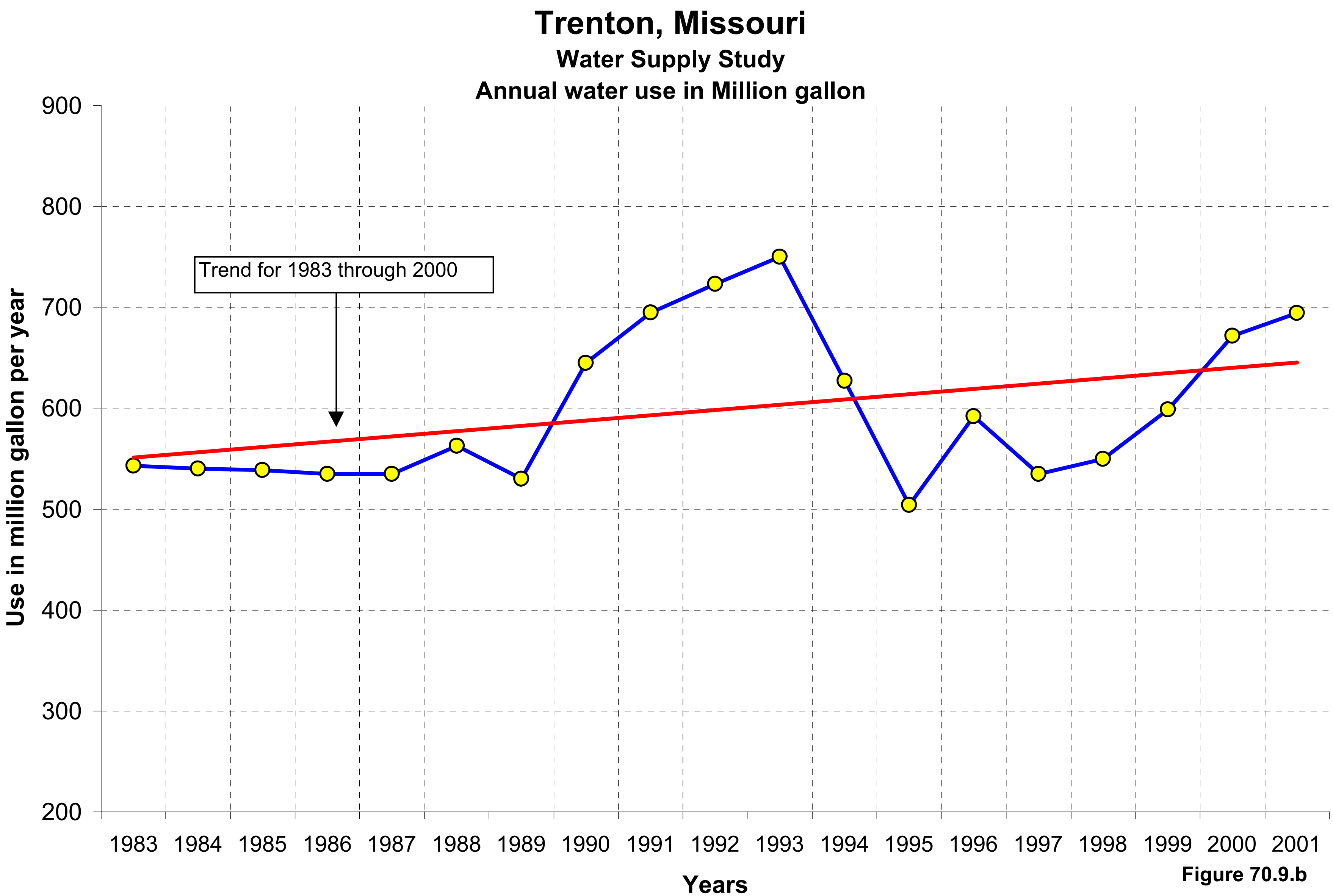


	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Deficit 1%	4.4	1.7	0	0	0	0	0	0	2	2.8	3.9	4.4
Deficit 2%	1.5	0	0	0	0	0	0	0	0	0	0.6	1.5

Month

Figure 70.8.e


Trenton, Missouri
Water Supply Study
Water Use
Water Use in million gallon per day
2.5
2.0
1.5
1.0
0.5
0.0
Trend
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
Year
Figure 70.9.a


Trenton, Missouri
Water Supply Study
Annual water use in Million gallon
Use in million gallon per year
900
800
700
600
500
400
300
200
Trend for 1983 through 2000
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
Years
Figure 70.9.b

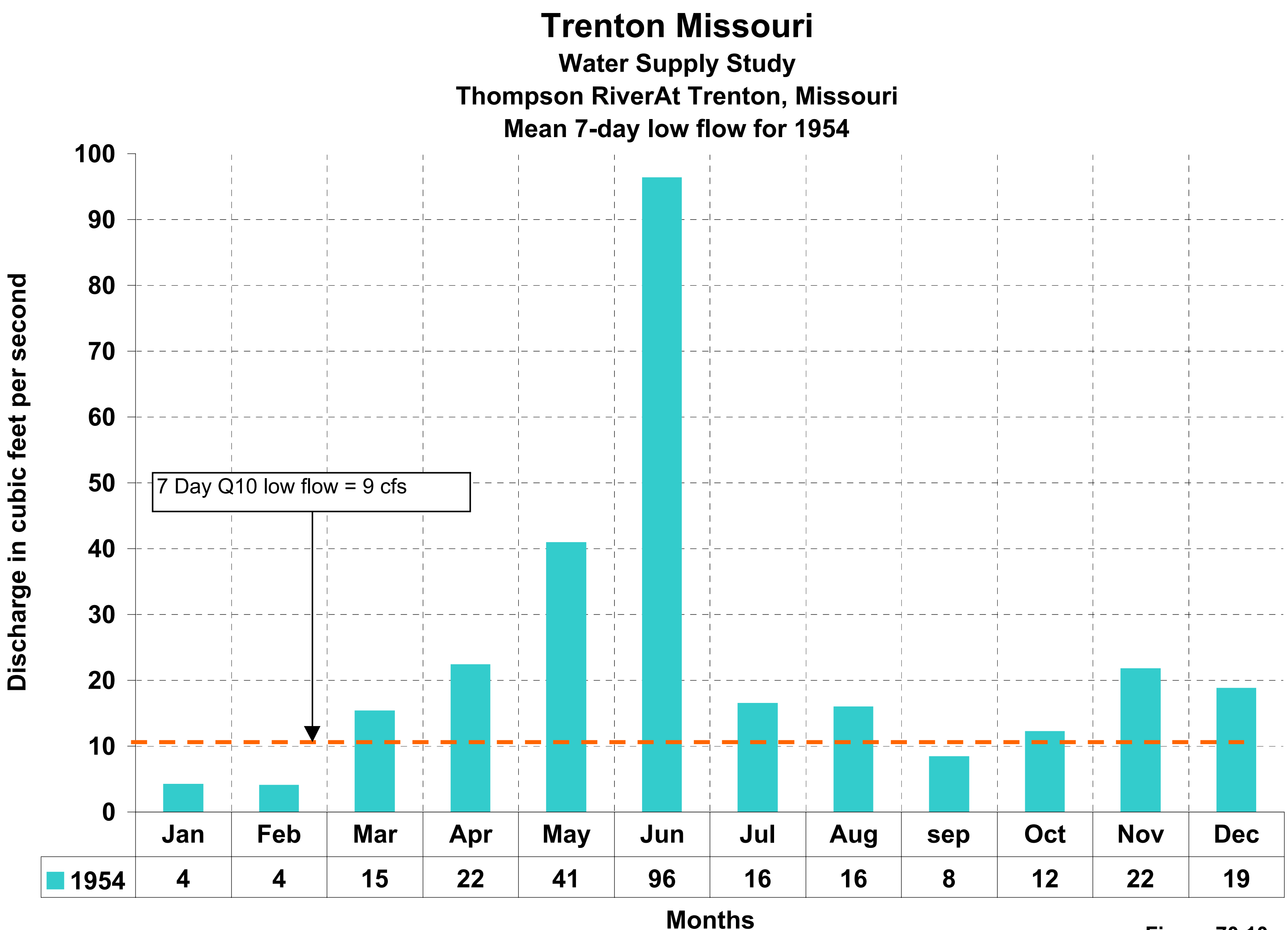


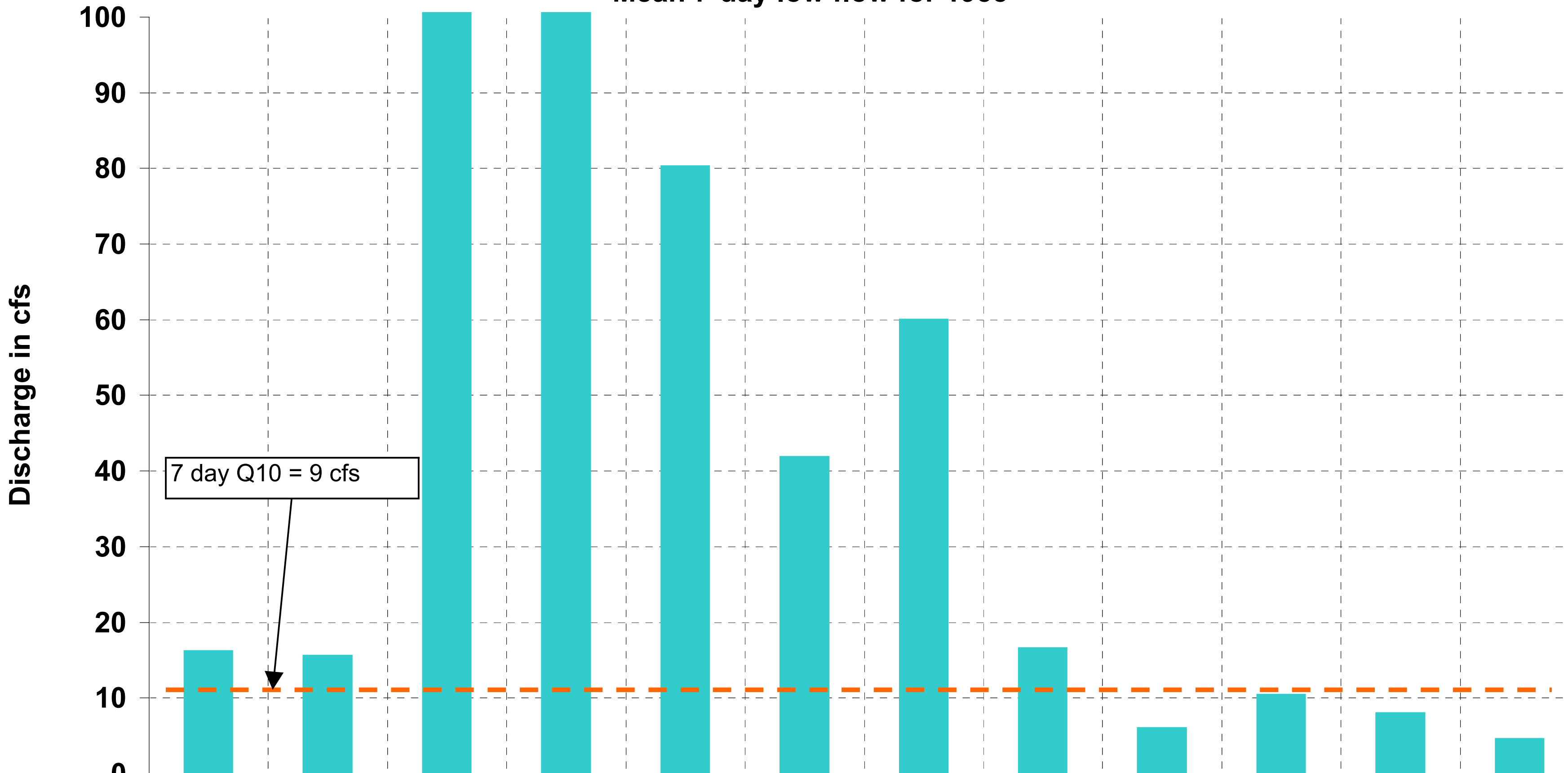
Figure 70.10.a

Trenton Missouri

Water Supply Study

Thompson RiverAt Trenton, Missouri

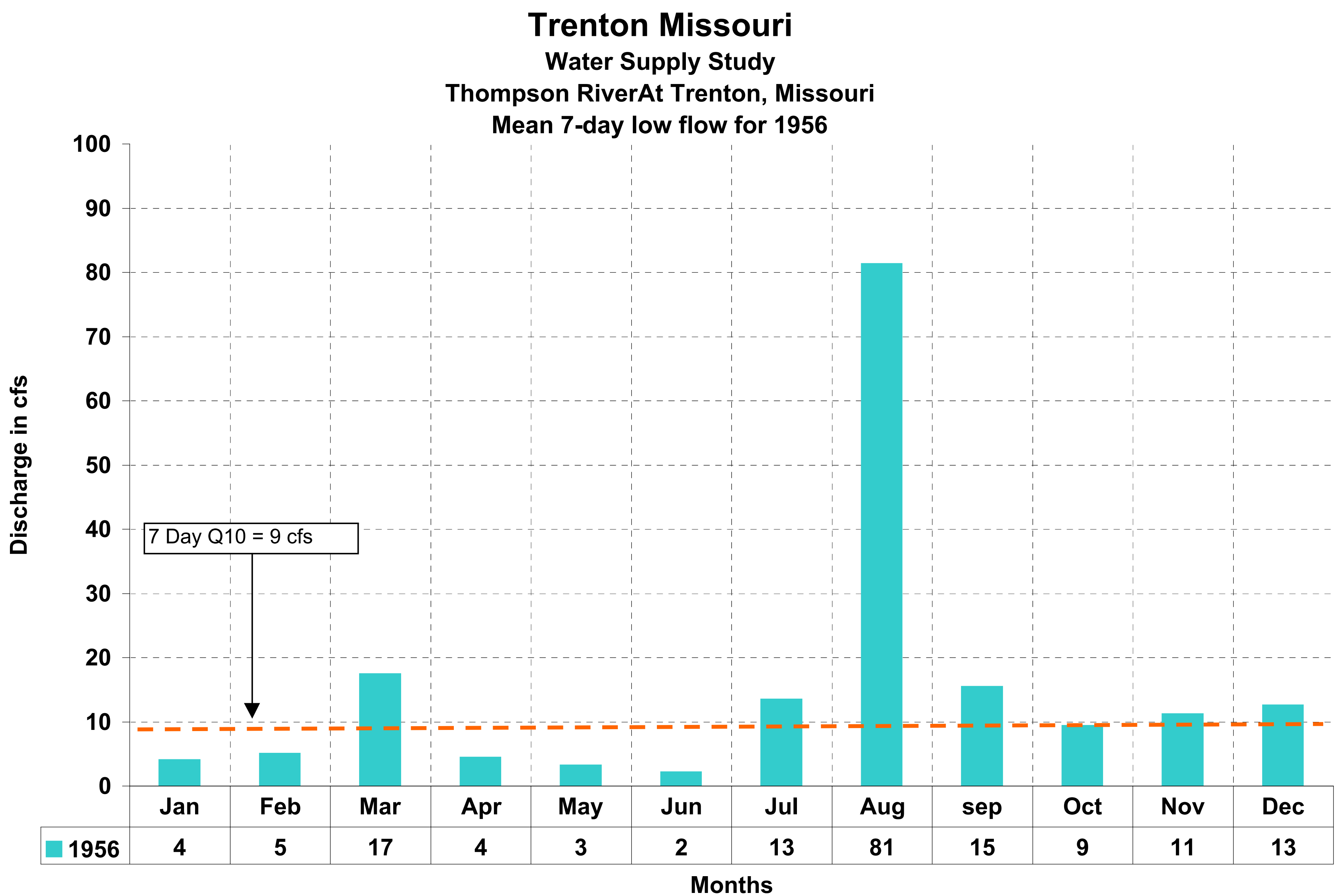
Mean 7-day low flow for 1955



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	sep	Oct	Nov	Dec
1955	16	16	262	143	80	42	60	17	6	10	8	5

Months

Figure 70.10.b



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	sep	Oct	Nov	Dec
1956	4	5	17	4	3	2	13	81	15	9	11	13

Figure 70.10.c

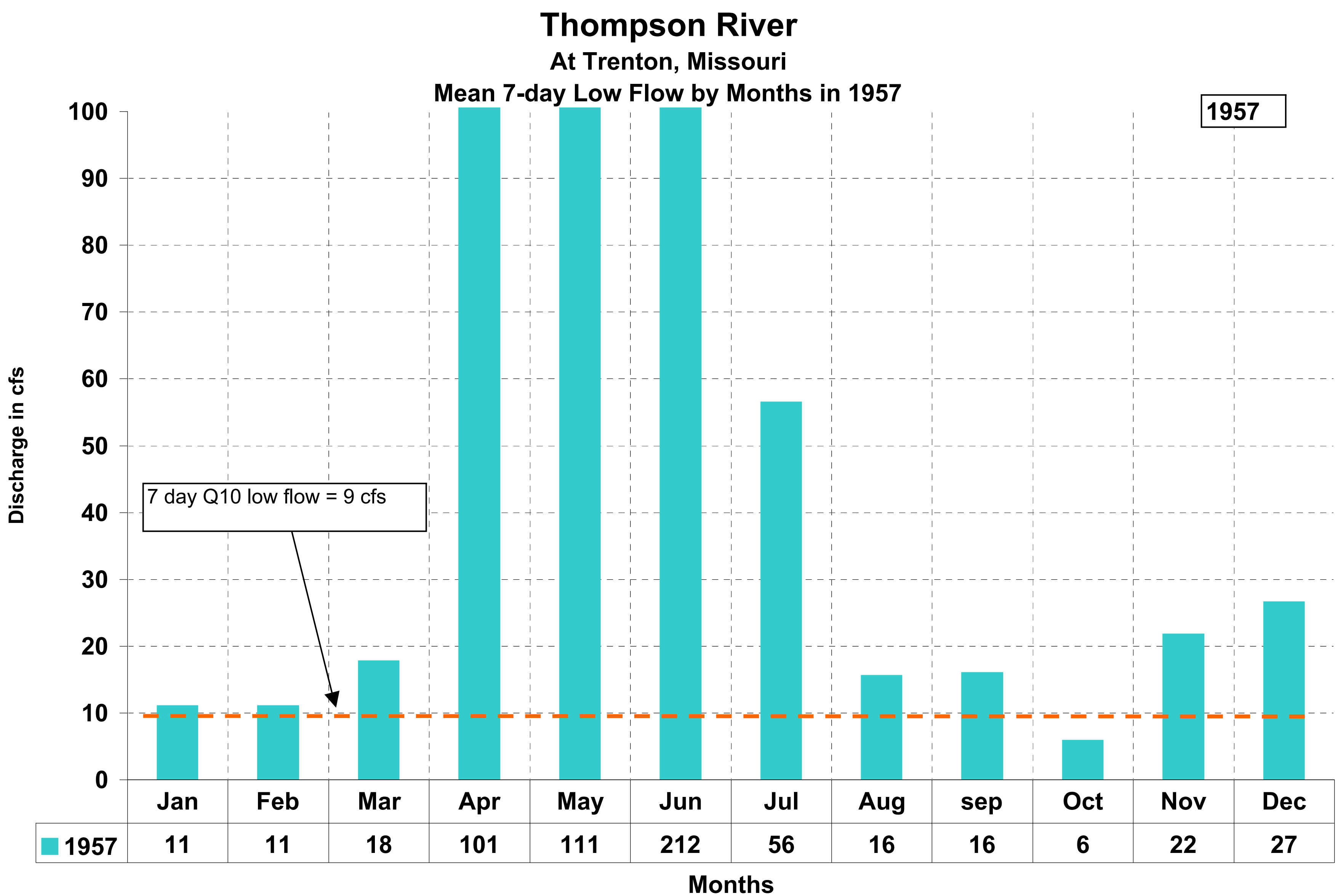


Figure 70.10.d

Staff Gages

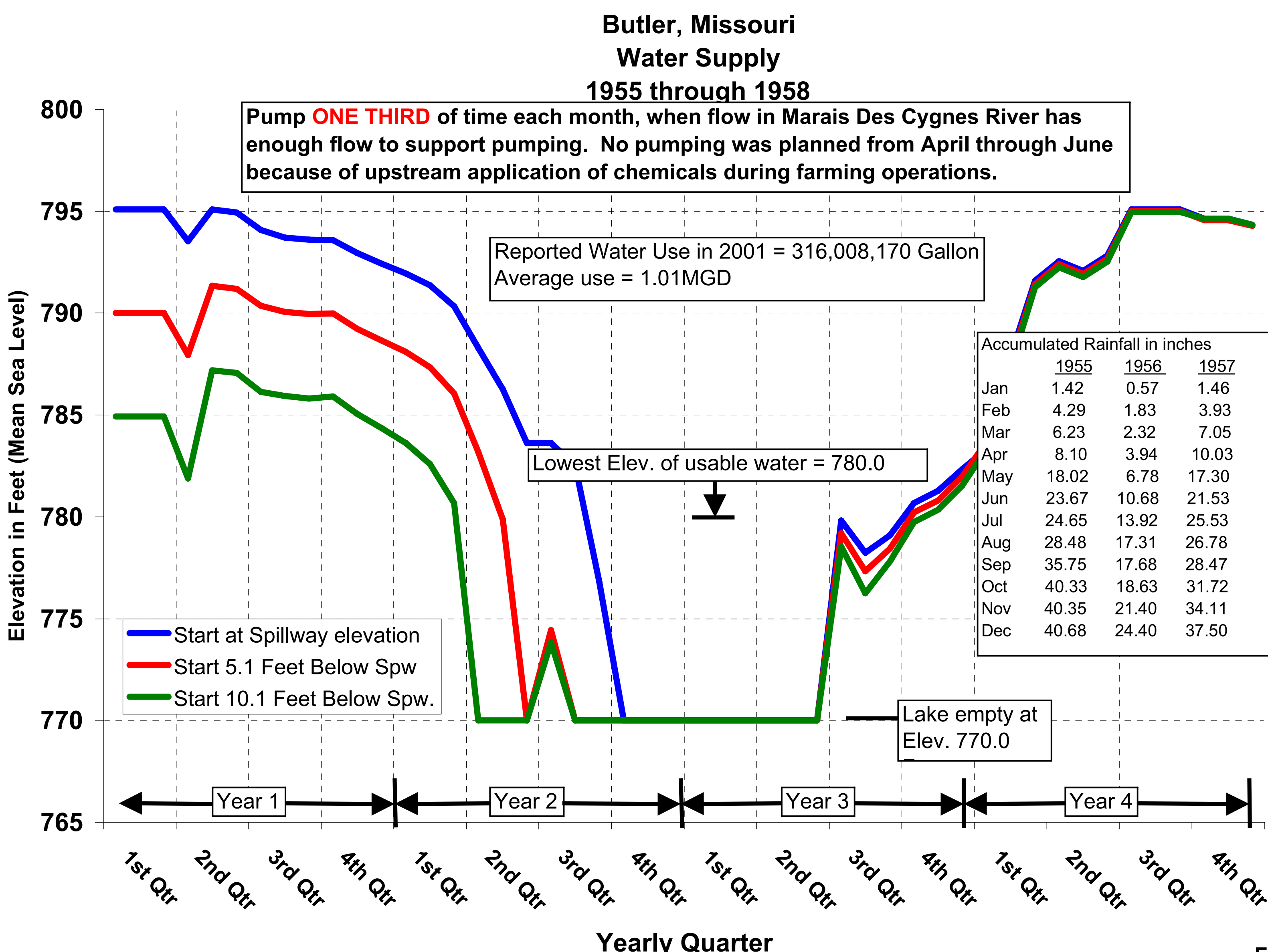
Introduction

Five of the lakes were selected for installation of staff gages for monitoring the volume of water in the lakes. Lakes with staff gages are Butler, Hamilton, Harrison County Public Water Supply District No. 1, Marceline and Monroe City. The volume in each lake is determined by reading the elevation on the staff gage and looking at the elevation-storage plot to determine the existing volume of water in the lake. With the storage and rainfall history, an estimate of future demands on the system can be made using one of the two recent historical drought periods of 1955 through 1957 and 1988 through 1990. Recent average daily municipal water demands were used to develop the charts. Year 2000 was used to develop the Marceline and Monroe City charts. Year 2001 was used for the other 3 cities. The year was selected based on the highest daily demand. By use of these charts and reading the staff gages, an estimate of remaining water supply may be made for planning future water needs.

Analysis for development for staff gage studies

Staff gages were installed for monitoring the volume of water in each of the five lakes selected and were used to project an estimate of future water availability for developing a plan to extend the water supply to get through the drought cycle.

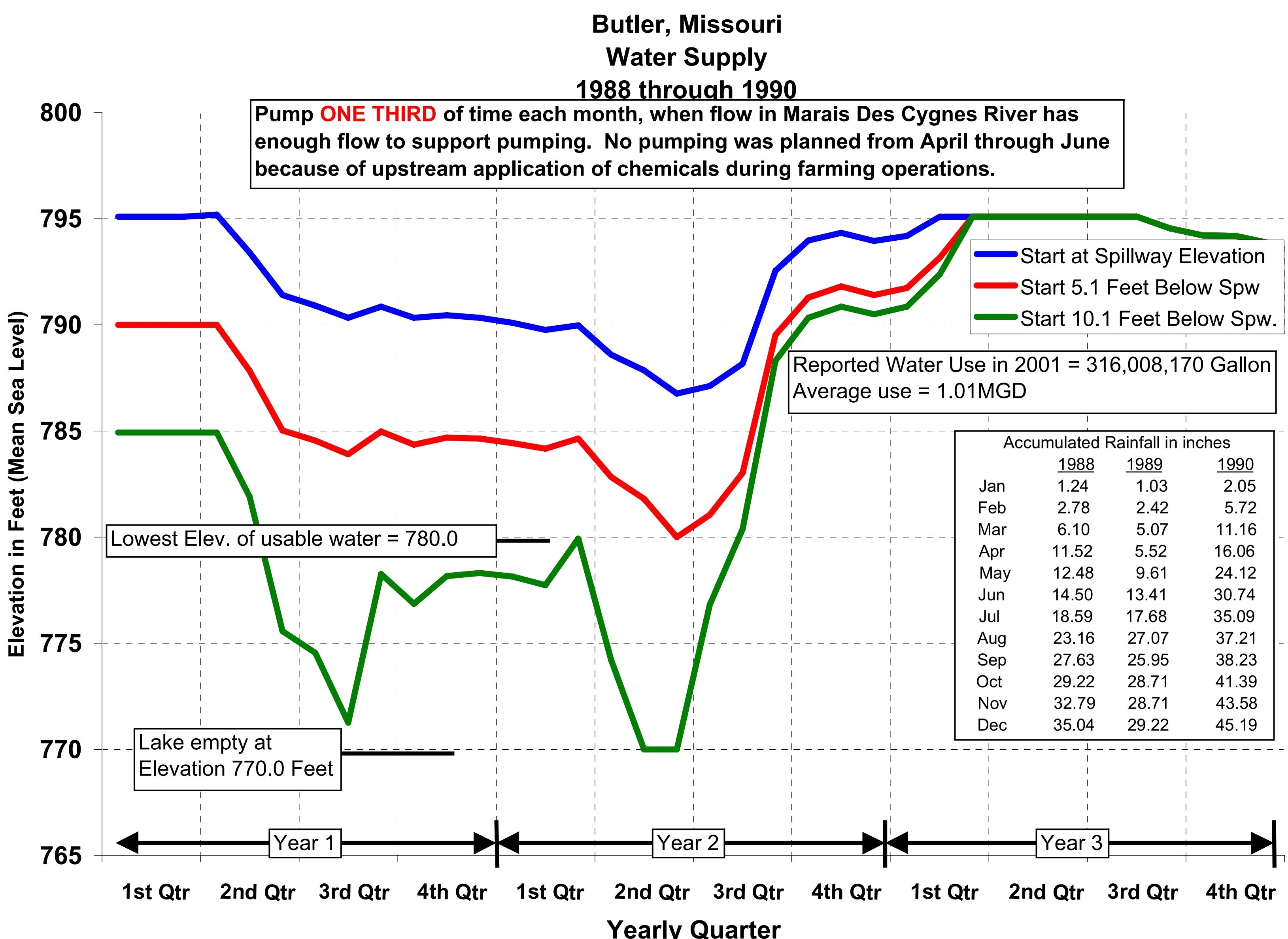
Two drought periods are presented for comparing to a drought condition. The most recent period extended from 1988 through 1989. The most severe extended from 1955 through 1958. The RESOP program was used to estimate the effects of each drought period. Three RESOP runs were made on each reservoir for both dry periods. One beginning at full pool, the second beginning five feet below the spillway and the third run beginning ten feet below the spillway. Monthly accumulated rainfall for each of the dry periods are presented so that comparisons can be made for a current drought and the historical dry period.



Accumulated Rainfall in inches

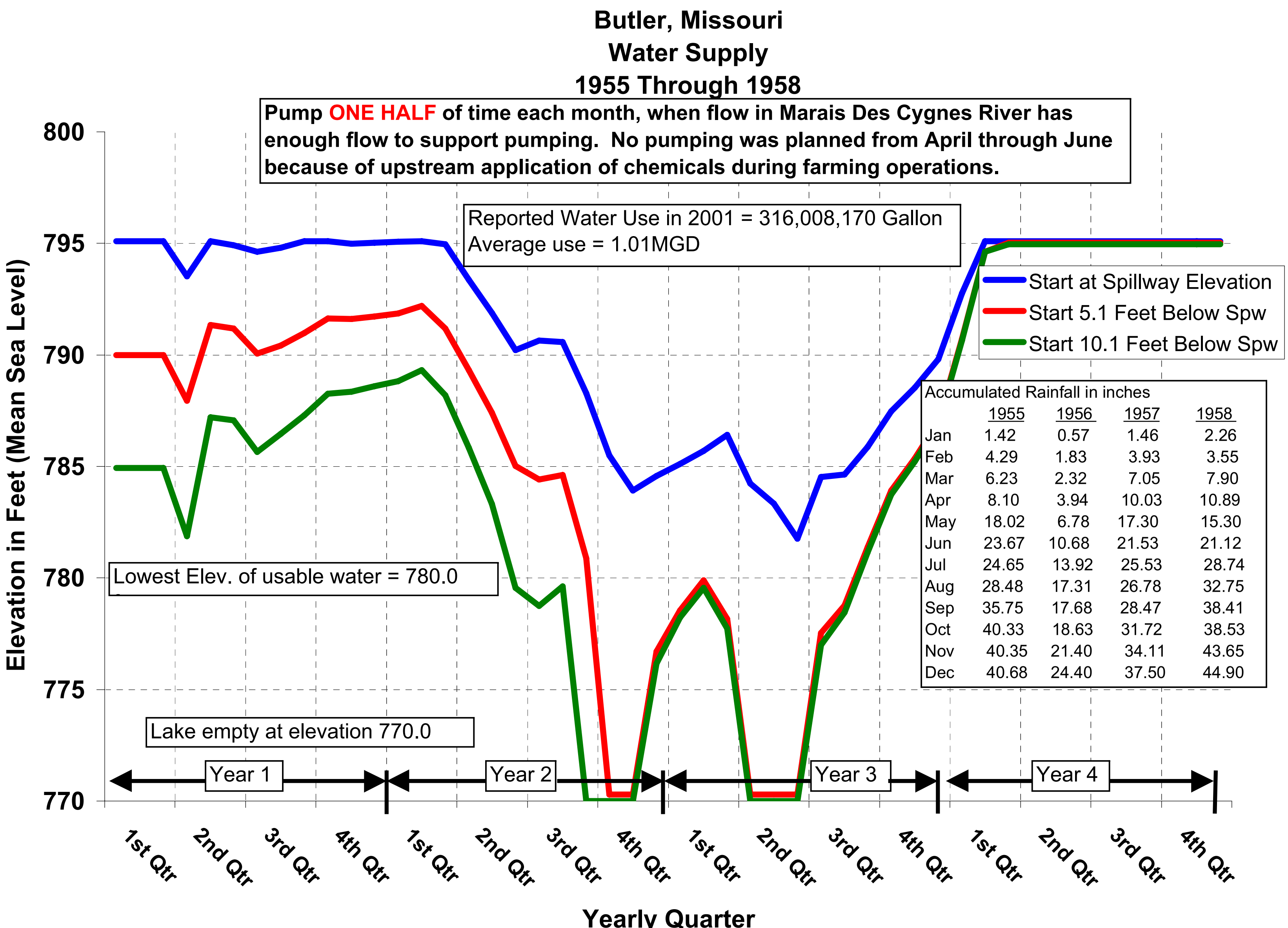
	1955	1956	1957	1958
Jan	1.42	0.57	1.46	2.26
Feb	4.29	1.83	3.93	3.55
Mar	6.23	2.32	7.05	7.90
Apr	8.10	3.94	10.03	10.89
May	18.02	6.78	17.30	15.30
Jun	23.67	10.68	21.53	21.12
Jul	24.65	13.92	25.53	28.74
Aug	28.48	17.31	26.78	32.75
Sep	35.75	17.68	28.47	38.41
Oct	40.33	18.63	31.72	38.53
Nov	40.35	21.40	34.11	43.65
Dec	40.68	24.40	37.50	44.90

Figure: 80.1.a



	1988	1989	1990
Jan	1.24	1.03	2.05
Feb	2.78	2.42	5.72
Mar	6.10	5.07	11.16
Apr	11.52	5.52	16.06
May	12.48	9.61	24.12
Jun	14.50	13.41	30.74
Jul	18.59	17.68	35.09
Aug	23.16	27.07	37.21
Sep	27.63	25.95	38.23
Oct	29.22	28.71	41.39
Nov	32.79	28.71	43.58
Dec	35.04	29.22	45.19

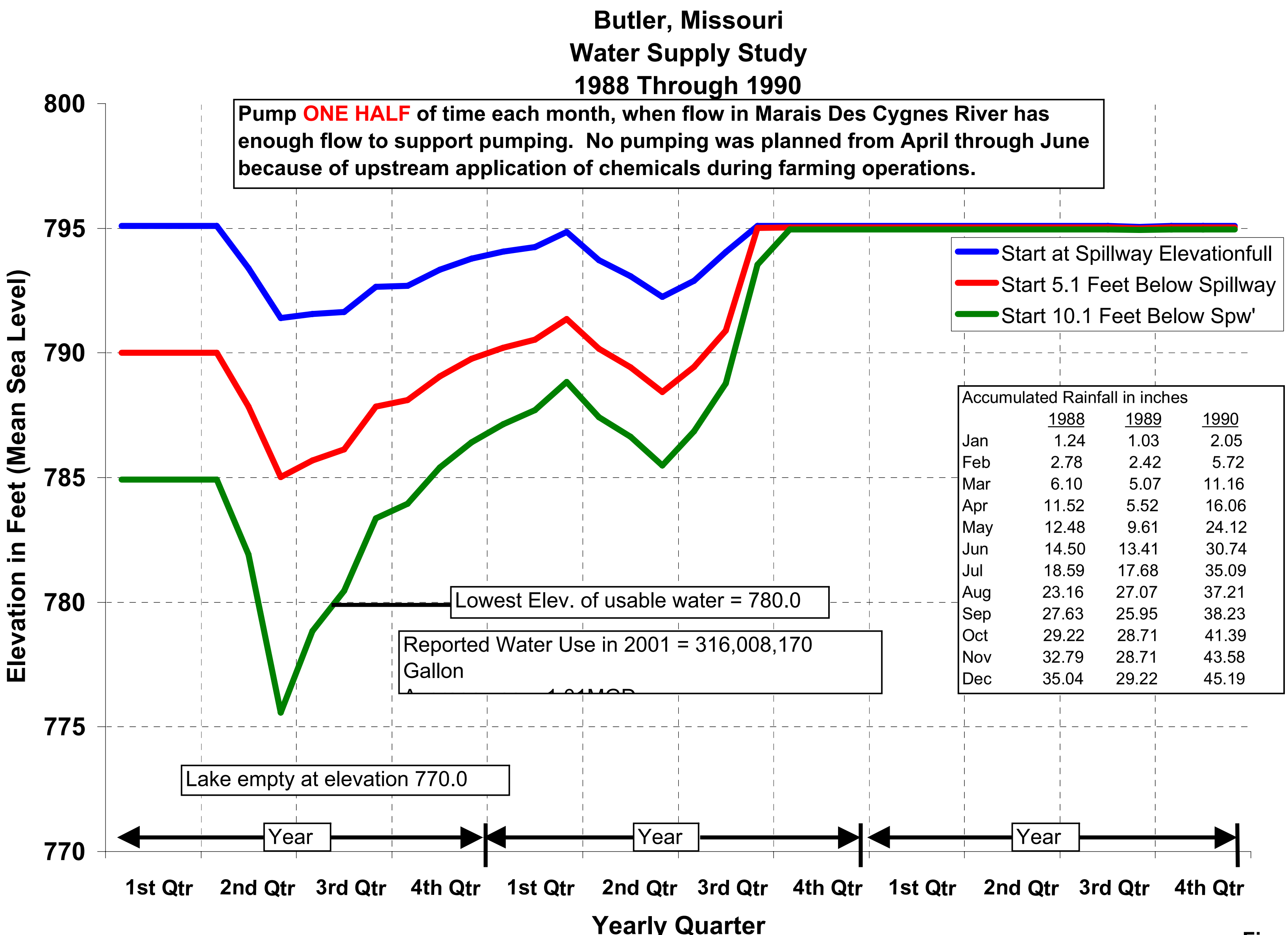
Figure: 80.1.b



Accumulated Rainfall in inches

	1955	1956	1957	1958
Jan	1.42	0.57	1.46	2.26
Feb	4.29	1.83	3.93	3.55
Mar	6.23	2.32	7.05	7.90
Apr	8.10	3.94	10.03	10.89
May	18.02	6.78	17.30	15.30
Jun	23.67	10.68	21.53	21.12
Jul	24.65	13.92	25.53	28.74
Aug	28.48	17.31	26.78	32.75
Sep	35.75	17.68	28.47	38.41
Oct	40.33	18.63	31.72	38.53
Nov	40.35	21.40	34.11	43.65
Dec	40.68	24.40	37.50	44.90

Figure: 80.1.c


Butler, Missouri
Water Supply Study
1988 Through 1990
Pump ONE HALF of time each month, when flow in Marais Des Cygnes River has enough flow to support pumping. No pumping was planned from April through June because of upstream application of chemicals during farming operations.
Start at Spillway Elevationfull
Start 5.1 Feet Below Spillway
Start 10.1 Feet Below Spw'
Lowest Elev. of usable water = 780.0
Reported Water Use in 2001 = 316,008,170 Gallon
Lake empty at elevation 770.0
Elevation in Feet (Mean Sea Level)
800
795
790
785
780
775
770
Year
Year
Year
1st Qtr
2nd Qtr
3rd Qtr
4th Qtr
1st Qtr
2nd Qtr
3rd Qtr
4th Qtr
1st Qtr
2nd Qtr
3rd Qtr
4th Qtr
Yearly Quarter
Accumulated Rainfall in inches

	1988	1989	1990
Jan	1.24	1.03	2.05
Feb	2.78	2.42	5.72
Mar	6.10	5.07	11.16
Apr	11.52	5.52	16.06
May	12.48	9.61	24.12
Jun	14.50	13.41	30.74
Jul	18.59	17.68	35.09
Aug	23.16	27.07	37.21
Sep	27.63	25.95	38.23
Oct	29.22	28.71	41.39
Nov	32.79	28.71	43.58
Dec	35.04	29.22	45.19

Figure: 80.1.d

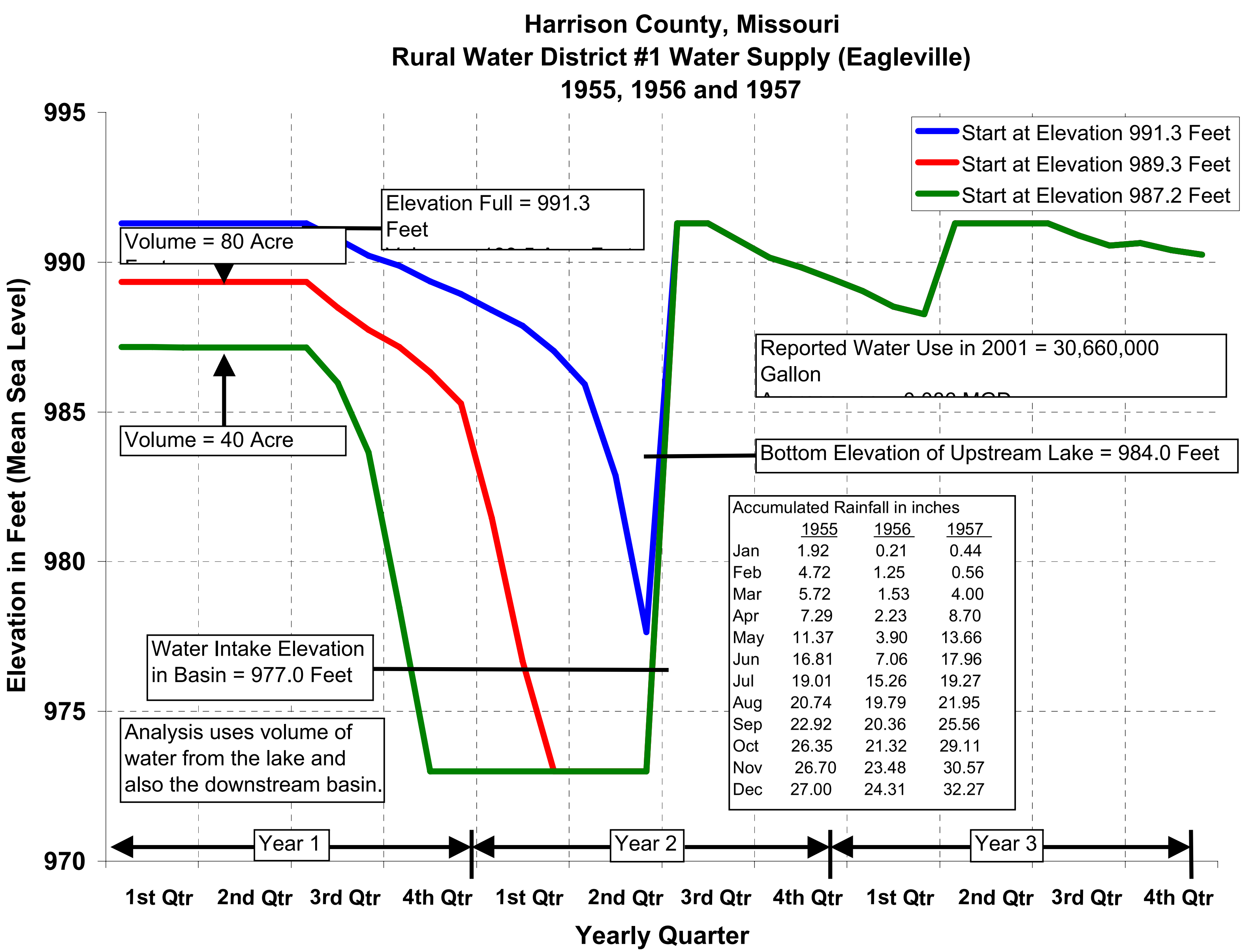
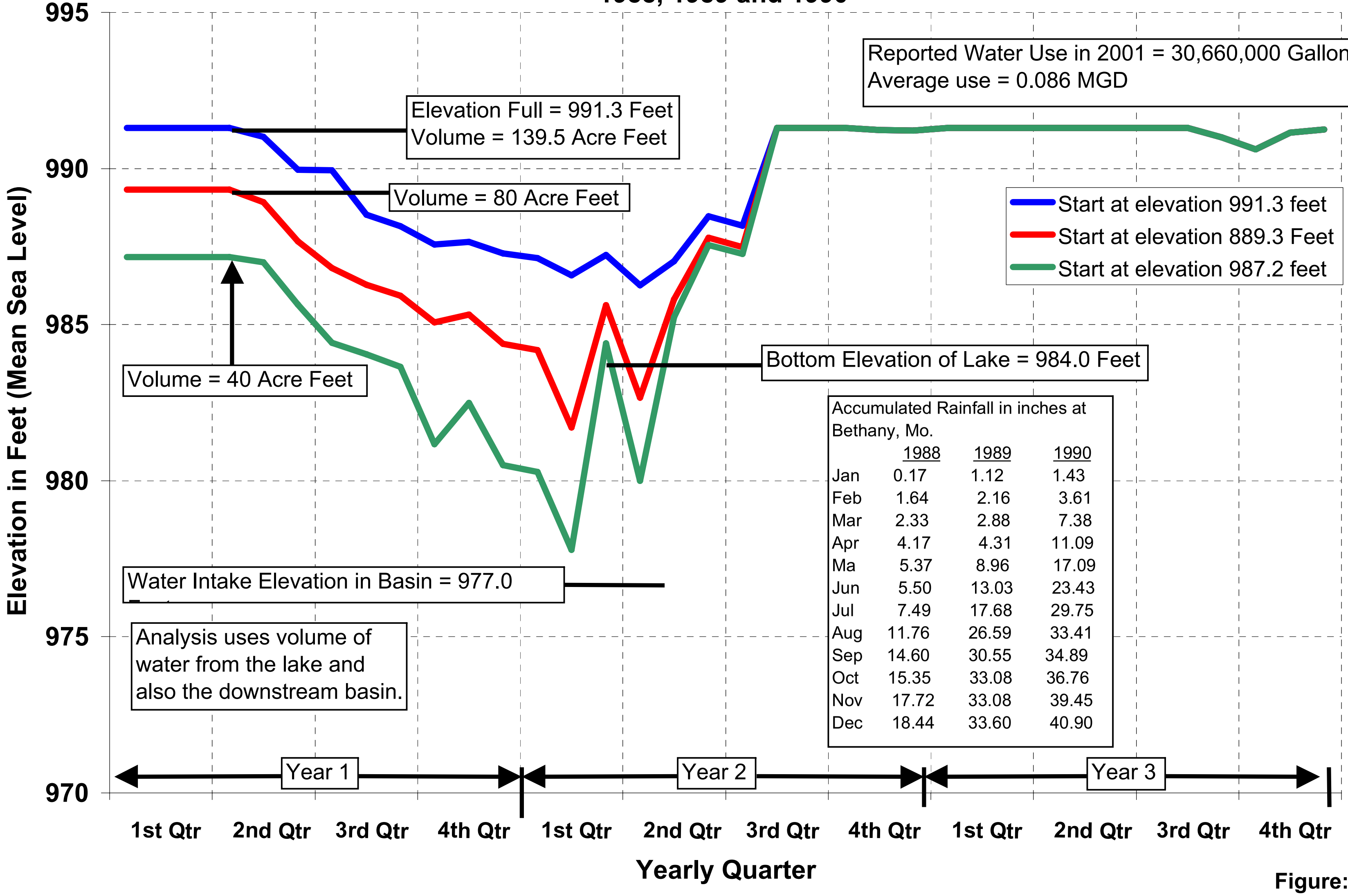

Harrison County, Missouri
Rural Water District #1 Water Supply (Eagleville)
1955, 1956 and 1957
Elevation in Feet (Mean Sea Level)
995
990
985
980
975
970
Start at Elevation 991.3 Feet
Start at Elevation 989.3 Feet
Start at Elevation 987.2 Feet
Elevation Full = 991.3 Feet
Volume = 80 Acre
Volume = 40 Acre
Reported Water Use in 2001 = 30,660,000 Gallon
Bottom Elevation of Upstream Lake = 984.0 Feet
Water Intake Elevation in Basin = 977.0 Feet
Analysis uses volume of water from the lake and also the downstream basin.
Accumulated Rainfall in inches
1955 1956 1957
Jan 1.92 0.21 0.44
Feb 4.72 1.25 0.56
Mar 5.72 1.53 4.00
Apr 7.29 2.23 8.70
May 11.37 3.90 13.66
Jun 16.81 7.06 17.96
Jul 19.01 15.26 19.27
Aug 20.74 19.79 21.95
Sep 22.92 20.36 25.56
Oct 26.35 21.32 29.11
Nov 26.70 23.48 30.57
Dec 27.00 24.31 32.27
Year 1
Year 2
Year 3
1st Qtr
2nd Qtr
3rd Qtr
4th Qtr
1st Qtr
2nd Qtr
3rd Qtr
4th Qtr
1st Qtr
2nd Qtr
3rd Qtr
4th Qtr
Yearly Quarter

Figure: 80.2.a

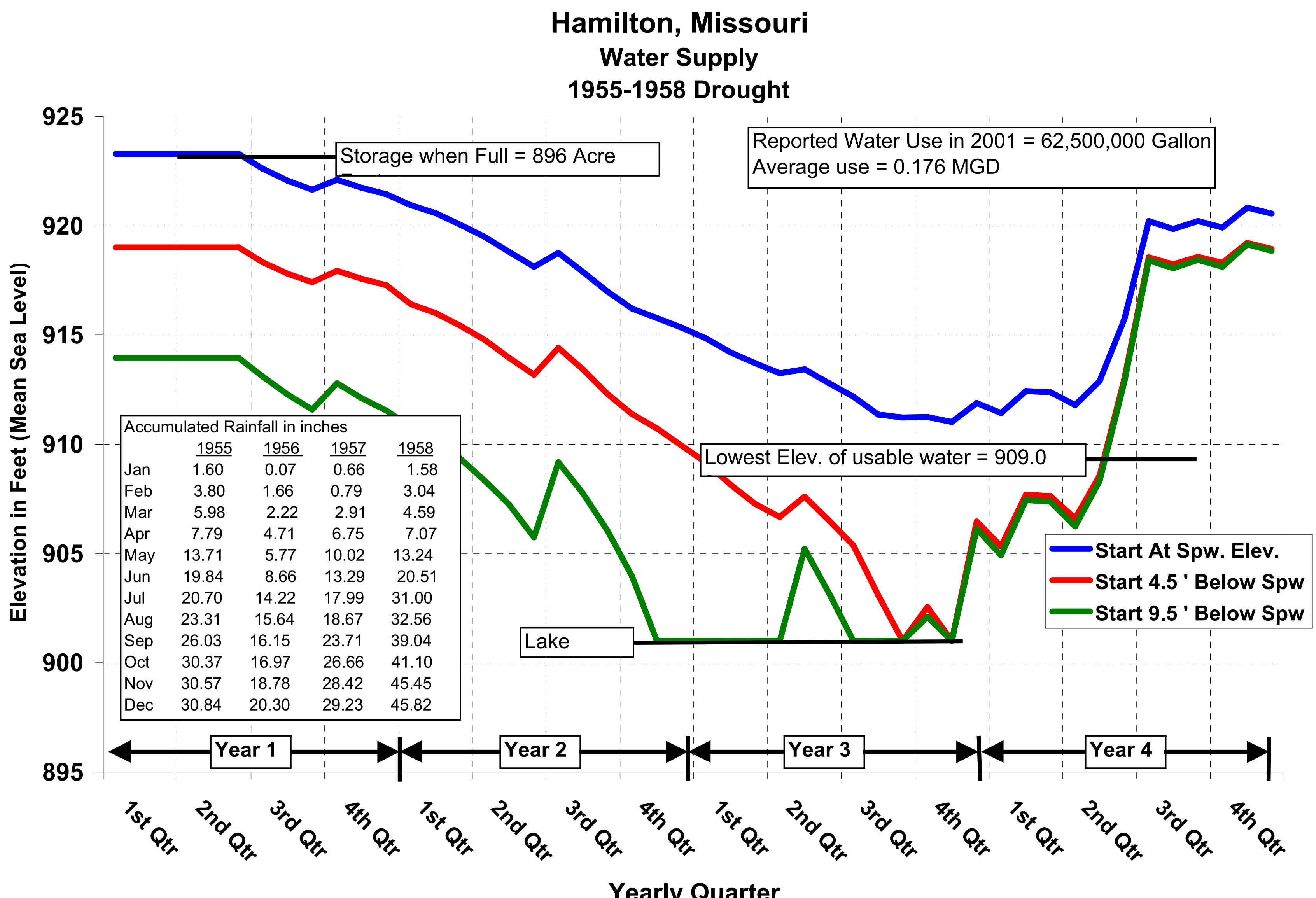
Harrison County, Missouri
Rural Water District #1 Water Supply (Eagleville)
1988, 1989 and 1990



Accumulated Rainfall in inches at Bethany, Mo.

	1988	1989	1990
Jan	0.17	1.12	1.43
Feb	1.64	2.16	3.61
Mar	2.33	2.88	7.38
Apr	4.17	4.31	11.09
Ma	5.37	8.96	17.09
Jun	5.50	13.03	23.43
Jul	7.49	17.68	29.75
Aug	11.76	26.59	33.41
Sep	14.60	30.55	34.89
Oct	15.35	33.08	36.76
Nov	17.72	33.08	39.45
Dec	18.44	33.60	40.90

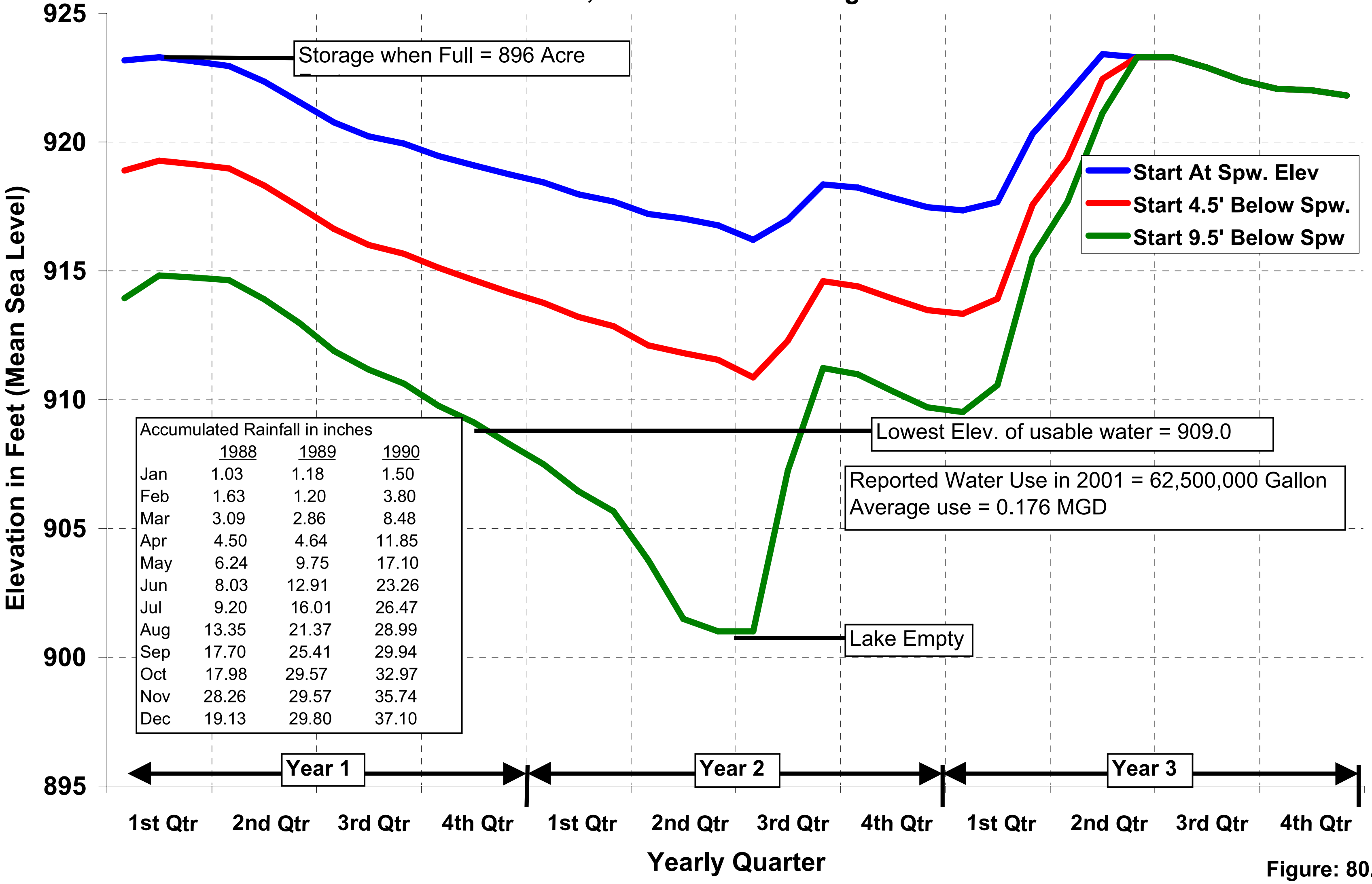
Figure: 80.2.b



Hamilton, Missouri
Water Supply
1955-1958 Drought
Elevation in Feet (Mean Sea Level)
925
920
915
910
905
900
895
Storage when Full = 896 Acre
Reported Water Use in 2001 = 62,500,000 Gallon
Average use = 0.176 MGD
Lowest Elev. of usable water = 909.0
Lake
Accumulated Rainfall in inches
1955 1956 1957 1958
Jan 1.60 0.07 0.66 1.58
Feb 3.80 1.66 0.79 3.04
Mar 5.98 2.22 2.91 4.59
Apr 7.79 4.71 6.75 7.07
May 13.71 5.77 10.02 13.24
Jun 19.84 8.66 13.29 20.51
Jul 20.70 14.22 17.99 31.00
Aug 23.31 15.64 18.67 32.56
Sep 26.03 16.15 23.71 39.04
Oct 30.37 16.97 26.66 41.10
Nov 30.57 18.78 28.42 45.45
Dec 30.84 20.30 29.23 45.82
Start At Spw. Elev.
Start 4.5 ' Below Spw
Start 9.5 ' Below Spw
Year 1
Year 2
Year 3
Year 4
1st Qtr
2nd Qtr
3rd Qtr
4th Qtr
1st Qtr
2nd Qtr
3rd Qtr
4th Qtr
1st Qtr
2nd Qtr
3rd Qtr
4th Qtr
1st Qtr
2nd Qtr
3rd Qtr
4th Qtr
Yearly Quarter

Figure 80.3.a

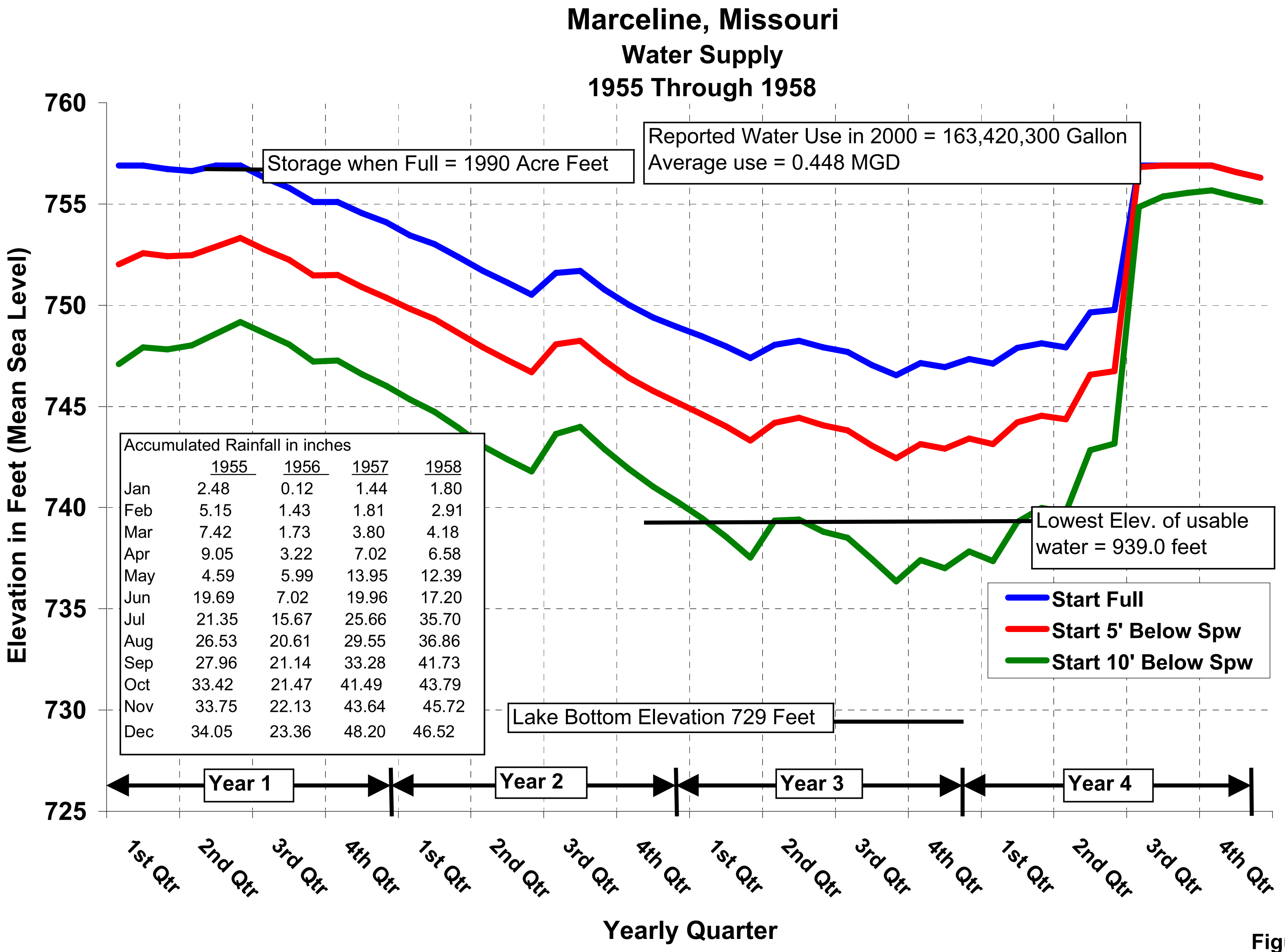
Hamilton, Missouri
Water Supply
1988, 1989 and 1990 Drought



Accumulated Rainfall in inches

	1988	1989	1990
Jan	1.03	1.18	1.50
Feb	1.63	1.20	3.80
Mar	3.09	2.86	8.48
Apr	4.50	4.64	11.85
May	6.24	9.75	17.10
Jun	8.03	12.91	23.26
Jul	9.20	16.01	26.47
Aug	13.35	21.37	28.99
Sep	17.70	25.41	29.94
Oct	17.98	29.57	32.97
Nov	28.26	29.57	35.74
Dec	19.13	29.80	37.10

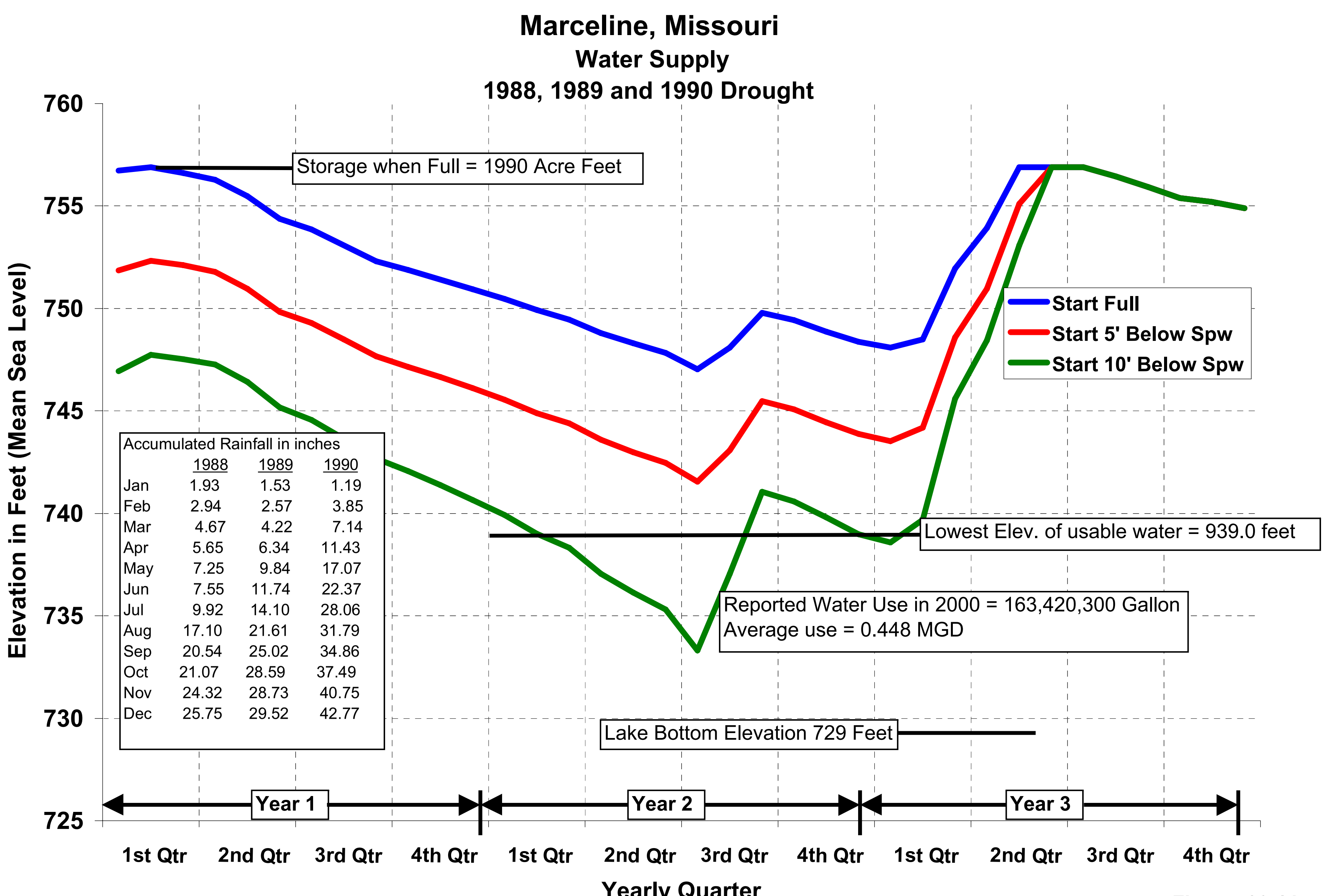
Figure: 80.3.b


Marceline, Missouri
Water Supply
1955 Through 1958
Elevation in Feet (Mean Sea Level)
760
755
750
745
740
735
730
725
Storage when Full = 1990 Acre Feet
Reported Water Use in 2000 = 163,420,300 Gallon
Average use = 0.448 MGD
Accumulated Rainfall in inches

	1955	1956	1957	1958
Jan	2.48	0.12	1.44	1.80
Feb	5.15	1.43	1.81	2.91
Mar	7.42	1.73	3.80	4.18
Apr	9.05	3.22	7.02	6.58
May	4.59	5.99	13.95	12.39
Jun	19.69	7.02	19.96	17.20
Jul	21.35	15.67	25.66	35.70
Aug	26.53	20.61	29.55	36.86
Sep	27.96	21.14	33.28	41.73
Oct	33.42	21.47	41.49	43.79
Nov	33.75	22.13	43.64	45.72
Dec	34.05	23.36	48.20	46.52

Lake Bottom Elevation 729 Feet
Lowest Elev. of usable
water = 939.0 feet
Start Full
Start 5' Below Spw
Start 10' Below Spw
Year 1
Year 2
Year 3
Year 4
1st Qtr
2nd Qtr
3rd Qtr
4th Qtr
1st Qtr
2nd Qtr
3rd Qtr
4th Qtr
1st Qtr
2nd Qtr
3rd Qtr
4th Qtr
1st Qtr
2nd Qtr
3rd Qtr
4th Qtr
Yearly Quarter

Figure 80.4.a

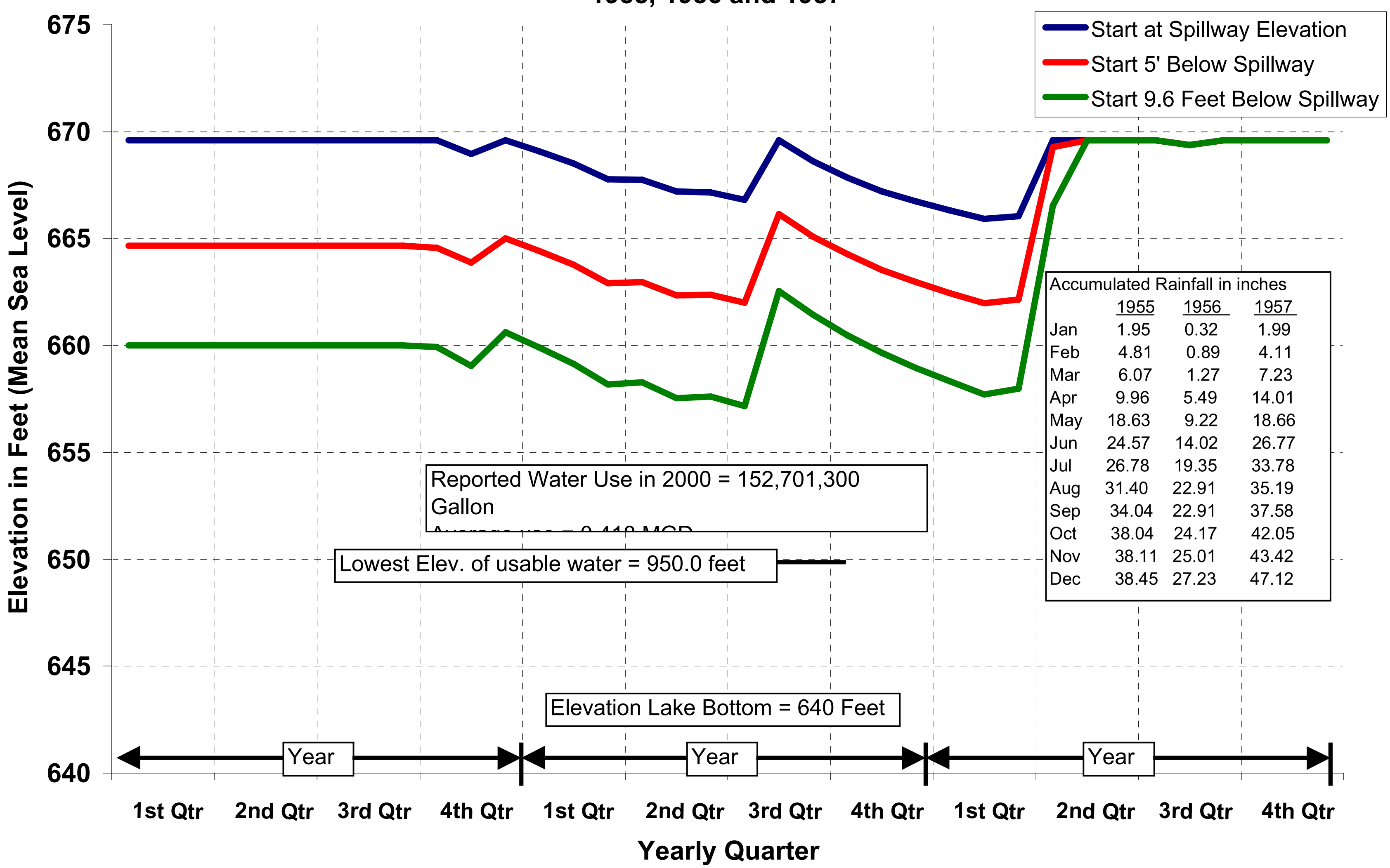


Accumulated Rainfall in inches

	1988	1989	1990
Jan	1.93	1.53	1.19
Feb	2.94	2.57	3.85
Mar	4.67	4.22	7.14
Apr	5.65	6.34	11.43
May	7.25	9.84	17.07
Jun	7.55	11.74	22.37
Jul	9.92	14.10	28.06
Aug	17.10	21.61	31.79
Sep	20.54	25.02	34.86
Oct	21.07	28.59	37.49
Nov	24.32	28.73	40.75
Dec	25.75	29.52	42.77

Figure: 80.4.b

MONROE CITY, MISSOURI
ROUTE "J" RESERVOIR
1955, 1956 and 1957



	1955	1956	1957
Jan	1.95	0.32	1.99
Feb	4.81	0.89	4.11
Mar	6.07	1.27	7.23
Apr	9.96	5.49	14.01
May	18.63	9.22	18.66
Jun	24.57	14.02	26.77
Jul	26.78	19.35	33.78
Aug	31.40	22.91	35.19
Sep	34.04	22.91	37.58
Oct	38.04	24.17	42.05
Nov	38.11	25.01	43.42
Dec	38.45	27.23	47.12

Figure: 80.5.a

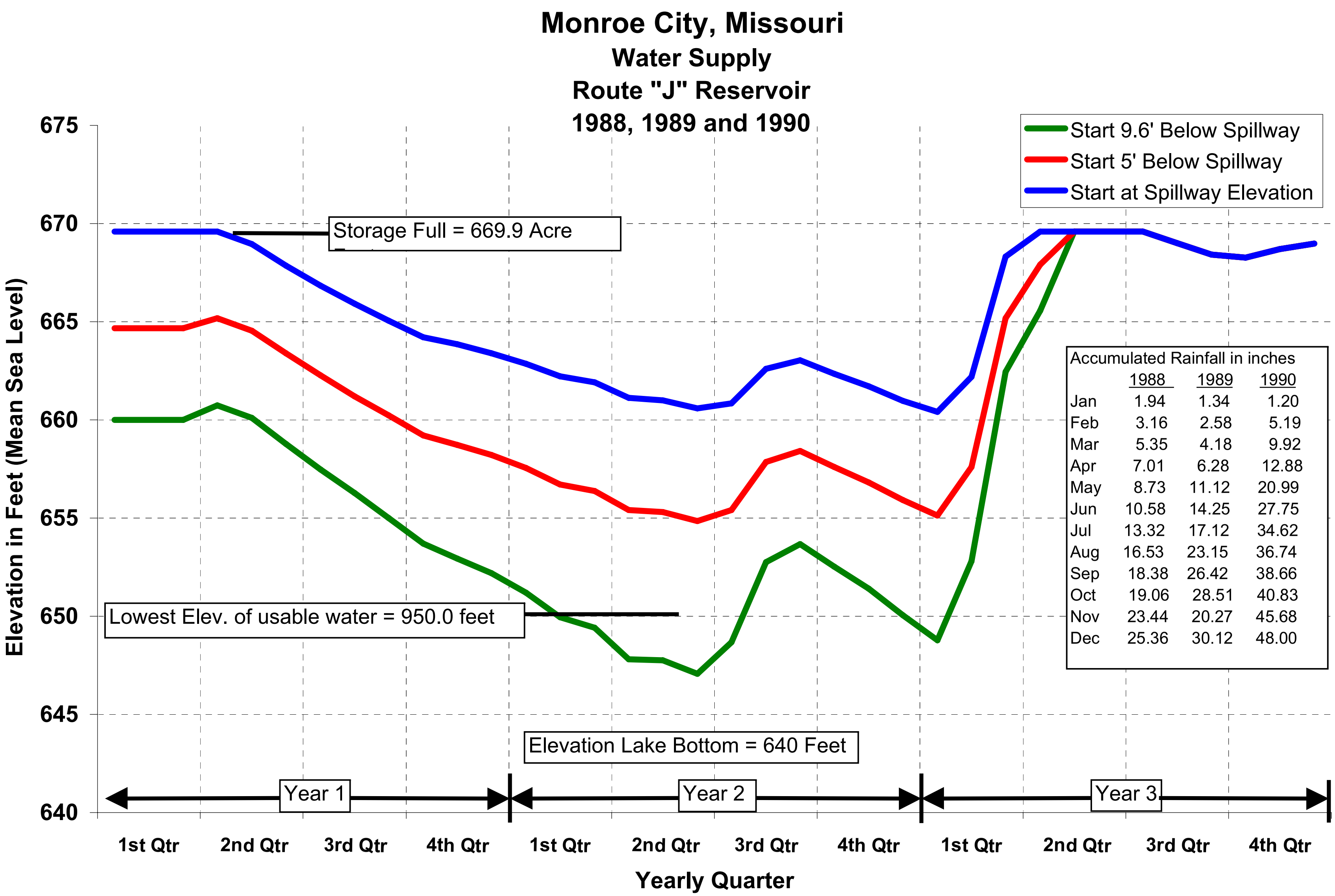

Monroe City, Missouri
Water Supply
Route "J" Reservoir
1988, 1989 and 1990
Start 9.6' Below Spillway
Start 5' Below Spillway
Start at Spillway Elevation
Storage Full = 669.9 Acre
Lowest Elev. of usable water = 950.0 feet
Elevation Lake Bottom = 640 Feet
Elevation in Feet (Mean Sea Level)
675
670
665
660
655
650
645
640
Year 1
Year 2
Year 3
1st Qtr
2nd Qtr
3rd Qtr
4th Qtr
1st Qtr
2nd Qtr
3rd Qtr
4th Qtr
1st Qtr
2nd Qtr
3rd Qtr
4th Qtr
Yearly Quarter
Accumulated Rainfall in inches
1988 1989 1990
Jan 1.94 1.34 1.20
Feb 3.16 2.58 5.19
Mar 5.35 4.18 9.92
Apr 7.01 6.28 12.88
May 8.73 11.12 20.99
Jun 10.58 14.25 27.75
Jul 13.32 17.12 34.62
Aug 16.53 23.15 36.74
Sep 18.38 26.42 38.66
Oct 19.06 28.51 40.83
Nov 23.44 20.27 45.68
Dec 25.36 30.12 48.00

Figure: 80.5.b

APPENDIX "A"

To estimate runoff from direct rainfall, soils and antecedent moisture needs to be considered.

This section describes adjustments to runoff based on rainfall and NRCS's runoff curve numbers (RCN). Figure 1 shows a generalized map of RCN's for the state. These RCN's were developed from stream gage runoff data and weighted rainfall data. These numbers were then correlated with soils and land use. The most detailed discussion of RCN development is in NRCS's TR-55 (Urban Hydrology). The RCN is based on soils, vegetative cover, land use and antecedent moisture. Soil scientists have divided soils into four hydrologic soil groups (HSG's).

HSG "A" Soils have low runoff potential. Infiltration rates are greater than 0.30 inches per hour.
HSG "B" Soils have moderate infiltration rates of 0.15 to 0.30 inches per hour. These soils are silt loams or loams.
HSG "C" Soils have low infiltration rates of 0.05 to 0.15 inches per hour. These soils are Sandy clay loams.
HSG "D" Soils have very low infiltration rates of less than 0.05 inches per hour. These soils are made up of clays.

A complete list of soils with their HSG is included in NRCS's TR-55. RCN's for various land uses and crops by HSG is included in TR-55. Table 1 shows broad ranges of RCN's.

Antecedent soil moisture can be estimated by using antecedent rainfall. Adjustment to the RCN can be made to estimate direct runoff. To do this the daily rainfall values for the month are tabulated. Antecedent rainfall could extend for as much as 30 days preceding the rainfall event. Five day antecedent rainfall gives very good results and added periods of time does not necessarily give additional accuracy.

To adjust for runoff, Used the nearest precipitation gage. Using the daily rainfall values, estimate antecedent rainfall to adjust the SCS runoff curve
number for each days rainfall event. Then added the daily runoff at the end of each month. The adjustments follow.

A guide to approximate Antecedent moisture.

Total of 5 day antecedent rainfall

CONDITION	Dormant Season	Growing Season
I (Dry)	Less Than 0.5 Inch	Less than 1.4 Inch
II (Average)	0.5 to 1.1 Inch	1.4 to 2.1 Inch
III (Wet)	Over 1.1 Inch	Over 2.1 Inch

To adjust the curve number for RCN of 80. Table 10.1 of NRCS National Engineering Handbook, Part 630(Hydrology).

CONDITION		
	I	RCN 63
	II	RCN 80
	III	RCN 94

It is sometimes desirable to interpolate between these numbers.

Day	1952 Mar	1952 Anti. Moist	1952 Run-off	1955 Feb	1955 Anti. Moist	1955 Run-off
1	0.00			0.00		
2	0.33	I	0.0	0.00		
3	0.68	I	0.0	0.00		
4	0.09			0.60	I	0.03
5	0.00			0.04	I	0.0
6	0.00			0.00		
7	0.05	I	0.0	0.00		
8	0.24	I	0.0	0.00		
9	0.00			0.00		
10	0.72	I	0.0	0.10	I	0.0
11	0.00			Trace		
12	Trace			0.00		
13	0.00			0.00		
14	Trace			0.00		
15	0.07	I	0.0	0.00		
16	0.00			0.00		
17	Trace			0.00		
18	0.32	I	0.0	2.02	I	0.10
19	0.00			0.42	III	0.10
20	0.00			0.00		
21	0.22	I	0.0	0.00		
22	0.20			0.00		
23	0.00			Trace		
24	0.00			0.42	II	0.0
25	Trace			0.00		
26	0.00			0.30	II	0.0
27	0.00			0.00		
28	0.00			0.00		
29	0.00			---		
30	0.00			---		
31	0.00			---		
Total	2.92		0.0	3.90		0.23

GENERALIZED RUNOFF CURVE NUMBERS

	HYDROLOGIC SOIL GROUP		
	A	B	C
CROPLAND			
NOT TREATED	81	88	91
TREATED	74	80	82
PASTURE			
NOT TREATED	79	86	89
TREATED	69	79	84
FOREST			
NOT TREATED	66	77	83
TREATED	55	70	77
OTHER	79	86	89

Treated is properly managed to control erosion. Cropland is terraced with waterways and residue left on ground. Pastures have good livestock rotation. Not treated is the absence of proper land use and treatment.