CHANNEL-STORAGE/DISCHARGE RELATIONS FOR THE PEORIA AND LA GRANGE DAMS ON THE ILLINOIS RIVER IN ILLINOIS

By George Garklavs, A. R. Klinger, and D. M. Mades

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 86-4112

Prepared in cooperation with

U.S. ARMY CORPS OF ENGINEERS,

ROCK ISLAND DISTRICT

URBANA, ILLINOIS

1986

UNITED STATES DEPARTMENT OF THE INTERIOR

DONALD PAUL HODEL, Secretary

GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information
write to:

District Chief
U.S. Geological Survey
Water Resources Division
102 E. Main St., 4th Floor
Urbana, IL 61801

Copies of this report can be
purchased from:

Open-File Services Section
Western Distribution Branch
U.S. Geological Survey
Box 25425, Federal Center
Denver, CO 80225

FACTORS FOR CONVERTING INCH-POUND UNITS TO INTERNATIONAL SYSTEM OF METRIC UNITS (SI)

Multiply inch-pound unit	By	To obtain SI unit
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
acre-foot	1,233	cubic meter (m^3)

CHANNEL-STORAGE/DISCHARGE RELATIONS FOR THE PEORIA AND LA GRANGE DAMS ON THE ILLINOIS RIVER IN ILLINOIS

By George Garklavs, A. R. Klinger, and D. M. Mades

ABSTRACT

The relations between channel storage and discharge at the Peoria and La Grange Dams on the Illinois River are defined. The relations were developed by regressing channel storage against peak discharge at the dams. Peak discharges at the Peoria Dam ranged from 19,700 to 79,500 cubic feet per second, whereas those at the La Grange Dam ranged from 27,200 to 122,000 cubic feet per second. The storage-discharge relations are linear for the range in discharges used in the analyses. For a given discharge, the channel storage upstream from the Peoria Dam is 2.4 to 4 times greater than that upstream from the La Grange Dam.

INTRODUCTION

The 327-mile long Illinois Waterway (fig. 1) connects Lake Michigan, at Chicago Harbor, with the Mississippi River at Grafton, Illinois. The Waterway is comprised of the Illinois, Des Plaines, Calumet, and Chicago Rivers, the Chicago Sanitary and Ship Canal, and the Calumet Sag Channel. The U.S. Army Corps of Engineers (Corps) operates eight locks and dams on the Waterway, and one on the Mississippi River near Alton, Illinois, to maintain a 9-foot minimum depth in the navigation channel in the Waterway. The Waterway can be thought of as a series of reservoirs, created by the dams, connected by channels of various lengths. The volume of water stored upstream from each dam can be related to the discharge at the dam. Knowing this relation can aid in operating the system of locks and dams to maintain stable pool elevations at various discharges, such as during the passage of a flood wave. In 1984, the U.S. Geological Survey (Survey), in cooperation with the U.S. Army Corps of Engineers, began an investigation to determine the relation between channel storage and discharge for the La Grange and Peoria Dams on the Illinois River.

This report presents a description of the study reach on the Illinois River, the approach used to define the channel-storage/discharge relations at the La Grange and Peoria Dams, and graphic and mathematical presentations of the channel-storage/discharge relations.

The study reach extends from the La Grange Dam, at river mile 80.2, to the Starved Rock Dam, at river mile 231, on the Illinois River (fig. 2). The Peoria Dam is located at river mile 157.8. The channel slope in the study

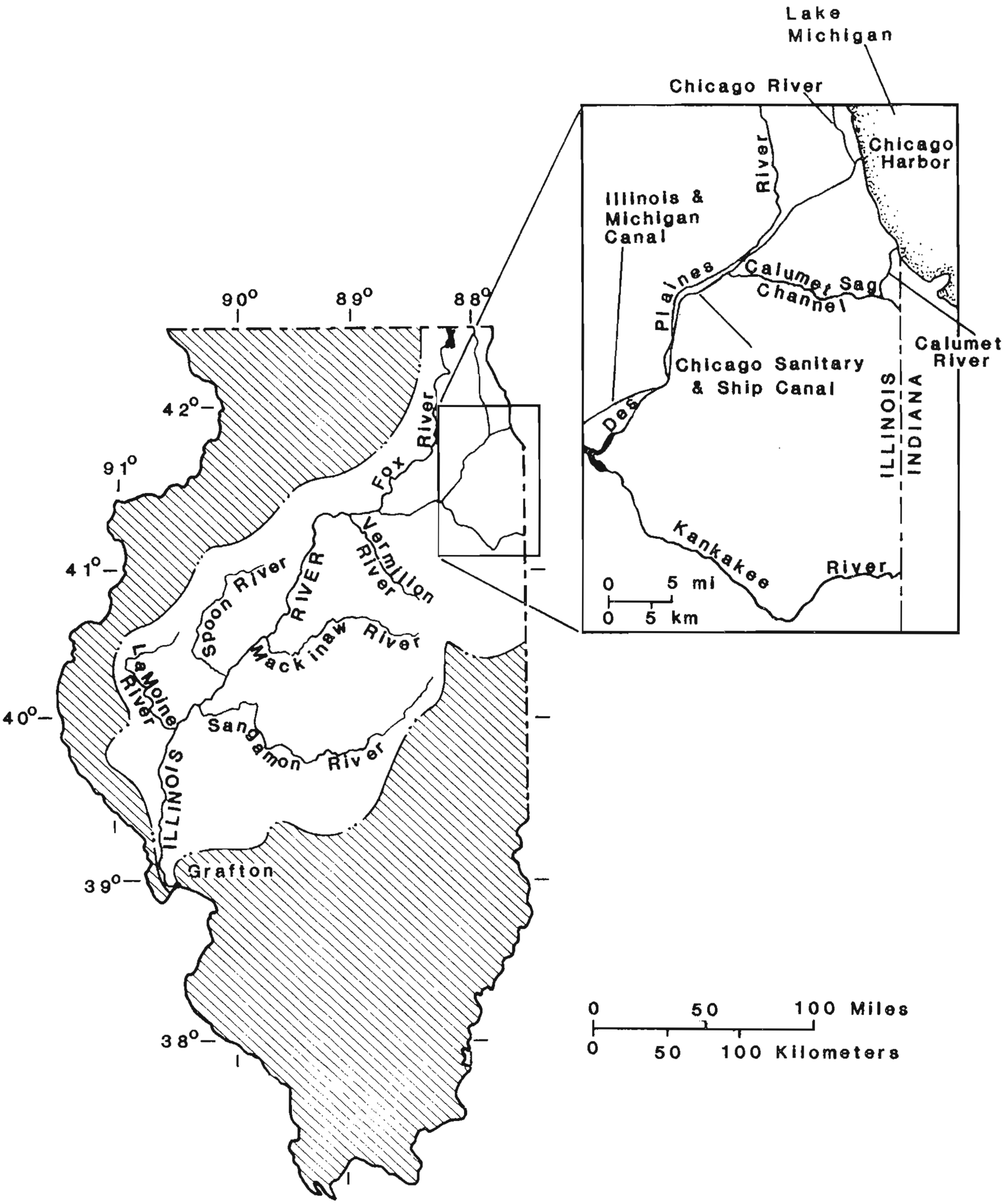

Figure 1.--Location and drainage basin of Illinois Waterway in Illinois.

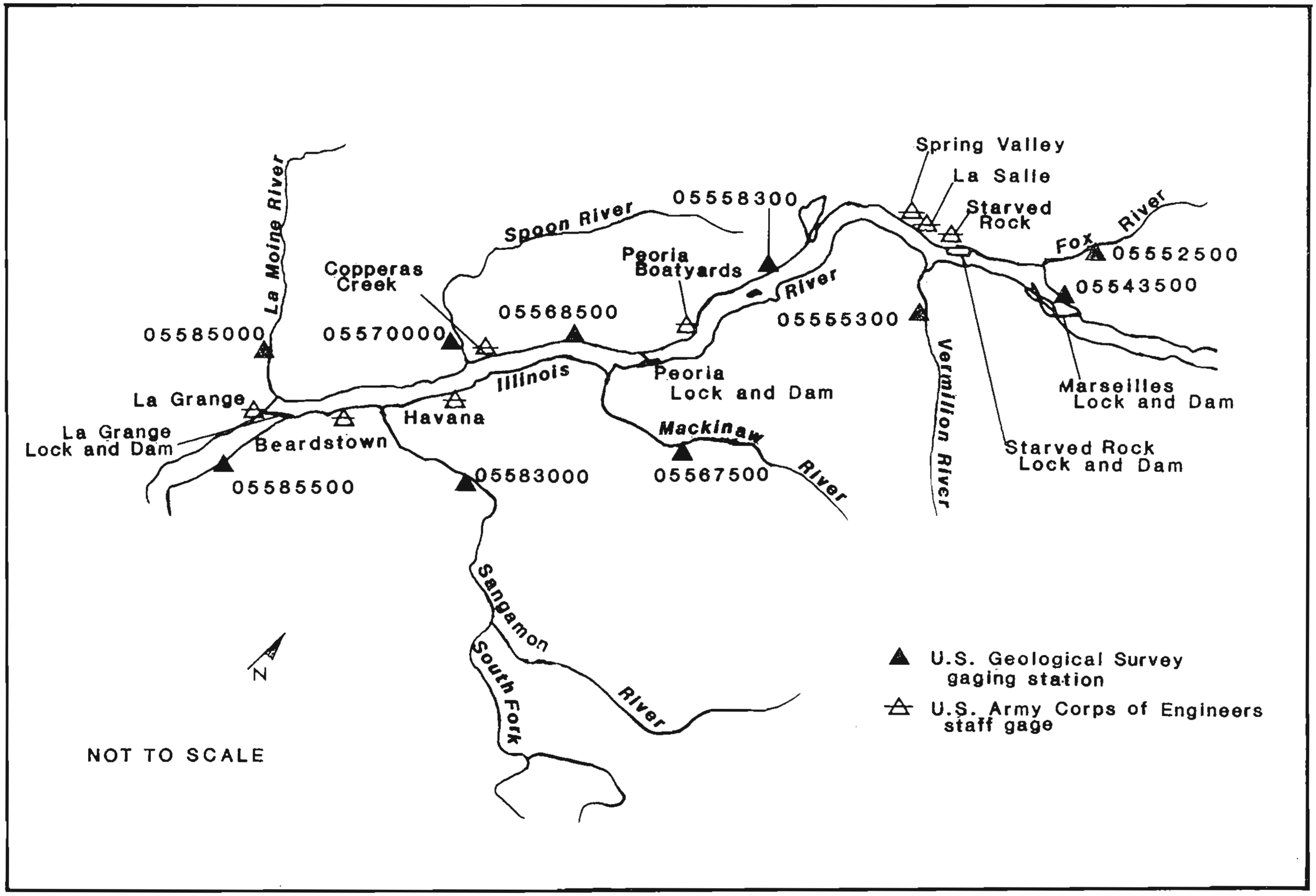

Figure 2.--Generalized location of dams and some gaging stations and staff gages along and near the Illinois River.

reach is about 0.1 foot per mile (fig. 3). The drainage areas of the Illinois River basin at the La Grange, Peoria, and Starved Rock Dams are 25,648, 14,550, and 11,071 square miles (mi^2), respectively. Flow into the study reach is regulated at the Starved Rock Dam, except during periods of very high flow when all of the gates at the dam are raised out of water. Five major tributaries discharge into the Illinois River in the study reach. They are the Vermilion, Mackinaw, Spoon, Sangamon, and La Moine Rivers.

The Survey operates four gaging stations on the Illinois River (fig. 2 and table 1). These are located at Marseilles, Henry, Kingston Mines, and Meredosia, Illinois, and are numbered 05543500, 05558300, 05568500, and 05585500, respectively. The gages at Henry and Kingston Mines are within the study reach. The gages at Marseilles and Meredosia are located just upstream and downstream of the study reach, respectively. The Survey also operates gaging stations on all five major tributaries to the Illinois River. Survey gaging stations continuously record river stage. River-stage values are converted to discharge by using a stage-discharge relation at Marseilles and the tributaries, stage-velocity-discharge relation at Henry, and stage-fall-discharge relation at Kingston Mines and Meredosia.

The Corps maintains nine staff gages for measuring river stage along the study reach (table 1 and fig. 3). Daily river-stage readings are obtained at these staff gages. The Corps also continuously records stage just upstream and downstream from each of the dams.

The U.S. Army Corps of Engineers, Rock Island District, provided cross-section and staff-gage-stage data used in this investigation. The cooperation of the Corps, and William Koellner, in particular, was greatly appreciated.

APPROACH

The channel-storage/discharge relations for each pool were determined using a four-step procedure. First, hydrologic records were examined to select floods representing a wide range of peak discharges. Second, a discharge hydrograph associated with each flood on the Illinois River was constructed for both the La Grange and Peoria Dams. Third, a channel-storage hydrograph was constructed for each flood. Fourth, average values of discharge, and concurrent storage, for each flood were calculated. These average values were calculated for that period of time during each flood when both storage and discharge hydrographs were at, or near, a maximum value and near steady conditions.

Steady flow does not exist during the passage of a flood wave. However, because of the low channel slope and large drainage area of the Illinois River in the study reach, flood waves are of low amplitude and long duration. Flood peaks often reach a stage which remains stable for several days, and can be thought of as approaching near steady-flow conditions. This extended time base, characteristic of the flood wave peak, also allows for computation of channel storage at near steady-state conditions.

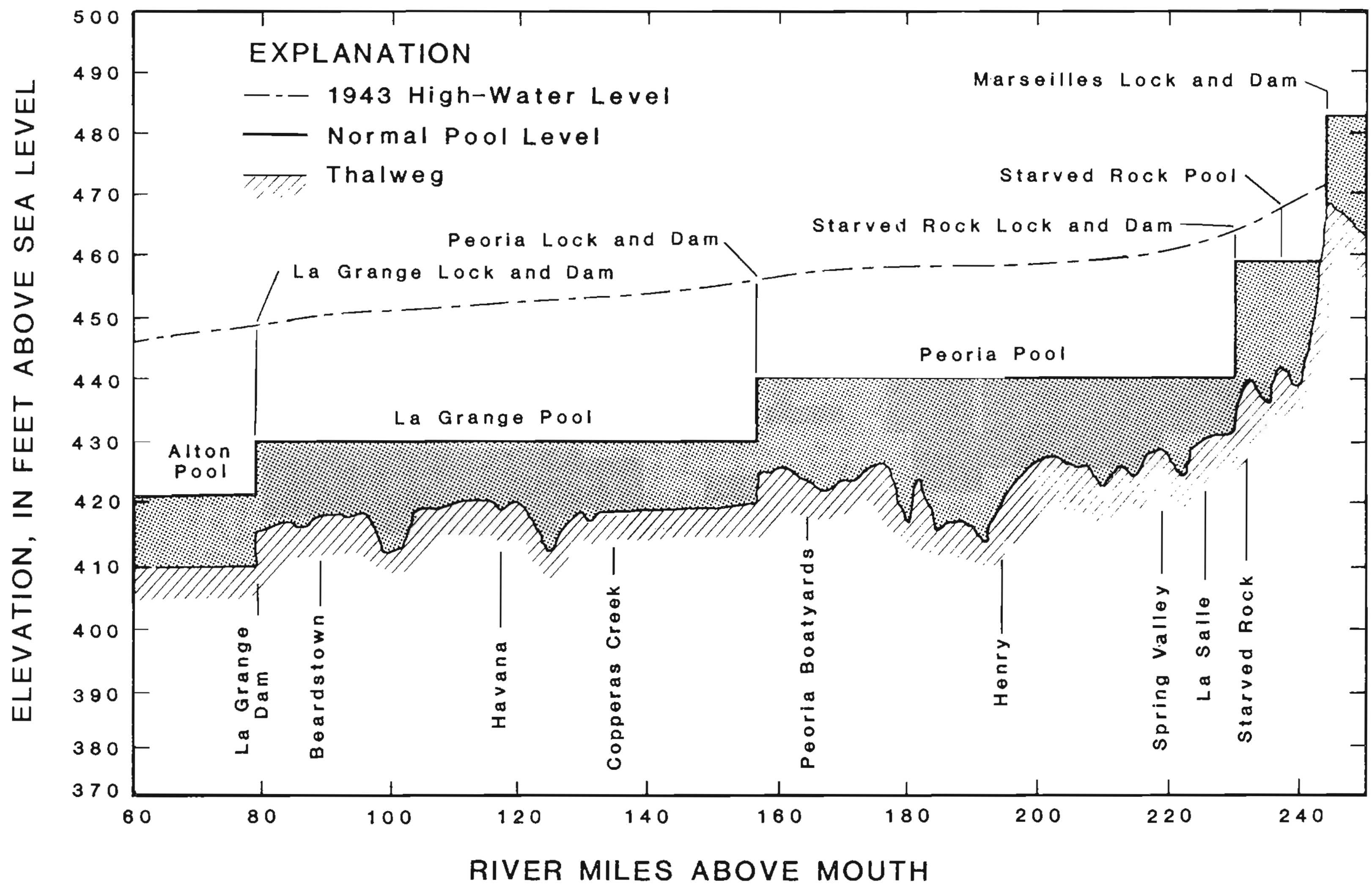

Figure 3.--A section of the Illinois River profile including location of U.S. Army Corps of Engineers staff gages.

Table 1.-- River miles at selected sites within the study area

Locations are referenced to river miles. River miles along the Illinois River begin at zero (0) at its mouth at the Mississippi River near Grafton, Illinois, and increase upstream. River miles along tributaries begin at 0 at their mouths at the Illinois River. The location of the mouth of a tributary is referenced to the river-mile location on the Illinois River. Locations of gaging stations on tributaries are referenced to the river mile of the tributary.

Gage: A, U.S. Geological Survey stream-gaging station.
B, U.S. Army Corps of Engineers staff gage.

Site	Gage	River mile
Illinois River at Marseilles	A	246.5
Illinois River at Starved Rock	B	230.9
Vermilion River, at mouth		226.3
Vermilion River near Leonore	A	5.6
Illinois River at La Salle	B	224.7
Illinois River at Spring Valley	B	218.4
Illinois River at Henry	A	196.0
Illinois River at Henry	B	195.6
Illinois River at Peoria boat yard	B	164.2
Mackinaw River, at mouth		147.7
Mackinaw River near Congerville	A	58.7
Illinois River at Kingston Mines	A	144.4
Illinois River at Copperas Creek	B	136.9
Illinois River at Havana	B	119.6
Spoon River, at mouth		119.4
Spoon River at Seville	A	39.2
Sangamon River, at mouth		98.0
Sangamon River near Oakford	A	25.7
Illinois River at Beardstown	B	88.6
La Moine River, at mouth		83.5
La Moine River at Ripley	A	12.3
La Grange lock, lower	B	80.2
Illinois River at Meredosia	A	71.3

Storage was related to discharge at the dams. Twenty-five well defined flood waves were used as the bases for defining the storage-discharge relation for the La Grange pool, and 24 were used at the Peoria pool. Daily discharge and stage hydrographs were constructed for each flood wave at both dams. The time period during which both stage and discharge were at, or near, maximum value and near steady-state conditions was defined for each flood wave. A daily stage hydrograph was constructed for this time period, which ranged from 3 to 5 days. Daily storage hydrographs were constructed for the time period defined above. For each flood wave the values of discharge at, and storage upstream from, each dam, averaged over the time period of near steady flow, were used to define the storage-discharge relations. Channel-storage/discharge relations at both dams were defined for the range in discharge from that just sufficient to maintain stable pool elevations to the maximum discharge of record.

Values of discharge for the Peoria Dam were obtained from the gaging station at Kingston Mines, located on the Illinois River 13.4 miles below the dam. The Mackinaw River discharges into the Illinois River between the Peoria Dam and the gage at Kingston Mines. The drainage area of the Illinois River at Peoria Dam, 14,550 mi^2, is 92 percent of the 15,818 mi^2 drainage area of the river at the gage at Kingston Mines. Ninety percent of the intervening area between the dam and gage at Kingston Mines is upstream from a gaging station located on the Mackinaw River near Congerville, Illinois (05567500). Discharge measured at the Mackinaw River near Congerville was subtracted from that measured at Kingston Mines to compensate for inflow to the Illinois River between the dam and gage at Kingston Mines.

Values of discharge for the La Grange Dam were obtained from the gaging station at Meredosia. The Meredosia gage is 8.9 miles downstream of the La Grange Dam. The drainage area at the dam is 25,648 mi^2, 99 percent of the 26,028 mi^2 drainage area at the Meredosia gage. This difference is small enough that no attempt was made to correct the discharge measured at the gage for any inflow between the La Grange Dam and Meredosia gage.

Daily storage hydrographs were calculated using the U.S. Army Corps of Engineers' Hydrologic Engineering Center Water Surface Profiles modeling system, HEC-2 (1982). HEC-2 calculates the volume of water in a pool based on channel cross sections, the distance between channel cross sections, altitudes of the channel bed, and water-surface profiles. Volume is defined as the region between two dams that is bounded by a water-surface profile and the channel bed. Water-surface profiles were developed from river stages recorded at gaging stations, staff gages, and dams. Stages at ungaged locations where cross sections were available were determined by linear interpolation of stages at gaged locations. The HEC-2 model determines channel storage using an incremental approach. The volume between channel cross sections is computed by multiplying the average of the two cross-section areas by the channel length. The channel storage of a pool above a dam is the sum of all incremental volumes between cross sections. Water-surface elevations at the downstream point of each pool were those measured at the Peoria and La Grange Dams. The water-surface elevations for the farthest upstream point above the La Grange Dam were those measured just downstream of the Peoria Dam. The water-surface elevations for the farthest upstream point above the Peoria Dam were those measured just downstream of the Starved Rock Dam.

Volumes associated with normal and low discharges were also computed. These volumes were computed using HEC-2 where the water-surface profile was defined by the elevation at the most downstream cross section with the elevations at upstream cross sections increasing based on channel slope.

CHANNEL-STORAGE/DISCHARGE RELATIONS

Channel-storage/discharge relations for the La Grange and Peoria pools were developed statistically from the paired discharge and computed channel-storage values using linear regression. The storage-discharge relations developed for both dams are applicable only to the range in discharge used in the regressions. The storage-discharge relation at the Peoria Dam was developed for discharges ranging from 19,700 to 79,500 ft^3/s (cubic feet per second), whereas that at the La Grange Dam was developed for discharges ranging from 27,200 to 122,000 ft^3/s. Storage upstream from both dams associated with the various flood waves is listed in tables 2 and 3. Discharge and storage values obtained for flood waves of 1982-83 most nearly approximate levee full conditions. The linear regression equations relating storage to discharge are

$$S = -29{,}400 + 12.3(D) \qquad \text{(Peoria Dam)}$$

and

$$S = 13{,}400 + 3.18(D) \qquad \text{(La Grange Dam)}$$

where S is channel storage (acre-feet), and D is discharge at a dam (ft^3/s). Regressions for both dams were significant at the 0.05 confidence level. The storage-discharge relations for the dams are shown graphically in figures 4 and 5.

The channel storage associated with normal and low discharge are not related to any specific discharge. Both of the dams consist of Chanoine wickets (Mades, 1981). At discharges greater than about 15,000 ft^3/s, the wickets are lowered to allow passage of the flood wave. Between discharges of about 10,000 and 15,000 ft^3/s, individual wickets may be raised or lowered to maintain stable pool elevations. During low-flow conditions, the dams can be regulated to maintain stable pool elevations by varying discharge from zero to 15,000 ft^3/s. The volumes of water in storage calculated for specific pool elevations, measured at the dams, are listed in table 4 and presented graphically in figures 4 and 5. In reality, the change in storage during the transition from low-flow conditions to passage of a flood wave is not characterized by an abrupt change as indicated in figures 4 and 5. The degree of variability in the storage-discharge relations introduced by the raising and lowering of wickets at the dams precluded defining the gradual change in storage during the transition between low and high flows. The low-flow pool elevation-storage relations are applicable during conditions of relatively steady flow.

Table 2.--Summary of data used in defining storage-discharge relation--Peoria Dam

Time period	Mean storage (acre-feet)	Mean outflow (ft^3/s)
May 22-24, 1943	982,000	79,500
April 25-28, 1944	690,000	57,500
April 26-29, 1950	727,000	63,100
March 16-22, 1953	272,000	25,200
October 10-16, 1954	384,000	30,000
May 3-7, 1956	245,000	22,900
June 15-19, 1958	481,000	38,900
September 27-29, 1961	454,000	34,400
April 24-28, 1964	212,000	21,100
April 26-29, 1965	461,000	38,300
May 13-17, 1966	578,000	49,000
April 3-7, 1967	484,000	43,700
May 16-19, 1970	838,000	73,200
September 26-30, 1970	405,000	38,800
April 23-27, 1972	366,000	32,400
June 16-20, 1972	370,000	35,100
April 23-26, 1973	701,000	53,300
May 23-25, 1974	757,000	69,400
May 7-9, 1977	199,000	19,700
April 7-13, 1978	498,000	41,800
June 3-9, 1980	515,000	47,900
June 15-18, 1981	520,000	44,000
March 21-23, 1982	903,000	72,000
December 5-9, 1982	910,000	78,000

Table 3.--Summary of data used in defining storage-discharge relation--La Grange Dam

Time period	Mean storage (acre-feet)	Mean outflow (ft^3/s)
May 25-26, 1943	401,000	122,000
April 29 to May 2, 1944	305,000	98,300
April 30 to May 2, 1950	267,000	75,800
March 25 to April 5, 1953	112,000	32,800
October 17-21, 1954	130,000	30,000
May 7-9, 1956	102,000	27,200
June 19-23, 1958	182,000	60,000
September 30 to October 1, 1961	186,000	52,200
April 28 to May 1, 1964	124,000	47,700
April 19-29, 1965	175,000	48,000
May 17-25, 1966	202,000	58,700
April 7-11, 1967	182,000	45,800
May 19-22, 1970	301,000	89,500
September 30 to October 1, 1970	215,000	60,100
April 27 to May 1, 1972	159,000	48,700
June 21-26, 1972	135,000	33,000
April 27-30, 1973	326,000	97,400
June 26-29, 1974	318,000	108,000
May 10-13, 1977	115,000	41,000
April 13-15, 1978	217,000	70,700
April 16-20, 1979	369,000	100,000
June 9-10, 1980	218,000	61,500
May 19-24, 1981	231,000	69,500
March 23-26, 1982	350,000	103,000
December 9-12, 1982	364,000	105,000

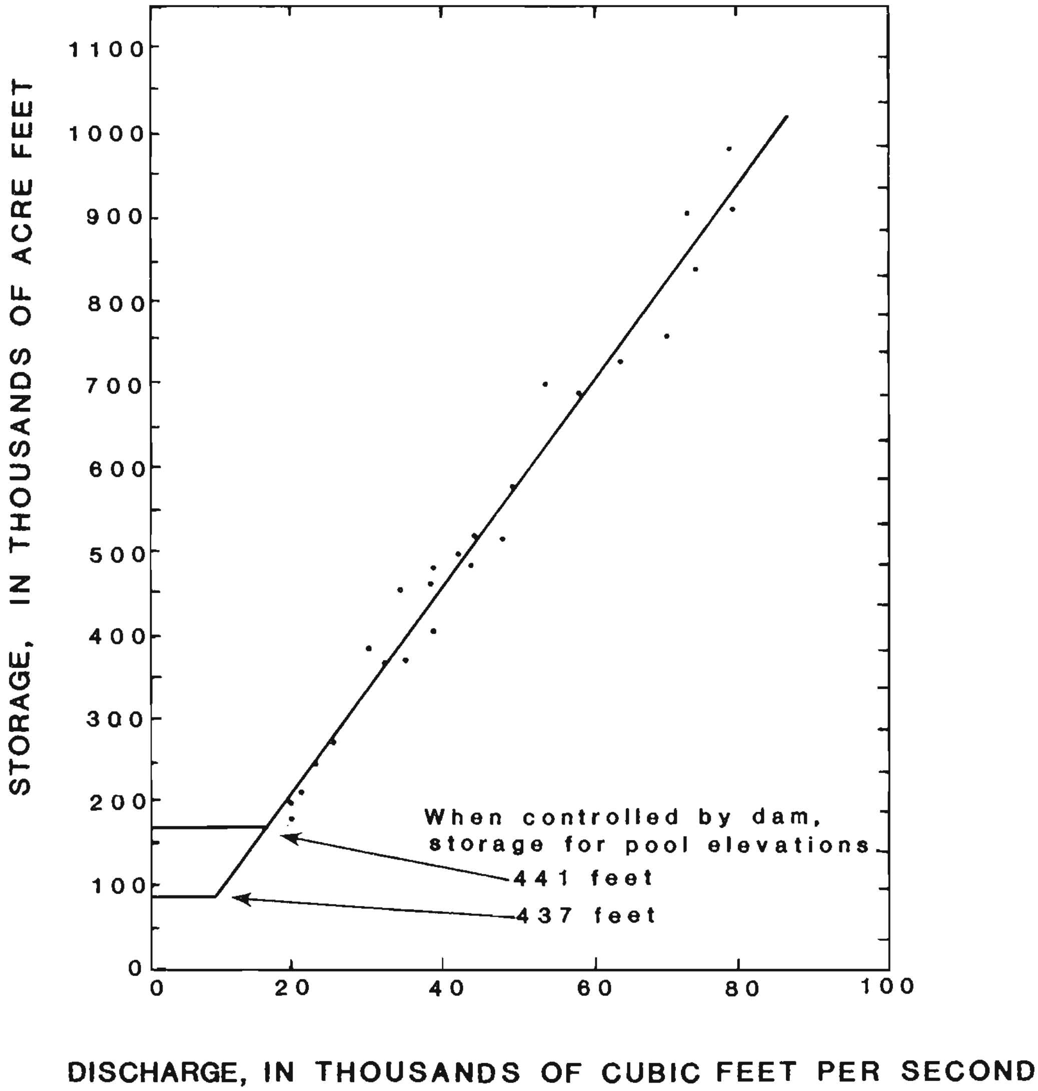

Figure 4.--Storage-discharge relation--Peoria Dam.

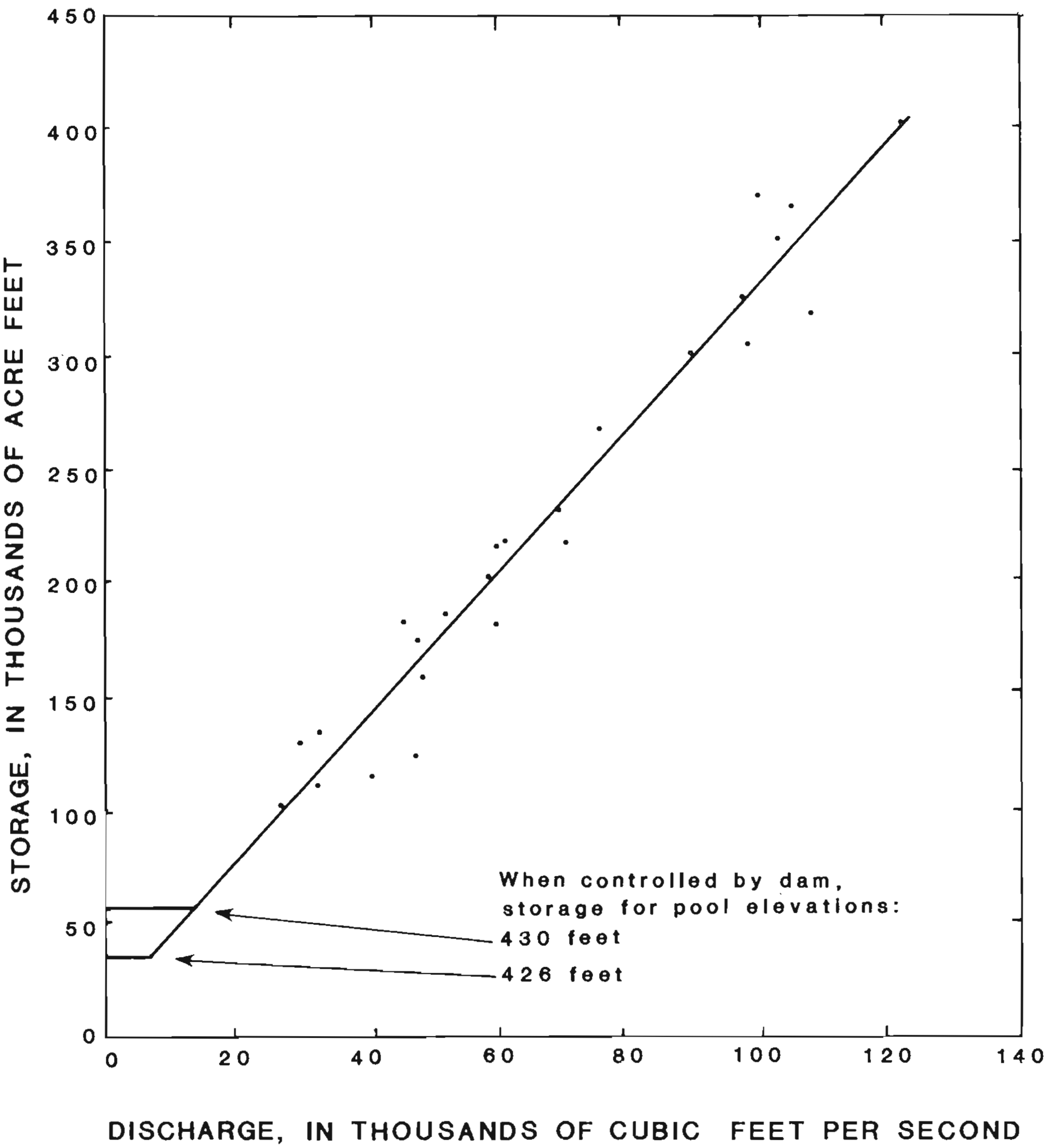

Figure 5.--Storage-discharge relation--La Grange Dam.

Table 4.--Low-flow pool elevation-storage relations for Peoria and La Grange Dams

Water surface elevation at dam (feet)	Volume (acre-feet)
PEORIA DAM	
441.0	168,000
440.5	153,000
440.0	139,000
439.5	127,000
439.0	115,000
438.5	104,000
438.0	93,700
437.0	79,600
LA GRANGE DAM	
430.0	58,300
429.5	55,400
429.0	52,500
428.5	49,800
428.0	47,100
427.5	44,400
427.0	41,900
426.0	36,900

The storage-discharge relations developed for the two pools represent mean storage-discharge conditions for periods of relatively steady flow. During flow conditions with higher than average antecedent storage, these relations may underpredict storage for a particular discharge, while during periods of lower than average antecedent storage the relations may overpredict storage.

Comparing the relations developed for each pool indicates a difference in storage capacity of the two pools upstream from the dams. In general, for a given discharge, the quantity of water stored in the Peoria pool will range from 2.4 to 4 times that stored in the La Grange pool. This is not unexpected, as the Peoria pool consists of a relatively unbroken chain of reservoirs, while the La Grange pool has longer reaches of narrow channel, with lower storage capacity, connecting the wider expanses of the river.

SUMMARY

Channel-storage/discharge relations were developed for the pools upstream from La Grange and Peoria Dams on the Illinois River. The relations were statistically derived from values of daily average discharge and storage for the range in discharges from those just sufficient to maintain stable pool elevations to the maximum flood of record. The relation between storage and discharge is linear. The two pools have significantly different storage characteristics for a given discharge; the storage in the Peoria pool is 2.4 to 4 times greater than that in the La Grange pool.

REFERENCES CITED

Mades, D. M., 1981, Stage-discharge relations at dams on the Illinois and Des Plaines Rivers in Illinois: U. S. Geological Survey Open-File Report 81-1009, 56 p.

U. S. Army Corps of Engineers, 1982, HEC-2 water surface profiles, users manual: Davis, California, Hydrologic Engineering Center, 224 p.

☆U.S. GOVERNMENT PRINTING OFFICE 1986—644-002/1025