Contract Report 2001-04

Yield Assessment for Lake Vermilion, Vermilion County

by
Sally A. McConkey and H. Vernon Knapp

Prepared for the
Consumers Illinois Water Company, Vermilion Division

February 2001

Illinois State Water Survey
Watershed Science Section
Champaign, Illinois

A Division of the Illinois Department of Natural Resources

Yield Assessment For Lake Vermilion, Vermilion County

by
Sally A. McConkey and H. Vernon Knapp
Watershed Science Section
Illinois State Water Survey

Prepared for the
>nsumers Illinois Water Company, Vermilion Division

Contents

Page

Tables

Figures

Abstract

The City of Danville's public water supply is operated by the Consumers Illinois Water Company, Vermilion Division (CIWC). Lake Vermilion impounds the North Fork Vermilion River. Water is released to supply the intake pumps located approximately one mile downstream of the lake. A low channel dam creates a pool at the intake structure. Reservoir storage is used in essentially the same manner as if the intake were located in the lake, drawing stored water from the lake when the natural flow of the North Fork alone is insufficient to supply the city's water needs.

Long-term planning for the city's water needs requires an evaluation of the existing system's sustainable yield. The sustainable net yield from the water supply may be defined as the water withdrawal rate that can be expected to be delivered during droughts of specific frequencies, e.g., 10-, 25-, 50-, and 100-year return periods. Several factors define the sustainable net yield of the CIWC water supply system, including the North Fork streamflow patterns, the storage volume of Lake Vermilion, precipitation on and evaporation from the surface of Lake Vermilion, and the amount of water that bypasses the intake and is not withdrawn.

Scope of Work

This study assesses the sustainable yield from Lake Vermilion. An in-depth analysis of available gaging station data was performed to determine drought inflows to the lake. Available volume and surface area data for Lake Vermilion were used to calculate evaporation losses and project future storage values. This information was used to compute yields from Lake Vermilion for droughts having 10-, 25-, 50-, and 100-year return periods. This assessment will provide CIWC with the information necessary to determine if the current system is adequate for projected water needs and the extent to which alternative sources may be needed to augment the system's yield. The analysis encompasses only those issues related to the raw water supply and does not include evaluation of any aspect of the water quality or treatment processes.

The streamflow analysis was performed under contract with CIWC in 1997, including yield calculations using available lake volume data. As per contract the information was communicated by letter to CIWC. A sediment survey of Lake Vermilion was performed in 1998 by the Illinois State Water Survey (Bogner and Hessler, 1999). This report provides an update of the yield calculations using the lake volume measured in 1998. The drought stream-flow analysis was completed in 1997 using streamflow records through 1996. Available data from 1997 - 1999 were taken into consideration when preparing the final analysis presented in this report.

Background

The City of Danville is located in Vermilion County. The North Fork Vermilion River has been the primary source of supply for the community since 1883. The first in-channel dam was constructed in 1902. As water needs increased over time, various projects have been undertaken to improve the reliability of the water supply. Lake Vermilion was originally created by the construction of a dam across the North Fork Vermilion River in 1914. The dam spillway and gates were modified in 1925 and 1991 to increase storage capacity. Increases in reservoir storage capacity were necessitated by both an increase in water demand and the progressive decrease in storage capacity due to sediment accumulation. Bogner and Hessler (1999) give a history of the water supply and reservoir.

Water demands are expected to increase over time. Planning to meet future demands and to ensure a reliable water supply requires an evaluation of the reservoir capacity and the natural inflow of water to the lake. Storage of water reserves in Lake Vermilion is necessary due to the seasonal variations in the flow of the North Fork Vermilion River that often result in flows less than demand. An evaluation of the relationship between storage capacity and inflows during severe drought conditions is needed to assess the reliability of the water supply. The statistical analysis of drought flows provides a mechanism to evaluate the reliability of the water source to meet various levels of demand and assess the risk of water shortages over the lifetime of the system.

Acknowledgments

This study was principally funded by a research contract from the Consumers Illinois Water Company, Vermilion Division. The views expressed in this report are those of the authors and do not necessarily reflect the views of the sponsor or of the Illinois State Water Survey. Eva Kingston edited the report. Linda Hascall provided graphic support and formatted the report.

Drought Inflows to Lake Vermilion

Available Streamgaging Records

Table 1 lists the nine gaging stations in the Vermilion River basin that have recorded continuous daily flow data for five or more years. Figure 1 shows the locations of these stations and the location of Lake Vermilion. Figure 2 shows the length of each station's record and illustrates the periods of time when various gages were concurrently in operation. As indicated in Table 1, four of the nine stations are currently active. All nine gages have been operated and maintained by the U.S. Geological Survey.

The gaging station on the North Fork Vermilion River near Bismarck is located 12 miles upstream from Lake Vermilion and has a drainage area of 262 square miles (sq. mi.), roughly 88 percent of the watershed area of Lake Vermilion. The drainage area of the North Fork Vermilion at the Lake Vermilion dam is 298 sq. mi. The flow from the North Fork Vermilion River is the primary source of water to Lake Vermilion, and this gage provides the most direct data concerning lake inflows. Unfortunately, this gage has been operated only since October 1988. This period of gaging does not include any of the most severe droughts that have affected Lake Vermilion, such as the drought of 1953-1954, and, in general, the record length is too short to use in estimating drought frequency. Estimates of drought inflows into the lake for years prior to 1988 must be made using information from other gages in the vicinity of Lake Vermilion.

Of the remaining gages listed in Table 2, the Vermilion River gages near Catlin and near Danville provide the most useful data from which to estimate the inflows into Lake Vermilion in earlier droughts. The gaging station near Catlin, in operation from 1940 to 1958, was located on the Vermilion River less than 6 miles upstream from the confluence of the North Fork Vermilion. The Vermilion River at the Catlin gage has a drainage area of 958 sq. mi., and flow recorded at this gage represents almost all of the flow in the Vermilion River upstream of the North Fork. This gage was also active in the 1940s and 1950s during several of the most severe droughts to affect the region. The gage on the Vermilion River near Danville is located only 3

Table 1. U.S. Geological Survey Gaging Stations in the Vermilion River Basin

Number	*Station*	*Drainage area (sq. mi.)*	*Period of record*
	Active stations		
3339000	Vermilion River near Danville	1290	10/1914-09/1921, 06/1928-09/present
3338780	North Fork Vermilion River near Bismarck	262	06/1970-09/1973 10/1988-present
3337000	Boneyard Creek at Urbana	4.46 (-0.88)*	07/1948-present
3336645	Middle Fork Vermilion River above Oakwood	432	10/1978-present
	Discontinued stations		
3336500	Bluegrass Creek at Potomac	35	1950-1971
3337500	Saline Branch at Urbana	68	1936-1958
3336900	Salt Fork near St. Joseph	134	1959-1991
3338000	Salt Fork near Homer	340	1945-1958
3338500	Vermilion River near Catlin	958	1940-1958

Note:
* Drainage area of Boneyard at this site is 4.46 sq. mi., but 0.88 sq. mi. is noncontributing.

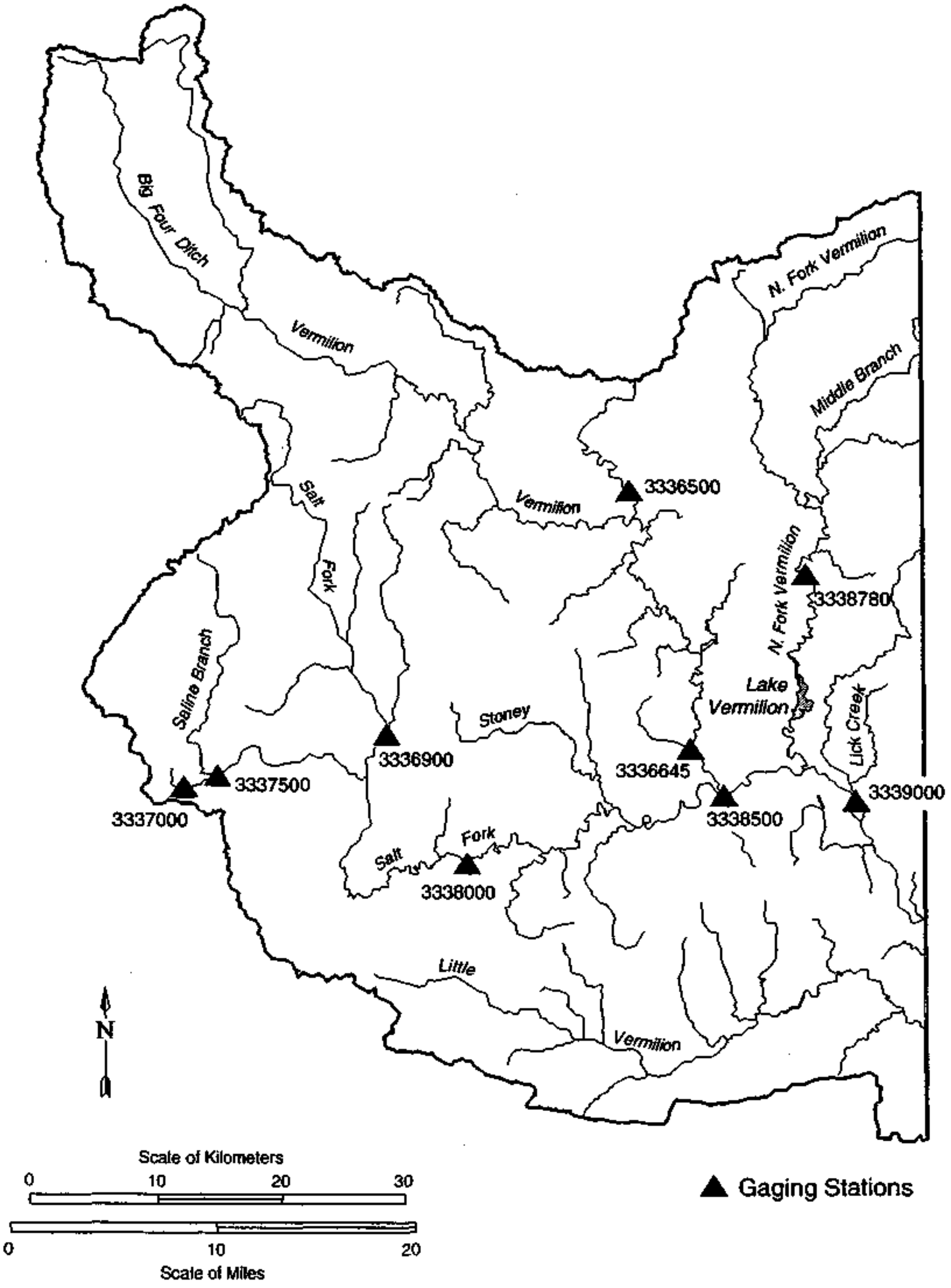

Figure 1. Location of Streamgages in the Vermilion River basin

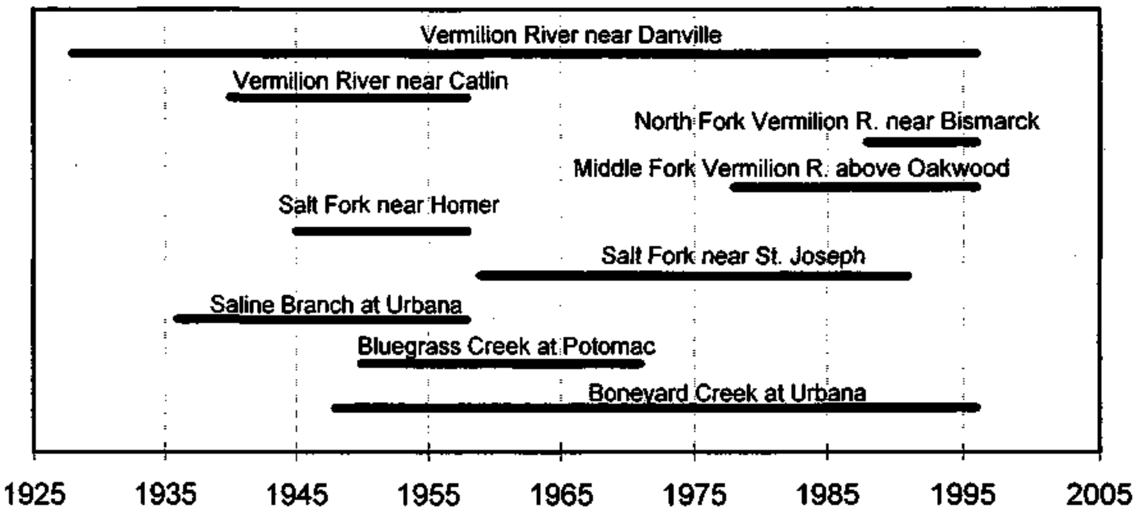

Figure 2. Period of record for stations in the Vermilion River basin

Table 2. Comparison of Annual Mean Runoff at Danville and Bismarck Gaging Stations

Water year	*Annual mean runoff (inches on drainage area)*		*Bismarck (% of Danville)*
	Danville	*Bismarck*	
1998	18.22	21.64	119
1997	10.92	14.65	134
1996	9.52	9.95	105
1995	11.41	13.14	115
1994	18.53	21.66	117
1993	28.35	36.16	128
1992	7.67	9.58	125
1991	16.10	19.54	121
1990	15.27	18.35	120
1989	8.11	9.39	116
1989-1998 average	14.41	17.41	121
1915-1998 average	10.80		

miles downstream of the confluence with the North Fork Vermilion River and has a drainage area of 1290 sq. mi. The Danville gage has a 78-year gaging record, which provides the long-term stream flow record needed to evaluate extreme drought conditions.

General Runoff Characteristics of Lake Vermilion Area

The mean annual runoff recorded at the Bismarck and at the Danville gages was compared for the concurrent period of record, Water Years 1989-1998 (Table 2). The drainage area of the North Fork Vermilion River at the Bismarck gage is 20.3 percent of the total drainage area of the Vermilion River at Danville. The mean annual flow for the entire period of record, expressed in terms of inches on drainage area, is 10.8 inches at the Danville gage. The mean annual flow at the Danville gage for the 1989-1998 period is 14 inches. The mean annual flow at Bismarck for this period is 17 inches. The period of time that the Bismarck gage has been operational represents higher than average runoff. This comparison also suggests that the runoff from the watershed of the North Fork Vermilion may be greater per square mile than runoff recorded at the Danville gage.

Estimation of North Fork Vermilion River Flow Record

The inflow from the North Fork Vermilion River is the primary source of water to Lake Vermilion. Accurate evaluation of drought inflows is a critical component of the yield analysis. The amount of flow in the North Fork Vermilion River measured upstream of Lake Vermilion near Bismarck provides valuable information on inflows into the lake, but it is not currently sufficient to directly estimate inflow during severe droughts. For the present study, it was necessary to estimate inflow to Lake Vermilion during drought periods using indirect measurements. Inflows to Lake Vermilion were estimated using methods dictated by data availability.

For the period since 1988, the flow record for the North Vermilion River near Bismarck was used to estimate inflows. For all other years, it was necessary to estimate lake inflows as a fraction of flows observed at the Danville gage. For their concurrent period of record, 1940-1958, the flow records for the Vermilion River gages near Catlin and Danville provided the data necessary to indirectly assess drought flow into Lake Vermilion.

Upstream water uses have an impact on the Vermilion River flows at both the Catlin and Danville gages. To maintain consistency in the estimate of drought conditions, it was necessary to quantify the impact of these water uses, which are described as artificial losses and additions to the flow. By adjusting the observed flow records in the Vermilion River, to account for the impact of these losses and additions, it is possible to estimate the "unaltered" flow conditions in the river, which are then used for estimating flows on the North Fork Vermilion River.

Artificial Losses and Additions to Flow in the Vermilion River

Consumptive water use and effluent discharges of water originating from other sources are artificial losses and additions to natural stream flows. During low flow periods such losses or additions may create a measurable difference in river flows. Data representative of natural flow are needed to perform a valid statistical analysis. Hence, an accounting must be made of the artificial losses and additions. Effluent discharges from community wastewater treatment plants vary seasonally. This seasonal variation is, in part, attributable to water use, but it is also affected by leakage into the sanitary sewer system. The 7-day, 10-year low flows for the various communities discharging effluents into the Vermilion River system (Singh and Stall, 1973; Singh, et al., 1988) provided guidance in estimating the effect of effluent discharges on low flows.

Effect of Water Use in Danville Area

The City of Danville discharges treated wastewater to the Vermilion River upstream of the Danville gage. The water originates from the North Fork Vermilion River; therefore, the effluent is not an addition to the natural flow when the inflow to Lake Vermilion is greater than or equal to demand. However, water withdrawals exceed effluent returns to the river, and consumptive losses must be taken into account. Historical water use data for Danville and available effluent discharge data were used to estimate the net streamflow loss as a percentage of water use. Table 3 presents available water use data for the City of Danville. An average consumptive loss of 10 percent of water use is a typical value for Dlinois communities; thus the net consumptive loss to streamflow recorded at the Danville gage is estimated to be 10 percent of the annual average water use for the City of Danville. Figure 3 plots Danville's average annual water use in millions of gallons per day (mgd). McConkey-Broeren and Singh (1989) developed water use projections to the year 2020 for Danville. Actual water use from 1987 to 1997 was slightly greater than the projections. Water use projections to 2020 were adjusted accordingly, and these adjusted values are shown in Figure 3.

Over the years, some area industries have withdrawn water from the Vermilion River upstream of the Danville gage and discharged treated ground water to the river. The Illinois State Water Survey maintains information on industrial water withdrawals and discharges; however, individual industrial water use data are confidential. The estimated impact of industrial water use and effluent discharge were combined with the City of Danville consumptive losses and are listed in the last column of Table 3.

Historical stream flow recorded at the Danville gage was adjusted using the combined net loss or gain to the flow listed in the last column of Table 3. Values for years when water use data were not available were estimated or interpolated from known values assuming a linear relationship.

Effluent Contributions from Watershed Communities

Several communities discharge treated wastewater into streams upstream of the Vermilion River gages at Catlin and Danville. These effluent inflows affect the flows recorded at the gages. The communities of Urbana, Champaign, and Rantoul obtain their water supply from ground-water sources. The Urbana-Champaign Sanitary District operates two wastewater treatment plants. About 60 percent of the recorded water used is treated and discharged at the wastewater treatment plant in the Vermilion basin.

Effluents from the water treatment plants serving these communities are an added component to flows recorded at the Catlin and Danville gages. Historical records for effluent flows are scant, but historical water use records are available. Historical water use records were used in combination with available effluent flow records to estimate the effluent contributions to the river flow over the years. Table 4 lists water use and effluent discharge data for these communities.

The effluent contribution to the streamflow was calculated as a percentage of the water use for each year that data were available. Years when water use data were not available were

Table 3. Water Use and Effect on Flows at Danville Gage

Year	*Danville water use (mgd)*	*Net streamflow loss as 10% of water use*		*Streamflow adjustment above Danville gage*[(a)] *(cfs)*
		(mgd)	*(cfs)*	
1912	3.18	0.3	0.5	0.5
1913	3.89	0.4	0.6	0.6
1948	6.45	0.6	1.0	-0.6
1952	6.5	0.7	1.0	-0.5
1953	6.5	0.7	1.0	-0.5
1954	7.0	0.7	1.1	-0.5
1962	8.0	0.8	1.2	-0.6
1967	8.6	0.9	1.3	-0.5
1969	8.94	0.9	1.4	-0.5
1970	8.83	0.9	1.4	0.6
1971	9.37	0.9	1.5	0.3
1972	8.71	0.9	1.4	-0.1
1973	8.87	0.9	1.4	-0.4
1974	8.52	0.9	1.3	-0.7
1975	8.54	0.9	1.3	-1.1
1976	8.65	0.9	1.3	-1.3
1980	8.85	0.9	1.4	-1.6
1982(b)	9.5	1.0	1.5	-1.9
1983(b)	9.2	0.9	1.4	-1.6
1984(b)	10.0	1.0	1.6	-1.6
1989	9.48	0.9	1.5	-1.1
1990	10.02	1.0	1.6	-0.4
1991	9.41	0.9	1.5	0.2
1992	9.32	0.9	1.4	0.8
1993	8.84	0.9	1.4	1.9
1994	9.1	0.9	1.4	2.0
1995	8.46	0.8	1.3	0.3
1996	8.15	0.8	1.3	0.5
1999	8.3(c)			

Notes:

(a)Combined net municipal and industrial streamflow adjustment.

(b)Water use interpolated.

(c)Estimated from water use reported for January through July 1999.

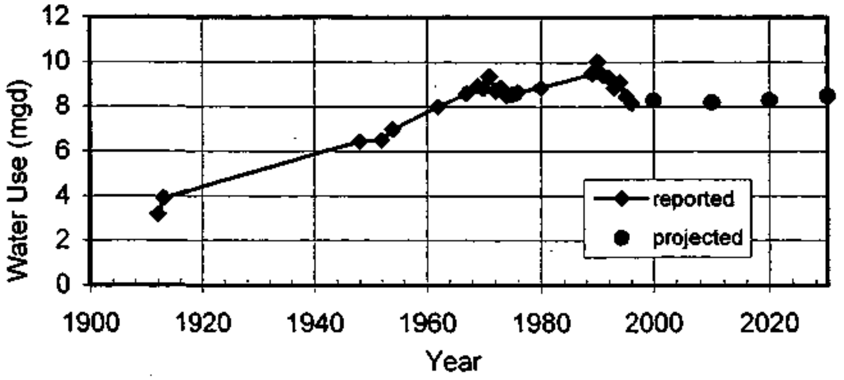

Figure 3. City of Danville water use

Table 4. Water Use and Effluent Discharges Upstream of Catlin Gage

	Rantoul		*Champaign/Urbana*			*Estimated contribution to flow from effluents(c)*	
Year	*Water use (mgd)*	*Effluent(a) (mgd)*	*Water use (mgd)*	*Effluent(a) (mgd)*	*Effluent (as % of water use)(b)*	*(mgd)*	*(cfs)*
1952	0.8		7.0			5.0	7.8
1960	0.8		8.5			5.9	9.1
1970	1.30	1.35	11.8	7.23	61.24	8.4	13.0
1979	1.32		15.28			10.5	16.3
1980	1.30		15.4			10.5	16.3
1984(d)	1.32	1.35	16.2	9.61	59.34	11.0	17.1
1989	1.34		17.46			11.8	18.3
1990	1.13		17.29			11.5	17.8
1991	1.31		18.48			12.4	19.2
1992	1.21		17.87			11.9	18.5
1993	1.08		16.79			11.2	17.3
1994	1.54		19.43			13.2	20.5
1995	1.29		18.87			12.6	19.5
1996	1.38		18.73			12.6	19.6

Notes:

(a)K.P. Singh and J.B. Stall, 1973; K.P. Singh et al., 1988.

(b)The Urbana-Champaign Sanitary District discharges some effluents to the Kaskaskia River basin.

(c)Rantoul, Champaign, and Urbana obtain water from ground-water sources. Subsequent discharges of effluents to surface waters are in addition to natural flow. Total contribution is calculated as fraction of water use.

(d)Water use is interpolated.

estimated or interpolated. These effluent contributions were subtracted from the recorded streamflows to determine the natural flow.

Contribution of Stored Water during Droughts

During low flow periods when water demand exceeds the North Fork Vermilion inflow to the lake, stored water is withdrawn for the public water supply. Subsequently, this water is discharged as treated wastewater upstream of the Danville gage. That portion of the returned water that was stored water accumulated during high flow is an added flow component to the natural low flow recorded at the Danville gage. Unfortunately, little information is available to quantify the volume of stored water that was withdrawn during the drought periods analyzed. Another factor, which cannot be quantified definitively, is the additional evaporative losses from the larger water surface of the lake. The timing of the drawdown as it relates to the low flow period must also be considered. Once the lake begins to refill, the effect is to decrease the flow reaching the gage. Thus the timing relative to the low flow period and the duration of the drawdown define the magnitude of the added flow component.

Lake Level Data Since 1985

The Illinois State Water Survey has been maintaining a record of the month-end water levels recorded at Lake Vermilion since 1985. In October 1991, an increase in the operating spillway level for Lake Vermilion was approved, and the normal pool level was increased from 578.2 to 582.2 feet. During at least the last two decades, the operational policy has been to maintain a lake level 0.5 feet below the permitted pool level. Figure 4 shows the lake levels recorded in 1988 and 1991 with the spillway at zero elevation and the target level at -0.5 feet. In 1988, the lowest 3-month flow period recorded at the Danville gage spanned July, August, and September. The lake was at its lowest level, 4.2 feet below the spillway in September, but the effect on streamflow is the difference in the storage between the level at the end of June and at the end of September, which is 3.4 feet. Evaporation averaged over the 3-month period would account for about one foot of the lake level decrease. Thus the stored water withdrawn for supply, given a 2.4 foot change in depth and assuming a lake surface of about 608 acre-feet (ac-ft) at that depth, is 1459 ac-ft. When averaged over a 3-month period, this volume corresponds to 8 cubic feet per second (cfs) of stored water withdrawn for Danville water supply and returned to the Vermilion River as wastewater. The 5-month low flow for 1988 occurred June 1 - October 31; the corresponding difference in lake level was 4.5 feet. That corresponds to 7 cfs averaged over the 5-month period after taking evaporation into account. The 7 months with the lowest flow occurred from May to November. During this period, the difference in lake level was negligible.

The first year that the gaging station at Bismarck was operational, 1989, the 3-month low flow recorded at Danville occurred October - December. The difference in the lake level over this period was only 0.4 feet. In 1991, during the 3-month low flow period July - September, the decrease in lake level was 1.5 feet; allowing for evaporation, the added flow component to the Vermilion River above Danville was about 1.7 cfs.

The contemporary data suggests that stored water withdrawn from Lake Vermilion may affect the streamflow record of the Vermilion River at Danville. The release of the stored water to the Vermilion River, via effluent discharges, is an additive component to flows. The extent of the drawdown is not only a function of drought severity, but also of reservoir operation and the amount of water withdrawn. Withdrawals from the lake are a function of the water use. The plot

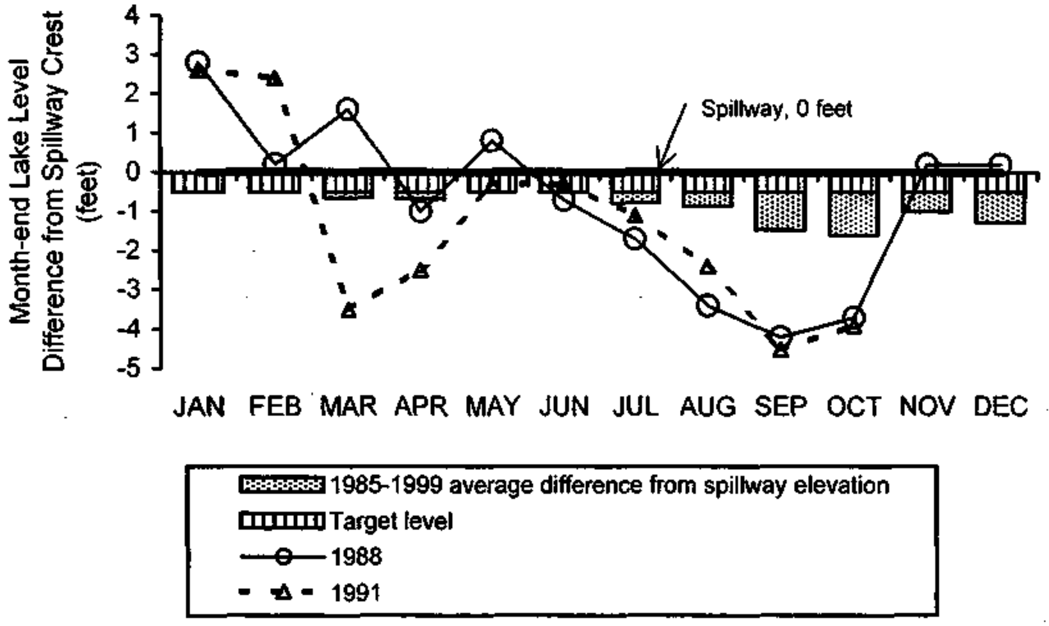

Figure 4. Lake Vermilion end-of-month water levels

in Figure 3 shows the trend of generally increasing water use over time, and thus demand on the lake reserves during droughts.

Historic Lake Level Data

Historical data on the drawdown of the lake during drought periods are scant. Observations made during January 1976 indicate that the water level was 4.5 feet below the normal pool elevation of 577.2 feet, National Geodetic Vertical Datum (NGVD) 1929. In the fall of 1963, the lake elevation was 5.5 feet below the crest.

During the 1940 - 1958 period, when the gaging station at Catlin was operational, the only information on lake drawdown is for December 4, 1953. Illinois State Water Survey engineer W. J. Roberts reports in a letter dated December 8, 1953, about Lake Vermilion that "On December 4, the water stood exactly two feet below the crest of the dam. This was the lowest reading all summer and during the hot weather the water level dropped approximately 1/8 of an inch per day." Over a 92-day period, a decline in water surface level of 1/8 of an inch per day is equivalent to 11.5 inches. In 1953 the average annual water use was 6.5 mgd, with peak usage June - August of 7.5 mgd.

Analysis of the Danville gage records shows that the 1953 drought ranks as the lowest 3-, 5-, and 7-month average flow period with a return period of 34.5 years and the third lowest 9-month average flow with a return period of 13.8 years. The lowest 3-month flow occurred between September 1953 and November 1953; the lowest 5-month flow occurred between September 1953 and January 1954; and the lowest 7-month flow occurred between August 1953 and February 1954.

Evaporation losses during these periods can be only estimated. Net evaporation during a 30-year return period drought is expected to be 14.5 inches (1.2 feet) for a 3-month duration, 19.1 inches (1.6 feet) for a 5-month duration, 20.9 inches (1.7 feet) for a 7-month duration, and 19.6 inches (1.6 feet) for a 9-month duration (Terstriep et al., 1982). The observed rate of water level decline indicates that evaporation losses may have been less in 1953.

The withdrawal and discharged of stored water during the 1953 drought would be an added component to the low flow recorded at the Danville gage. Some assumptions must be made to estimate the magnitude of the additional flow. If it is assumed that the lake was full at the beginning of September 1953 and was 2 feet below the spillway in November 1953, and one foot of decline is attributable to evaporation, then one foot of the decline in water level is attributable to water withdrawals. Plots of the cross section of the lake in 1976 show little difference in surface area between normal pool and a depth of 2 feet. Using the reported surface area of 608 ac-ft, the volume of water stored per foot is about 600 ac-ft, which corresponds over a 3-month period to a flow rate of 3.4 cfs. Applying this same analysis to the 5-, 7-, and 9-month duration droughts, the stored water withdrawals are estimated to be 2 cfs for the 5-month drought, one cfs for the 7-month drought, and negligible for the 9-month drought period.

The effect of this added component on flows recorded at the Danville gage during 1940-1958 may be measurable for short duration droughts, but the difference for long duration droughts is less significant. An adjustment was made to account for the added flow component in the analysis of the gaging station data. In the analysis of 3-month duration droughts for the 1940-1958 period, 3.5 cfs was subtracted from the flow recorded at the Danville gage to adjust for the potential increase in flow from stored water withdrawn from the lake. In the analysis of 5-month duration droughts for the 1940-1958 period, 2 cfs was subtracted from the flow recorded at the Danville gage to adjust for the potential increase in flow from stored water withdrawn from the lake. In the analysis of the 7-month duration droughts, one cfs was subtracted for the 1953 and 1954 events only.

Analysis of Gaging Station Data

Reservoirs, such as Lake Vermilion, that have a small capacity compared to the average amount of runoff expected from the watersheds tend to experience the most limiting yields during droughts of less than 12 months duration rather than muti-year droughts. When a reservoir receives inflow from a relatively large watershed, there is a high likelihood that there will be sufficient precipitation and runoff during the spring season to refill the lake, even during extreme drought. A previous estimate of the drought yields from Lake Vermilion is reported in Illinois State Water Survey Contract Report 477, *Adequacy of Illinois Surface Water Supply Systems to Meet Future Demands* (McConkey-Broeren and Singh, 1989). That analysis indicates that the critical drought duration for the lake is 7 to 8 months. Drought flows having 3-, 5-, 7-, and 9-month duration were thus considered for this detailed study.

The continuous discharge record at Danville starts in 1928. Historical, mean monthly flow data from the Danville gage from 1928 to 1996 were used to develop a partial duration series of 3-, 5-, 7-, and 9-month droughts. A drought year starting April 1 and ending March 30 was used. Low flow periods in central Illinois typically occur from late summer into the winter. Definition of the "drought year" allows identification of sequential drought months that otherwise would be split into different years if the calendar year or traditional water year from October 1 to September 30 were used. A sequential search of the mean monthly flows was performed to compute the mean 3-, 5-, 7-, and 9-month mean flows. The lowest independent mean flows for each duration were thus identified. The partial duration series includes the lowest 68 events on record at the gage for each drought duration. During an extremely dry year such as 1944, there may be more than one independent 3-month or 5-month low flow that rank in the lowest 68 events. The longer duration droughts will have a one-to-one correspondence with each year of record. The return periods for the ranked drought events were computed using the standard formula of n/m+1, where n = rank and m = number of events in the series. For example, the lowest flow experienced at the Danville gage for the 3-month duration occurred during the drought of 1930. Thus the estimated return period for this drought is 69 years.

Both the Catlin and Danville gages were in operation during an 18-year period from 1940 to 1958. The data from these concurrent years, which include several of the more severe droughts recorded at Danville, were used to estimate the drought flows for the North Fork Vermilion. Tables 5-8 show data used in the calculations for the 3-, 5-, 7-, and 9-month drought duration, respectively.

The year, middle month of the drought, return period in years (T-year), and mean flows recorded at the Danville gage for the 3-month drought are listed in the first four columns of Table 5. For the purposes of analysis, the return period of the estimate and observed low flows at the Catlin and Bismarck gages is assumed to be the same as the return period of the flows at Danville for the concurrent period. For example, the 3-month low flow that occurred at Catlin in 1953 (see Table 5) is assumed to be 34.5 years even though there are only 18 years of record at the Catlin gage. The effluent contributions to flows from Rantoul, Urbana, and Champaign for the given year are listed in column 5, and the net effect of Danville and area industry discharges and withdrawals on flows recorded at the Danville gage for those years are listed in column 6. The mean 3-month drought discharges recorded simultaneously at Catlin are tabulated next (column 7). In addition to the North Fork Vermilion River, there are 34 sq. mi. of contributing

Table 5. Vermilion and North Fork Vermilion Rivers 3-Month Drought Flows

Year (col 1)	Month (col 2)	Danville T-year (col 3)	Gage discharge Danville (cfs) (col 4)	Effluent from Rantoul and Urbana-Champaign (cfs) (col 5)	Combined effect of Danville and area industry (cfs) (col 6)	Gage discharge Catlin[(a)] (cfs) (col 7)	net Estimated additional flow downstream of Catlin[(b)] (cfs) (col 8)	Adjusted Danville flow (cfs) (col 9)	Estimated flow North Fork Vermilion at dam (cfs) (col 10)	Estimated flow North Fork Vermilion (% of Danville flow) (col 11)
1953	Oct	34.5	35.08	-7.9	-4	23.95	0.61	23.2	7	28
1954	Oct	23	35.56	-8.1	-4	23.93	0.62	23.5	7	30
1940	Sep	17.25	36.72	-6.3	-3.8	24.53	0.70	26.6	8	29
1944	Dec	7.67	46.95	-6.8	-4	31.51	0.95	36.2	10	29
1944	Sep	6.9	47.11	-6.8	-4	38.26	0.96	36.3	4	11
1954	Jan	4.93	53.93	-8.1	-4	43.07	1.10	41.8	6	14
1956	Oct	4.6	55.42	-8.4	-3.9	33.23	1.14	43.1	17	40
1952	Oct	3.63	64.73	-7.8	-4	42.72	1.40	53.0	17	31
1943	Nov	2.23	86.42	-6.7	-3.9	56.65	2.00	75.8	24	31
1948	Oct	2.09	90.76	-7.3	-4.1	59.37	2.10	79.4	25	32
1946	Sep	1.97	93.60	-7.0	-4	65.76	2.18	82.6	22	26
1940	Dec	1.86	94.95	-6.3	-3.8	74.46	2.24	84.9	14	17
1954	Jul	1.64	112.98	-8.1	-4	82.76	2.66	100.9	24	23
1947	Sep	1.57	117.82	-7.1	-4.1	63.06	2.81	106.6	48	45(c)
1955	Aug	1.4	141.01	-8.3	-3.9	104.94	3.40	128.8	29	22
1953	Jan	1.17	212.62	-7.9	-4	128.78	5.30	200.7	75	37
									Average	27

Year	Month	Danville T-year	Gage discharge Danville (cfs)	Effluentfrom Rantoul and Urbana-Champaign (cfs)	Combined net effect of Danville and area industry (cfs)	Gage discharge Bismarck (cfs)	Ratio of drainage area at dam to gage	Adjusted Danville flow (cfs)	Estimated flow North Fork Vermilion at dam (cfs)	Estimated flow North Fork Vermilion (% of Danville flow)
1989	Nov	1.35	154.36	-18.3	-1.1	25.35	1.14	135.0	29	21
1991	Aug/Sep	2.56	78.34	-19.2	-1.5	8.05	1.14	57.6	9	16
1992	Sep	<1	427.00	-18.5	0.8	101.35	1.14	409.3	116	28
1993	Feb	<1	1275.00	-17.3	1.9	305	1.14	1259.6	348	28
1994	Sep	3.14	71.80	-20.5	2.0	20.83	1.14	53.3	24	45
1995	Oct/Sep	1.25	185.90	-19.5	0.3	20.47	1.14	166.7	23	14
1996	Oct	2.03	93.3	-19.6	0.5	19.37	1.14	74.2	22	30
1999(d)	Oct	~5	61.2	-20.0	-3.0	6.87	1.14	38.2	8	21
									Average	**25**

Notes:

T-year = return period.

(a)Catlin flows include Rantoul and Urbana-Champaign effluent.

(b)An additional 34 sq. mi. (2.64% of total drainage area at the Danville gage) drains directly to the Vermilion River between Caitlin and Danville.

(c)Outlier.

(d)The 1999 data are provisional.

Table 6. Vermilion and North Fork Vermilion Rivers 5-Month Drought Flows

Year (col 1)	*Month (col 2)*	*Danville T-year (col 3)*	*Gage discharge Danville (cfs) (col 4)*	*Effluent from Rantoul and Urbana-Champaign (cfs) (col 5)*	*Combined net effect of Danville and area industry (cfs) (col 6)*	*Gage discharge Catlin(a) (cfs) (col 7)*	*Estimated additional flow downstream of Catlin(b) (cfs) (col 8)*	*Adjusted Danville flow (cfs) (col 9)*	*Estimated flow North Fork Vermilion at dam (cfs) (col 10)*	*Estimated flow North Fork Vermilion (% of Danville flow) (col 11)*
1953	Nov	34.5	40.57	-7.9	-2.5	30.44	0.80	30.2	7	23
1954	Oct	23	42.36	-8.1	-2.5	28.98	0.84	31.8	10	32
1944	Nov	17.25	46.97	-6.8	-2.5	33.86	0.99	37.7	10	26
1940	Sep	8.63	54.97	-6.3	-2.3	40.93	1.22	46.4	11	23
1943	Nov	5.75	84.33	-6.7	-2.4	52.44	1.99	75.2	28	37
1952	Oct	5.31	86.56	-7.8	-2.5	49.96	2.01	76.3	32	42(c)
1956	Nov	3.83	101.9	-8.4	-2.4	71.91	2.41	91.1	25	28
1948	Oct	2.46	181.48	-7.3	-2.6	118.32	4.53	171.6	56	33
1947	Sep	2.3	191	-7.1	-2.6	116.32	4.79	181.3	67	37
1946	Oct	2.16	209.69	-7.0	-2.5	151.5	5.29	200.2	50	25
1954	May	1.68	271.26	-8.1	-2.5	199.25	6.88	260.7	63	24
1941	Feb	1.53	302.83	-6.4	-2.4	243.56	7.76	294.0	49	17
1942	Aug	1.47	318.2	-6.5	-2.4	223.88	8.17	309.3	84	27
1955	Oct	1.41	353.78	-8.3	-2.4	245.07	9.06	343.1	97	28
1949	Sep	1.19	468.69	-7.4	-2.6	307.08	12.11	458.7	147	32
1941	Jul	1.13	517.4	-6.4	-2.4	410.49	13.43	508.6	91	18
									Average	**27**

Year	*Month*	*Danville T-year*	*Gage discharge Danville (cfs)*	*Effluent from Rantoul and Urbana-Champaign (cfs)*	*Combined net effect of Danville and area industry (cfs)*	*Gage discharge Bismarck (cfs)*	*Ratio of drainage area dam to gage*	*Adjusted Danville flow (cfs)*	*Estimated flow North Fork Vermilion at dam (cfs)*	*Estimated flow North Fork Vermilion (% of Danville flow)*
1989	Oct	1.77	230.03	-18.3	-1.1	30.87	1.14	210.6	35	17
1991	Sep	2.76	136.97	-19.2	0.2	24.29	1.14	118.0	28	23
1992	Aug	<1	794.4	-18.5	0.8	206.67	1.14	776.7	236	30
1993	Jan	<1	1681.6	-17.3	1.9	384	1.14	1666.2	438	26
1994	Sep	2.56	171.7	-20.5	2.0	55.2	1.14	153.2	63	41
1995	Oct	1.86	226	-19.5	0.3	29.7	1.14	206.8	34	16
1996	Sep	2.38	190.4	-19.6	0.5	46	1.14	171.3	52	31
1999(d)	Nov/Oct	~10	61.4	-20.0	-1.4	8.2	1.14	40.0	9	23
									Average	***26***

Notes:

T-year = return period.

(a)Catlin flows include Rantoul and Urbana-Champaign effluent.

(b)An additional 34 sq. mi. (2.64% of total drainage area at the Danville gage) drains directly to the Vermilion River between Caitlin and Danville.

(c)Outlier.

(d)The 1999 data are provisional.

Table 7. Vermilion and North Fork Vermilion Rivers 7-Month Drought Flows

Year (col 1)	*Month (col 2)*	*Danville T-year (col 3)*	*Gage discharge Danville (cfs) (col 4)*	*Effluent from Rantoul and Urbana-Champaign (cfs) (col 5)*	*Combined net effect of Danville and area industry (cfs) (col 6)*	*Gage discharge Catlin$^{(a)}$ (cfs) (col 7)*	*Estimated additional flow downstream of Catlin$^{(b)}$ (cfs) (col 8)*	*Adjusted Danville flow (cfs) (col 9)*	*Estimated flow North Fork Vermilion at dam (cfs) (col 10)*	*Estimated flow North Fork Vermilion (% of Danville flow) (col 11)*
1953	Nov	34.5	49.01	-7.9	-1.5	36.18	1.05	39.61	10	26
1944	Oct	23	59.81	-6.8	-0.5	43.66	1.39	52.51	14	27
1954	Sep	11.5	70.04	-8.1	-1.5	49.36	1.60	60.44	18	29
1940	Oct	9.86	71	-6.3	-0.3	53.33	1.70	64.4	16	24
1952	Aug	5.75	132.85	-7.8	-0.5	82.95	3.29	124.6	46	37
1956	Dec	3.83	236.21	-8.4	-0.4	182.78	6.00	227.41	47	21
1943	Oct	3.14	277.93	-6.7	-0.4	182.06	7.15	270.83	88	33
1955	Oct	2.46	312.84	-8.3	-0.4	223.54	8.03	304.14	81	27
1947	Oct	2.38	318.9	-7.1	-0.6	196.45	8.22	311.2	114	37
1946	Nov	1.86	382.17	-7	-0.5	296.07	9.89	374.67	76	20
1948	Sep	1.82	400.11	-7.3	-0.6	300.1	10.35	392.21	89	23
1942	Aug	1.53	512.39	-6.5	-0.4	379.59	13.34	505.49	119	24
1941	Jun	1.5	530.22	-6.4	-0.4	424.49	13.82	523.42	92	17
1949	Aug	1.35	617.92	-7.4	-0.6	427.28	16.10	609.92	174	29
1945	Jun	1.21	851.65	-6.9	-0.5	586.23	22.29	844.25	243	29
1950	Jan	1.13	899.89	-7.5	-0.6	641.4	23.54	891.79	234	26
1951	Jun	1.08	948.25	-7.6	-0.5	722.1	24.82	940.15	201	21
									Average	**26**

Year	*Month*	*Danville T-year*	*Gage discharge Danville (cfs)*	*Effluentfrom Rantoul and Urbana-Champaign (cfs)*	*Combined net effect of Danville and area industry (cfs)*	*Gage discharge Bismarck (cfs)*	*Ratio of drainage area dam to gage*	*Adjusted Danville flow (cfs)*	*Estimated flow North Fork Vermilion at dam (cfs)*	*Estimated flow North Fork Vermilion (% of Danville flow)*
1989	Oct	3.63	240.28	-18.3	-1.1	32.71	1.14	220.88	37	17
1990	Aug/Jul	<1	1621.57	-17.8	-0.4	392.14	1.14	1603.37	447	28
1991	Oct	3.29	277.31	-19.2	0.2	54.55	1.14	258.31	62	24
1992	Aug	1.19	877.4	-18.5	0.8	204.45	1.14	859.7	233	27
1993	Nov	<1	1974.57	-17.3	1.9	421.14	1.14	1959.17	479	24
1994	Sep	2.76	302	-20.5	2.0	93.29	1.14	283.5	106	37
1995	Oct	2.56	308.4	-19.5	0.3	55.03	1.14	289.2	63	22
1996	Oct	1.97	378.8	-19.6	0.5	107	1.14	359.7	122	34
1999$^{(c)}$	Nov	~20	73	-20.0	-2.8	9.61	1.14	50.2	11	22
									Average	**26**

Notes:

T-year = return period.

(a)The Catlin flows include Rantoul and Urbana-Champaign effluent.

(b)An additional 34 sq. mi. (2.64% of total drainage area at the Danville gage) drains directly to the Vermilion River between Caitlin and Danville.

(c)The 1999-2000 data are estimated.

Table 8. Vermilion and North Fork Vermilion Rivers 9-Month Drought Flows

Year (col 1)	*Month (col 2)*	*Danville T-year (col 3)*	*Gage discharge Danville (cfs) (col 4)*	*Effluentfrom Rantoul and Urbana-Champaign (cfs) (col 5)*	*Combined net effect of Danville and area industry (cfs) (col 6)*	*Gage discharge Catlin[(a)] (cfs) (col 7)*	*Estimated additional flow downstream of Catlin[(b)] (cfs) (col 8)*	*Adjusted Danville flow (cfs) (col 9)*	*Estimated flow North Fork Vermilion at dam (cfs) (col 10))*	*Estimated flow North Fork Vermilion (% of Danville flow) (col 11)*
1940	Nov	23	92.64	-6.3	-0.3	69.62	2.27	86.04	20	24
1954	Sep	17.25	126.80	-8.1	-0.5	89.51	3.12	118.2	34	28
1953	Dec	13.8	137.74	-7.9	-0.5	101.23	3.41	129.34	33	25
1944	Oct	8.63	186.14	-6.8	-0.5	130.1	4.72	178.84	51	28
1952	Nov	4.6	361.34	-7.8	-0.5	251.04	9.32	353.09	100	28
1956	Nov	3.14	397.03	-8.4	-0.4	315.6	10.25	388.23	71	18
1955	Sep	3	416.61	-8.3	-0.4	304.35	10.77	407.91	101	25
1943	Oct	2.76	432.17	-6.7	-0.4	304.03	11.22	425.07	117	27
1946	Nov	2.56	453.07	-7.0	-0.5	350.56	11.76	445.57	90	20
1947	Oct	1.92	649.65	-7.1	-0.6	430.15	16.95	641.95	202	31
1948	Aug	1.73	679.71	-7.3	-0.6	536.24	17.74	671.81	125	19
1949	Jul	1.53	728.83	-7.4	-0.6	515.58	19.03	720.83	194	27
1942	Sep	1.47	743.58	-6.5	-0.4	558.38	19.45	736.68	165	22
1941	Sep	1.33	829.02	-6.4	-0.4	675.91	21.71	822.22	131	16
1950	Sep	1.21	1057.61	-7.5	-0.6	737.44	27.71	1049.51	292	28
1951	Sep	1.19	1110.81	-7.6	-0.5	824.09	29.11	1102.71	257	23
1945	Nov	1.17	1113.15	-6.9	-0.5	776.09	29.19	1105.75	307	28
									Average	**25**

Year	*Month*	*Danville T-year*	*Gage discharge Danville (cfs)*	*Effluentfrom Rantoul and Urbana-Champaign (cfs)*	*Combined net effect of Danville and area industry (cfs)*	*Gage discharge Bismarck (cfs)*	*Ratio of drainage area dam to gage*	*Adjusted Danville flow (cfs)*	*Estimated flow North Fork Vermilion at dam (cfs)*	*Estimated flow North Fork Vermilion (% of Danville flow)*
1989	Sep	2.09	546.96	-18.3	-1.1	104.46	1.14	527.56	119	23
1990	Oct	<1	1762.74	-17.8	-0.4	443.37	1.14	1744.54	505	29
1991	Nov	3.83	381.54	-19.2	0.2	82.89	1.14	362.54	94	26
1992	Jun	1.08	1352.11	-18.5	0.8	319.38	1.14	1334.41	364	27
1993	Nov	<1	2149.44	-17.3	1.9	507	1.14	2134.04	578	27
1994	Oct	2.88	427.7	-20.5	2.0	116.89	1.14	409.2	133	33
1995	Nov	5.31	350	-19.5	0.3	65.9	1.14	330.8	75	23
1996	Oct/Aug	1.35	816.7	-19.6	0.5	212	1.14	797.6	242	30
									Average	27

Notes:
T-year = return period.
(a)Catlin flows include Rantoul and Urbana-Champaign effluent.
(b)An additional 34 sq. mi. (2.64% of total drainage area at the Danville gage) drains directly to the Vermilion River between Caitlin and Danville.

watershed between the Catlin and Danville gages. The drought flow contribution from this area was estimated and is listed in column 8.

The adjusted, or natural, Danville flow tabulated in column 9 is computed as the flow recorded at the gage (column 4), plus the values (positive and negative) listed under the effluent flows (column 5), and the combined net effect of the Danville and area industry (column 6). The flow attributed to discharge of reserve water from the lake is part of the value listed in column 6 for the 3-, 5-, and 7-month duration droughts, respectively.

The North Fork Vermilion flow for each drought event is listed in column 10. The drought flow for the North Fork Vermilion is estimated starting with the flow recorded at the Danville gage (column 4), adding the combined net flow from the Danville area (column 5), subtracting the flow recorded at Catlin (column 7), and subtracting the flow contribution from the 34-sq.-mi. area (column 8). The effluent from Rantoul, Urbana, and Champaign enters the Salt Fork upstream of the Catlin gage and thus are included in flows recorded at the Catlin gage. In this calculation, taking the difference between the Danville flow and the Catlin flow circumvents the need to directly incorporate the impact of effluents discharged from the wastewater treatment plants serving Rantoul, Urbana, and Champaign.

The estimated North Fork Vermilion flows are listed in column 10. These flow estimates are approximate for individual years in the 1940-1958 period, since they rely upon the relative accuracies of flows measured at the Catlin and Danville gages. However, as a whole, they give a good representation of the expected flow conditions on the North Fork Vermilion River. The last column of the table shows the percentage of the adjusted Danville flow originating from the North Fork Vermilion. The percentage is calculated by dividing the estimated North Fork Vermilion flow (column 10) by the adjusted Danville flow (column 9). The same calculation procedures were repeated for the 5-, 7-, and 9-month drought flows presented in Tables 6-8, respectively.

The concurrent period of record for the Danville and Bismarck gages does not include any severe droughts with the possible exception of provisional data available for 1999. However, for completeness, the drought flows recorded at Danville and Bismarck corresponding to each duration are tabulated at the bottom of Tables 5-8. In several cases, the drought periods did not occur during the same 3 months. For those years when there was an overlap, the middle month of the drought period recorded at the Danville gage is listed first, and the middle month of the drought period recorded at Bismarck is listed second under the column heading "Month." The adjusted Danville flow shown in this section of the tables was computed as described above. The Bismarck gage is located upstream of Lake Vermilion and thus measures flows from a drainage area less than the total contributing drainage area at the dam. Flows recorded at Bismarck were adjusted accordingly. The percentage of the flow measured at the Danville gage flow originating from the North Fork Vermilion (above Lake Vermilion) is listed in the last column. These percentages do not represent severe drought periods, and they are provided for comparison with the percentages computed for the extreme drought events.

Interpretation of Low Flow Analysis

The analysis of the Catlin and Danville gage records (1940-1958) shows that for severe droughts of a 3-month and 5-month duration, the flow from the North Fork Vermilion River contributes, on the average, 27 percent of the "natural" flow recorded at the Danville gage. During 7-month and 9-month duration droughts, the percentage of flow recorded at Danville coming from the North Fork Vermilion is 26 percent and 25 percent, respectively. These percentages were applied to estimate 3-, 5-, 7-, and 9-month drought flows for the North Fork Vermilion River from the entire drought series developed from the Vermilion River at Danville.

Table 9 presents a summary of drought flows and return periods. The return period, year of occurrence, the reported flow, and the adjusted (natural) drought flow for the Danville gage are listed for each of the four selected drought durations. Adjusted drought flows were computed as described earlier, subtracting effluents entering from Rantoul, Urbana, and Champaign; adjusting for consumptive water use by Danville and adjusting for industrial effluents in the Danville area. Available lake level data were used to estimate the potential added flow component of stored water from Lake Vermilion contributing to the flow recorded at the Danville gage. As noted earlier, lake level data are incomplete and scarce prior to 1985, and evaporation must be estimated. However, on the basis of the available information, the added flow component from stored lake water introduced via wastewater above the Danville gage should be considered for 3-, 5-, and 7-month duration drought flows. The stored lake water component was estimated for the 14 lowest flows corresponding to 3-, 5-, and 7-month drought duration, and the record was adjusted accordingly.

The North Fork Vermilion flow was computed from the adjusted flows at the Danville gage using the percentage corresponding to the drought duration. Table 9 lists the 14 lowest flows. Data from the most recent dry period in 1999 were provisional when the analysis was performed and thus were not used in the low flow analysis. Figure 5 shows a log-log plot of the North Fork Vermilion drought flows versus return period. The 10-, 25-, 50-, and 100-year drought flows for the North Fork Vermilion for each duration were determined from these data either by interpolation (10-, 25-, and 50-year return period) or extrapolation (100-year return period). Table 10 lists the drought inflows to Lake Vermilion determined from the data. Also shown in Figure 5 are 12-month low flows simulated for the North Fork Vermilion River from using the average annual flows at Danville for Water Years 1929-1996. The 12-month low flows are considerably higher than the 9-month drought flows.

The graph in Figure 6 shows the calculated North Fork Vermilion flows for each return period plotted versus duration in months. This graph illustrates how, for a given return period, the average flow increases with increasing duration of the drought period.

Past, Present, and Future Reservoir Storage Volume

Lake Vermilion was constructed by impounding the North Fork Vermilion River. The reservoir was first created in 1916. The existing dam was constructed in 1925 with a reported volume of 2.6 billion gallons (7975 ac-ft) and a normal pool elevation of 577.2 feet (NGVD 1929). The free spillway and tainter gates at the Lake Vermilion dam were modified in 1991 to add an additional 5 feet to the normal pool elevation of the lake. Normal pool elevation was raised from 577.2 feet to 582.2 feet. The modifications included adding extensions to the 10 tainter gates used to control water releases. This work was completed in 1991 and the lake level reached the target elevation of 581.7 feet (0.5 feet below the permitted level) by December 1991. The rubbish sluice spillway crest is operational and has a spillway elevation of 574.2 feet. The spillway elevation crest for the tainter gates is 563.2 feet. Lake Vermilion was surveyed in 1925, 1963, 1976, and 1998. The volume of the lake determined from these surveys was 8514, 5318, 4641, and 7971 ac-ft, respectively. Potential reservoir storage given a spillway elevation of 582.2 feet, and corresponding to the volumes measured in previous surveys, is 13,209, 9810, and

Table 9. Summary of Drought Flows and Return Periods

	3-month drousht flow			*5-month drousht flows*			*7-month drousht flows*			*9-month drousht flows*		
Return period (years)	Year	*Adjusted flow at Danville* (cfs)	*North Fork Vermilion* as 27% of Danville flow (cfs)	Year	Adjusted flow at Danville (cfs)	*North Fork Vermilion* as 27% of Danville flow (cfs)	Year	Adjusted flow at Danville (cfs)	*North Fork Vermilion* as 26% of Danville flow (cfs)	Year	Adjusted flow at Danville (cfs)	*North Fork Vermilion* as 25% of Danville flow (cfs)
69	1930	17.8	4.8	1930	28.8	7.8	1930	33.8	8.8	1930	39.4	9.8
34.50	1953	23.2	6.3	1953	30.2	8.1	1953	39.6	10.3	1963	81.0	20.3
23	1954	23.5	6.3	1954	31.8	8.6	1976	48.8	12.7	1940	86.0	21.5
17.25	1940	26.6	7.2	1976	32.4	8.8	1963	49.1	12.8	1954	118.2	29.6
13.80	1988	27.3	7.4	1963	33.5	9.1	1944	52.6	13.7	1953	129.3	32.3
11.50	1976	27.3	7.4	1944	37.7	10.2	1954	60.4	15.7	1933	133.3	33.3
9.86	1963	29.2	7.9	1988	44.9	12.1	1940	64.4	16.7	1980	157.7	39.4
8.63	1934	30.5	8.2	1939	45.4	12.2	1980	79.9	20.8	1976	173.7	43.4
7.67	1984	34.1	9.2	1940	46.4	12.5	1933	108.9	28.3	1944	178.9	44.7
6.90	1944	36.2	9.8	1964	55.0	14.8	1960	109.5	28.5	1932	224.0	56.0
6.27	1944	36.4	9.8	1980	56.2	15.2	1939	122.9	32.0	1939	243.5	60.9
5.75	1931	36.7	9.9	1960	73.6	19.9	1952	124.60	32.4	1988	266.8	66.7
5.31	1964	37.5	10.1	1943	75.3	20.3	1932	129.0	33.5	1995	330.8	82.7
4.93	1954	41.8	11.3	1952	76.3	20.6	1934	140.8	36.6	1978	338.7	84.7

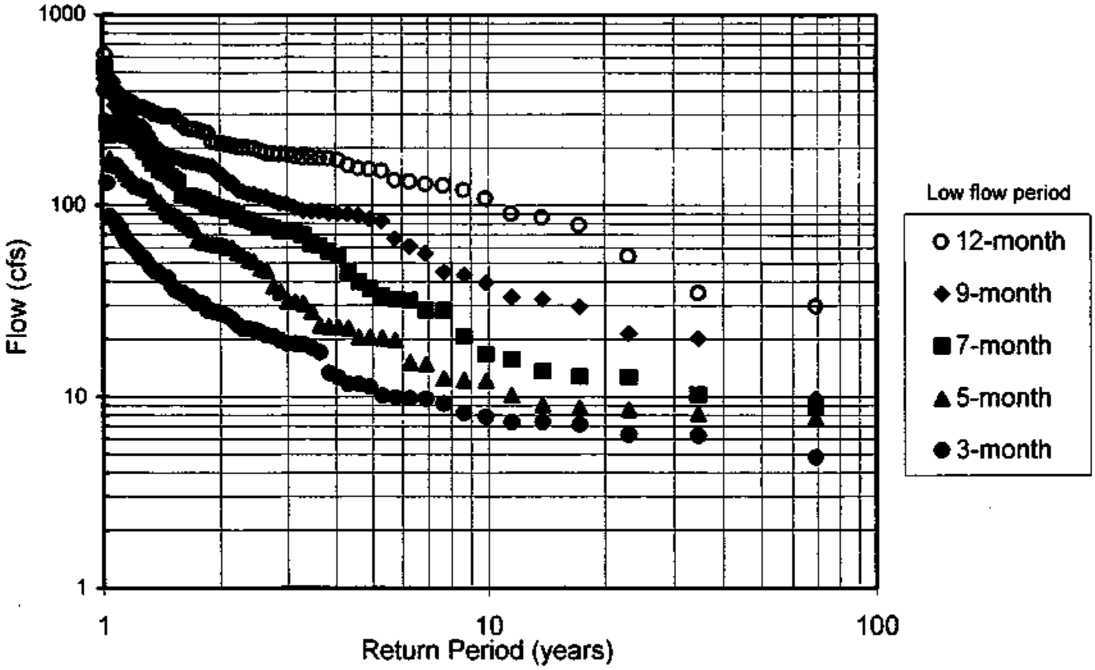

Figure 5. Simulated North Fork Vermilion flows

Table 10. North Fork Vermilion River Drought Flow into Lake Vermilion

Duration (months)	*Average flow for return period (cfs)*			
	10-yr	*25-yr*	*50-yr*	*100-yr*
3	8	6.2	5.4	4.5
5	11	8	7.8	7.2
7	17	11	9.2	8
9	39	20	13	9.8

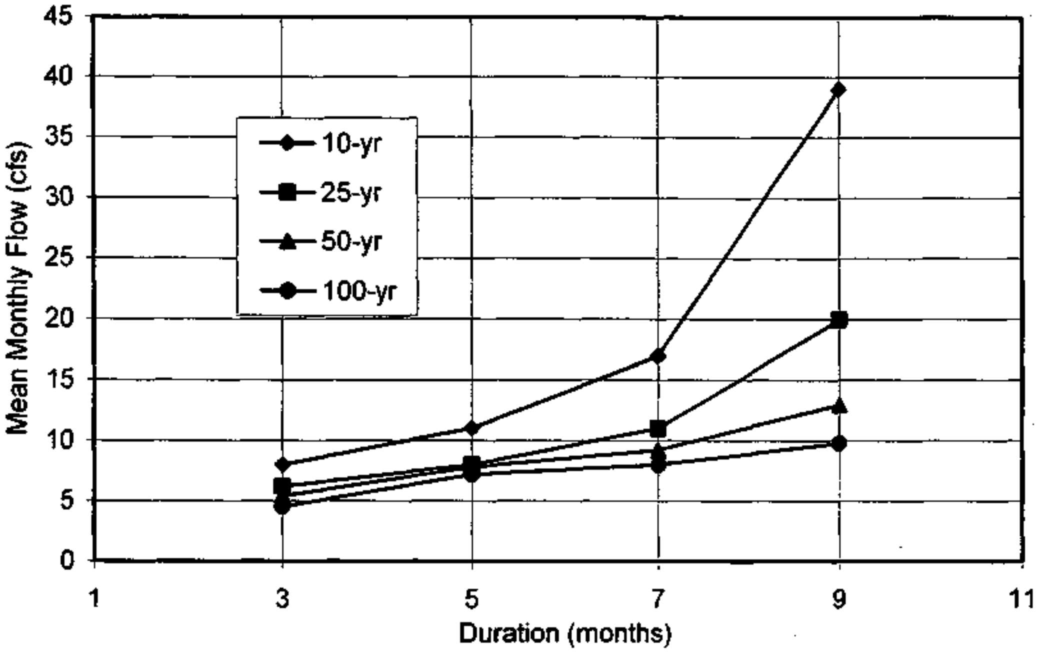

Figure 6. North Fork Vermilion River drought flow into Lake Vermilion

9157 ac-ft for the years 1925, 1963, and 1976, respectively (Bogner and Hessler, 1999). Several sources were reviewed to acquire estimates of future decreases in volume due to sedimentation.

Water Survey historical files contain a plot of elevation versus volume in billions of gallons for Lake Vermilion circa 1925. The U.S. Army Corps of Engineers (USACOE), Chicago District, published a dam inspection report for Lake Vermilion (USACOE, 1978). This report provides data on the lake surface area and volume for elevations from 577.2 feet to 592 feet. Projected reservoir surface areas at various elevations were measured from topographic maps, and incremental increases in volume were calculated. These volume estimates were made on the basis of the 1976 lake survey. Volume versus elevation data from the 1925 sedimentation survey, the USACOE report, and the 1998 sedimentation survey are shown in Figure 7. The graph illustrates that, due to sedimentation in the lake, higher and higher water elevations are needed to reach the same water storage capacity.

Singh and Durgunoglu (1990) report projections of future volumes for Lake Vermilion. If the spillway modifications had been complete in 1990, the 1990 volume at a normal pool of 582.2 feet would have been about 7985 ac-ft. Interpolating between the 1990 and 2000 volume projections, the approximate 1998 volume is projected to be 7528 ac-ft compared to the measured volume of 7971 ac-ft. The difference is 443 ac-ft or 5.5 percent of the measured volume. The storage capacities of Lake Vermilion projected by Singh and Durgunolgu are listed in Table 11. Future volumes for Lake Vermilion were estimated by subtracting the difference in projected storage volume from the volumes calculated from the 1998 sediment survey of the lake. Table 11 shows the total storage volume available at various elevations and the projected volume for the years 2010, 2020, 2030, and 2040. Although sediment will fill the upper portion of the lake, for the purposes of these volume calculations it was assumed that sediment will fill the lowest elevation of the lake first. These calculations project little or no useful storage volume below the tainter gate spillway elevation (563.2 feet) after the year 2000.

Net Evaporation Losses from Lake Surface

Net evaporation is the difference between total lake evaporation and precipitation over the lake. Net evaporation during drought years can reduce the water level in lakes by several feet, reducing the storage available for water supply. Net evaporation losses for Lake Vermilion were calculated following the methodology and data in Illinois State Water Survey Bulletin 67, *Hydrologic Design of Impounding Reservoirs in Illinois* (Terstriep et al., 1982).

During a drought, as water is withdrawn from the lake, the water level drops and the lake surface area decreases. Net evaporation losses are calculated on the basis of a typical or representative lake surface area. Furthermore, lake surface area tends to decrease over time as sediment deposits accumulate in the upper portions of the lake. Changes in the surface area of Lake Vermilion are discussed in Bogner and Hessler (1999) and McConkey-Broeren and Singh (1989).

The increase in the spillway elevation in 1991 has changed the relationship between elevation and volume and surface area. Therefore, historical data provide a perspective, but the projections of lake surface area must be made on the basis of the current lake geometry.

The 1998 surface areas at various elevations are listed in Table 11. Inspection of Table 11 shows that, on average over time, about 50 percent of the lake volume, and hence available stored water, is above 578.2 feet. Therefore, during a severe drought, when the available stored water is withdrawn, the elevation would remain above 578.2 feet about half of the time. The

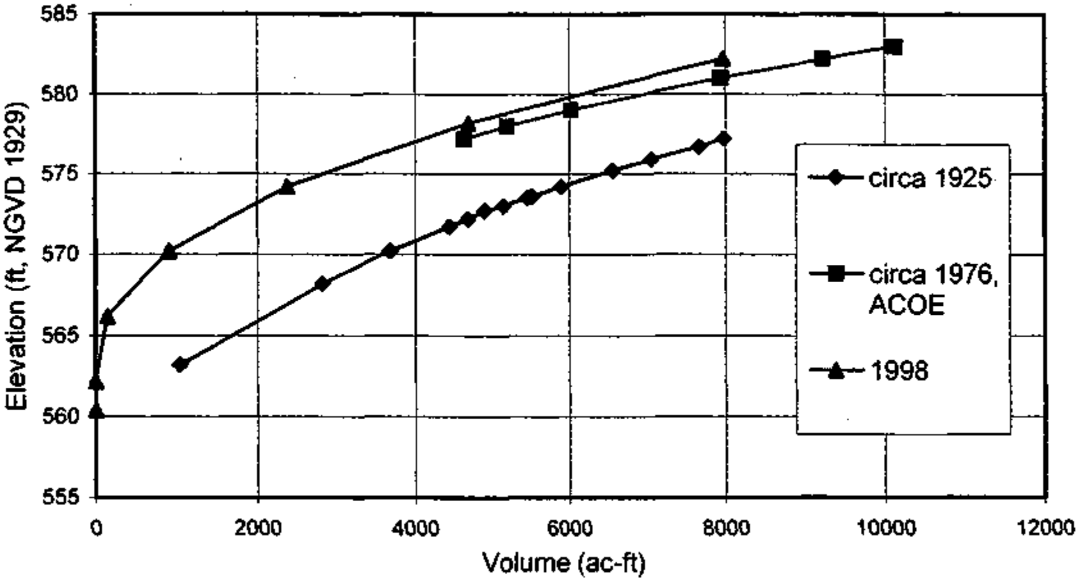

Figure 7. Comparison of original and current volume of Lake Vermilion

Table 11. Lake Vermilion 1998 and Estimated Future Storage Volume

	1998 survey(a)			*Total volume (ac-ft)*			
Elevation (feet)(b)	*Surface area (acres)*	*Incremental volume (ac-ft)*	*Total volume (ac-ft)*	*2010*	*2020*	*2030*	*2040*
582.2			7528	6881(c)	6397(c)	5964(c)	5582(c)
582.2	878	3276.2	7971	7324	6840	6407	6025
578.2	698	2321.4	4695	4048	3564	3131	2749
574.2	417	1466.8	2373	1726	1242	810	427
570.2	285	757.4	906	259	0	0	0
566.2	98	148.6	149	0	0	0	0
562.2	1	0.5	0.5	0	0	0	0
560.4	0	0	0	0	0	0	0

Notes:

(a)The 1998 lake survey (Bogner and Hessler, 1999).

(b)National Geodetic Vertical Datum of 1929.

(c)Volume projections from Singh and Durgunoglu (1990).

surface area of the lake is about 697 acres at this elevation. A surface area of 700 acres was used to calculate net evaporation losses. Net evaporation losses in inches, in units of acre-feet, and in units of cubic feet per second for specific drought durations are provided in Table 12.

Evaporation losses can be significant and are a direct function of the water surface area of the lake. A 200-acre difference in exposed water surface area translates into a difference of about 1.2 to 0.6 cfs (0.8 to 0.6 mgd) in the net yield for Lake Vermilion for the droughts considered.

Reservoir Yield

The yield of Lake Vermilion was computed using a water budget analysis similar to that in Water Survey Bulletin 67 (Terstriep et al., 1982), with the data inputs described above. Yields were computed for the years 1998, 2010, 2020, 2030, and 2040 for droughts having return periods of 10-, 25-, 50-, and 100-years. Using the methodology presented in Bulletin 67, for a selected return period, droughts of various durations are considered. *The drought duration that results in the lowest yield from the reservoir is the critical duration for the given return period.* Several drought durations were examined to determine the drought duration that resulted in the lowest net yield for the given return period.

The volume of available water was converted to a flow rate corresponding to drought durations of 3, 5, 7, and 9 months for the years 1998, 2010, 2020, 2030, and 2040. The assumption was made that only 90 percent of the estimated total reservoir volume would be usable, thus the total volume of reservoir water was multiplied by 90 percent to compute the available stored water. The volume of water was converted to units of cubic feet by multiplying the volume expressed in acre-feet by 43,560 square feet per acre. This volume is expressed as a flow rate of cubic feet per day by dividing the volume of water by the number of days of drought (drought duration in months multiplied by an average value of 30.4 days per month). The flow rate is converted to units of cubic feet per second using the factor of 24 hours per day/3600 seconds per hour. The available stored water expressed as a flow rate in units of cubic feet per second for each duration and year is shown in Table 13. For example, in the first column of Table 13 (year 1998), a flow rate of 39.7 cfs over a 3-month period is equivalent to a volume of 7174 ac-ft.

The gross draft rate (or yield) from a reservoir is the sum of the inflow during the drought period to the lake and the usable stored water. The net yield from the reservoir is the gross draft rate less net evaporation and other identified losses. Table 14 presents the predicted gross draft rate and the gross draft rate less evaporation losses. Data used in calculations are reviewed below.

The predicted drought inflow for the selected drought return periods and durations are reported in Table 10. Net evaporation from the lake surface for each drought duration and return period were taken from Table 12. The reservoir storage, hence the usable stored water, declines with time. The usable stored water expressed as a flow rate is listed in Table 13 for each drought duration and repeated in the second column of Table 14 for each year (1998, 2010, 2020, 2030, and 2040). The net yield for the selected drought durations, return periods, and years are listed in Table 14 in units of cubic feet per second and millions of gallons per day.

The lowest yield for each of the four return periods (10-, 25-, 50-, and 100-year) is shown in bold/italic type for the years 1998 - 2040. The critical drought duration is the drought for which the various factors combine to produce the lowest yield from the reservoir. Droughts with 10-year return periods have the lowest yields when the duration is 5 months. Droughts with 25-

Table 12. Expected Net Evaporation Losses for Selected Return Periods and Drought Durations

Return-period (years)	*Total net evaporation (in.)*[a]					*Total net evaporation from 700-acre water surface (ac-ft)*[b]					*Total net evaporation (cfs)*[c]				
	3 months	*5 months*	*7 months*	*9 months*	*12 months*	*3 months*	*5 months*	*7 months*	*9 months*	*12 months*	*3 months*	*5 months*	*7 months*	*9 months*	*12 months*
100	14.91	19.71	22.27	20.66	21.63	869.75	1149.75	1299.08	1205.17	1261.75	4.81	3.81	3.08	2.22	1.74
70	14.84	19.58	22.07	20.53	21.14	865.67	1142.17	1287.42	1197.58	1233.17	4.79	3.79	3.05	2.21	1.70
60	14.79	19.48	21.91	20.41	20.89	862.75	1136.33	1278.08	1190.58	1218.58	4.77	3.77	3.03	2.19	1.68
50	14.72	19.35	21.72	20.21	20.57	858.67	1128.75	1267.00	1178.92	1199.92	4.75	3.74	3.00	2.17	1.66
40	14.62	19.22	21.41	19.90	20.15	852.83	1121.17	1248.92	1160.83	1175.42	4.71	3.72	2.96	2.14	1.62
30	14.48	19.08	20.93	19.63	19.59	844.67	1113.00	1220.92	1145.08	1142.75	4.67	3.69	2.89	2.11	1.58
25	14.25	18.91	20.72	19.26	18.78	831.25	1103.08	1208.67	1123.50	1095.50	4.60	3.66	2.86	2.07	1.51
20	14.08	18.77	20.31	18.94	18.21	821.33	1094.92	1184.75	1104.83	1062.25	4.54	3.63	2.81	2.04	1.47
15	13.85	18.55	19.52	18.45	17.46	807.92	1082.08	1138.67	1076.25	1018.50	4.47	3.59	2.70	1.98	1.41
10	13.52	18.12	18.52	17.67	16.41	788.67	1057.00	1080.33	1030.75	957.25	4.36	3.51	2.56	1.90	1.32
8	12.96	17.13	17.39	16.27	14.73	756.00	999.25	1014.42	949.08	859.25	4.18	3.31	2.40	1.75	1.19
6	12.61	16.32	16.49	15.33	13.71	735.58	952.00	961.92	894.25	799.75	4.07	3.16	2.28	1.65	1.11
5	12.1	14.89	14.99	13.94	12.27	705.83	868.58	874.42	813.17	715.75	3.90	2.88	2.07	1.50	0.99

Notes:

Net evaporation is equal to evaporation less expected precipitation. Net evaporation was calculated using an intermediate lake surface area, not area at spillway elevation.

(a)Maximum net lake evaporation in inches calculated from Springfield evaporation station (M.L. Terstriep, M. Demissie, D.C. Noel, and H.V. Knapp, 1982).

(b)ac -ft = evaporation (in.)/(12 in./ft) X surface area of lake.

(c)Total net evaporation for given lake surface area and drought period, expressed as the average flow in cubic feet per second (cfs):

cfs = (total evaporation in ac-ft) X (43,560 sq ft/ac)/ (number of months X 30.4 days per month X 24 hours per day X 3600 seconds per hour).

Table 13. Lake Vermilion Future Stored Water Volume

	1998	2010	2020	2030	2040
Volume (ac-ft)	7971	7324	6840	6407	6025
90% useful storage (ac-ft)	7174	6592	6156	5767	5422
Drought duration (months)			*Available stored water (cfs)*		
3	39.7	36.4	34.0	31.9	30.0
5	23.8	21.9	20.4	19.1	18.0
7	17.0	15.6	14.6	13.7	12.8
9	13.2	12.1	11.3	10.6	10.0

Table 14. Lake Vermillion Drought Yields for Selected Return Periods and Years

A. 1998 with Usable Lake Storage Volume of 7174 ac-ft*

Duration	*Reservoir*	*Gross draft rate (cfs)*				*Gross draft less net evaporation (cfs)*				*Gross draft less net evaporation (mgd)*			
(months)	*storage (cfs)**	*10-yr*	*25-yr*	*50-yr*	*100-yr*	*10-yr*	*25-yr*	*50-yr*	*100-yr*	*10-yr*	*25-yr*	*50-yr*	*100-yr*
3	39.7	47.7	45.9	45.1	44.2	43.3	41.3	40.3	39.3	27.9	26.6	26.0	25.4
5	23.8	34.8	31.8	31.6	31.0	31.3	28.1	27.9	27.2	**20.2**	18.2	18.0	17.5
7	17.0	34.0	28.0	26.2	25.0	31.4	25.1	23.2	21.9	20.3	**16.2**	**15.0**	14.1
9	13.2	52.2	33.2	26.2	23.0	50.3	31.1	24.0	20.8	32.5	20.1	15.5	**13.4**

B. 2010 with Usable Lake Storage Volume of 6592 ac-ft*

Duration	*Reservoir*	*Gross draft rate (cfs)*				*Gross draft less net evaporation (cfs)*				*Gross draft less net evaporation (mgd)*			
(months)	*storage (cfs)**	*10-yr*	*25-yr*	*50-yr*	*100-yr*	*10-yr*	*25-yr*	*50-yr*	*100-yr*	*10-yr*	*25-yr*	*50-yr*	*100-yr*
3	36.4	44.4	42.6	41.8	40.9	40.1	38.0	37.1	36.1	25.9	24.5	23.9	23.3
5	21.9	32.9	29.9	29.7	29.1	29.4	26.2	25.9	25.3	**18.9**	16.9	16.7	16.3
7	15.6	32.6	26.6	24.8	23.6	30.1	23.8	21.8	20.5	19.4	**15.3**	**14.1**	13.2
9	12.1	51.1	32.1	25.1	21.9	49.2	30.1	23.0	19.7	31.8	19.4	14.8	**12.7**

C. 2020 with Usable Lake Storage Volume of 6156 ac-ft*

Duration	*Reservoir*	*Gross draft rate (cfs)*				*Gross draft less net evaporation (cfs)*				*Gross draft less net evaporation (mgd)*			
(months)	*storage (cfs)**	*10-yr*	*25-yr*	*50-yr*	*100-yr*	*10-yr*	*25-yr*	*50-yr*	*100-yr*	*10-yr*	*25-yr*	*50-yr*	*100-yr*
3	34.0	42.0	40.2	39.4	38.5	37.7	35.6	34.7	33.7	24.3	23.0	22.4	21.8
5	20.4	31.4	28.4	28.2	27.6	27.9	24.8	24.5	23.8	**18.0**	16.0	15.8	15.4
7	14.6	31.6	25.6	23.8	22.6	29.0	22.7	20.8	19.5	18.7	**14.7**	**13.4**	12.6
9	11.3	50.3	31.3	24.3	21.1	48.4	29.3	22.2	18.9	31.3	18.9	14.3	**12.2**

D. 2030 with Usable Lake Storage Volume of 5767 ac-ft*

Duration	*Reservoir*	*Gross draft rate (cfs)*				*Gross draft less net evaporation (cfs)*				*Gross draft less net evaporation (mgd)*			
(months)	*storage (cfs)**	*10-yr*	*25-yr*	*50-yr*	*100-yr*	*10-yr*	*25-yr*	*50-yr*	*100-yr*	*10-yr*	*25-yr*	*50-yr*	*100-yr*
3	31.9	39.9	38.1	37.3	36.4	35.5	33.5	32.5	31.6	22.9	21.6	21.0	20.4
5	19.1	30.1	27.1	26.9	26.3	26.6	23.5	23.2	22.5	**17.2**	15.1	15.0	14.5
7	13.7	30.7	24.7	22.9	21.7	28.1	21.8	19.9	18.6	18.1	**14.1**	**12.8**	12.0
9	10.6	49.6	30.6	23.6	20.4	47.7	28.6	21.5	18.2	30.8	18.4	13.8	**11.7**

E. 2040 with Usable Lake Storage Volume of 5422 ac-ft*

Duration	*Reservoir*	*Gross draft rate (cfs)*				*Gross draft less net evaporation (cfs)*				*Gross draft less net evaporation (mgd)*			
(months)	*storage (cfs)**	*10-yr*	*25-yr*	*50-yr*	*100-yr*	*10-yr*	*25-yr*	*50-yr*	*100-yr*	*10-yr*	*25-yr*	*50-yr*	*100-yr*
3	30.0	38.0	36.2	35.4	34.5	33.6	31.6	30.6	29.7	21.7	20.4	19.8	19.1
5	18.0	29.0	26.0	25.8	25.2	25.5	22.3	22.0	21.4	**16.4**	14.4	14.2	13.8
7	12.8	29.8	23.8	22.0	20.8	27.3	21.0	19.0	17.8	17.6	**13.5**	**12.3**	11.5
9	10.0	49.0	30.0	23.0	19.8	47.1	27.9	20.8	17.6	30.4	18.0	13.4	**11.3**

Notes:

Lowest gross draft less evaporation (mgd) shown in bold.

*Usable storage volume calculated as 90 percent of reservoir volume.

and 50-year return periods have the lowest yields when the duration is 7 months. During a drought with a 100-year return period, the critical duration is 9 months. The net yields and critical drought durations are summarized in Table 15. These values are a function of the estimated inflow, lake volume, and evaporation. There is an inherent uncertainty for all these parameters. Sample yield calculations were performed testing the possible range of these values; on the basis of these calculations, the error of the yield values was roughly estimated to be ± 15 percent.

Factors That Can Reduce Drought Net Yield

Climate Variability

Drought yields estimated in this report have been calculated using historical climatic and hydrologic conditions from 1928-1998. It should be considered that climate conditions in the next 50 years might not be the same as observed in the historical record and there is the potential that droughts could be either more severe, as indicated by some global climate forecasts, or less severe. These climate influences, combined with future watershed management practices, also have the potential to modify the rate of sediment inflow into Lake Vermilion, influencing future yields. Water supply planning should account for these uncertainties.

Seepage Losses

Typically, seepage losses are not directly measured. When sufficient data are available, a water budget for the reservoir can be constructed to indirectly estimate seepage and other losses. Unfortunately, historical data are not adequate to formulate a drought period water budget that has the precision needed to quantify these other losses.

Seepage losses are usually considered insignificant. Chow (1964, pp. 18-19) observes that "Seepage losses tend to be lower during droughts than during periods of normal streamflow since the seepage driving force is reduced by reservoir drawdown." Lake Vermilion is underlain by sand and gravel aquifers. While sufficient data were not available to compute volume and flow rates, Larson et al. (1997) conclude that pumping from these aquifers could induce leakage from Lake Vermilion. The probability of inducing subsurface flow from the lake is one reason it is not recommended to establish a well field in the hydrologically connected aquifers in the vicinity of Lake Vermilion. Other consequences are discussed in the above noted report.

Flow Over Low Channel Dam at Withdrawal Facility Site

As noted earlier, water withdrawals are not made directly from Lake Vermilion. Rather, the intake pumps are located more than one mile downstream. A low channel dam at the intake structure is used in combination with controlled releases from Lake Vermilion to maintain submergence of the intake pumps. Therefore, sufficient flow must be released from Lake Vermilion during drought periods to maintain submergence of the pumps and avoid damaging cavitation. In a perfectly controlled situation, water released from Lake Vermilion would be exactly equal to the water pumped at the intake. In the event that releases from Lake Vermilion exceed pumping rates at the intake, there would be flow over the low channel dam. The rate of flow for a given water depth over the dam crest (head) may be estimated using the standard equation for weir flow, $Q = CLH^{3/2}$, where Q is discharge in cubic feet per second, C is the weir discharge coefficient, L is the length of the weir in feet, and H is the depth of water over the weir crest in feet. A value of 2.6 was used for the weir discharge coefficient. The value could be as high as 3, which would predict higher discharges over the dam. The length of the low channel dam is 196.1 feet. Table 16 shows the flow that would pass over the low channel dam for various depths and lengths of time. For example, maintaining a depth of flow over the dam of 0.05 feet (a little more than half an inch) would release 3.68 mgd. In 2010, during a drought comparable to a 50-year drought, that would reduce the net yield from 14.1 mgd to 10.4 mgd.

Table 15. Lake Vermilion Net Drought Yields for Selected Return Periods

	Net yield (mgd)/drought duration (months)			
Year	10-yr	25-yr	50-yr	100-yr
1998	20.2/5	16.2/7	15.0/7	13.4/9
2010	18.9/5	15.3/7	14.1/7	12.7/9
2020	18.0/5	14.7/7	13.4/7	12.2/9
2030	17.2/5	14.1/7	12.8/7	11.7/9
2040	16.4/5	13.5/7	12.3/7	11.3/9

Table 16. Flow over Low Channel Dam at Intake Pumps

Head (feet)	*Flow (cfs)*	*Flow (mgd)*	*Volume* 4 hours	*Volume* 8 hours	*Volume* 12 hours
0.10	16.12	10.42	1.74	3.47	5.21
0.05	5.70	3.68	0.61	1.23	1.84
0.04	4.08	2.64	0.44	0.88	1.32
0.01	0.51	0.33	0.05	0.11	0.16

Note:

Flow computed as $Q = CLH^{3/2}$
Q = discharge (cfs)
C, discharge coefficient = 2.6
L, spillway length =196.1 feet
H, head the depth of water above spillway (feet)

Summary

Lake Vermilion provides reserve water to supply the City of Danville during drought periods when flow in the North Branch Vermilion River is less than demand. During extreme droughts the usable reserves in the lake may be used to meet water demand. To avoid water shortfalls, it is necessary to evaluate the net yield (maximum draft rate) that can be met during droughts of varying severity. The severity of the drought is related to the return period, the longer the return period, the more unusual and severe the drought.

The reservoir yield is a function of the inflow to the reservoir, the reservoir storage volume, evaporation from the water surface, and other identified losses. A detailed streamflow analysis was performed to estimate inflows to the reservoir during severe droughts. The reservoir volume was determined from a 1998 survey conducted by the Illinois State Water Survey for Consumers Illinois Water Company. Decreases in available storage due to sedimentation in the lake were estimated. The net yield from the reservoir for 10-, 25-, 50-, and 100-year return period droughts for the years 1998, 2010, 2020, 2030, and 2040 was computed. Potential losses from the reservoir that would decrease drought yields are discussed. Given the inherent uncertainty in the data, the computed yields have an error of roughly 15 percent.

It would be beneficial to the Consumers Illinois Water Company to continue with these studies at a frequency of every 10 years.

References

Bogner, W., and K.E. Hessler. 1999. *Sedimentation Survey of Lake Vermilion, Vermilion County, Illinois.* Illinois State Water Survey Contract Report 643.

Chow. V.T. (ed). 1964. *Handbook of Applied Hydrology,* McGraw-Hill, Inc., New York.

Larson, D.R., J.P. Kempton, and S. Meyer. 1997. *Geologic, Geophysical, and Hydrologic Investigations for a Supplemental Municipal Groundwater Supply, Danville, Illinois.* Cooperative Groundwater Report 18. Illinois Department of Natural Resources, p. 62.

McConkey-Broeren, S., and K.P. Singh. 1989. *Adequacy of Illinois Surface Water Supply Systems to Meet Future Demands.* Illinois State Water Survey, Contract Report 477, p. 54.

Singh, K.P., and A. Durgunoglu. 1988. *An Improved Methodology for Estimating Future Reservoir Storage Capacities.* Illinois State Water Survey Contract Report 446.

Singh, K.P., and A. Durgunoglu. 1990. *An Improved Methodology for Estimating Future Reservoir Storage Capacities, Second Edition.* Illinois State Water Survey Contract Report 493.

Singh, K.P., and J.B. Stall, 1973. *The 7-Day 10-Year Low Flows of Illinois Streams.* Illinois State Water Survey Bulletin 57.

Singh, K.P., G.S. Ramamurthy, and I.W. Seo. 1988. *7-Day and 10-Year Low Flows of Streams in the Kankakee, Sangamon, Embarras, Little Wabash, and Southern Regions.* Illinois State Water Survey Contract Report 441.

Terstriep, M.L., M. Demissie, D.C. Noel, and H.V. Knapp. 1982. *Hydrologic Design of Impounding Reservoirs in Illinois.* Illinois State Water Survey Bulletin 67.

U.S. Army Corps of Engineers (USACOE) Chicago District. 1978. *Wabash River Basin Ilnoname Dam 502, Lake Vermilion, Vermilion County Illinois, Inventory Number 00525 Inspection Report National Dam Safety Program.* Department of the Army Chicago District Corps of Engineers, Chicago, Illinois.

ILLINOIS
DEPARTMENT OF
NATURAL
RESOURCES