e. Henderson Creek

Henderson Creek enters the Mississippi River at river mile 409.9. The area of the watershed is 598 square miles. The gaging station, located at Oquawka, Ill., has a period of record extending from 1938 to current year. Flood stage is 21.5 feet. The Flood of 1993 had two peaks that ranked in the top five for this station. The flood of record occurred on July 25, 1993 and had a peak stage of 32.48 feet. The second highest event occurred in 1982 and reached 31.05 feet. June 9, 1993 had a stage of 29.40 feet. The two other notable events occurred in 1982 with a stage of 28.88 feet and in 1950 with a stage of 28.17 feet.

V. Des Moines River Basin

A. Basin Description

The Des Moines River basin extends across central Iowa to the southeastern part of the state (Plate 31). The watershed has an area of 14,802 square miles. Des Moines, Ottumwa and Fort Dodge are the largest population centers. This basin contains 9.4 million acres of land and 42,000 acres of lake surface. The Des Moines River has numerous tributaries, many of which are very short with small drainage areas. The major tributaries include the East Fork, the Boone River, the Raccoon River, Middle River and the South River.

The Des Moines River basin has an average width of 40 miles and extends 360 miles from its headwaters north of Slayton, Minn., to its confluence with the Mississippi River near Keokuk, Iowa. Downstream of its confluence with the Raccoon River near Des Moines, Iowa, the river valley changes both in direction and character. North of this point, the valley topography is shallow, with steep walls and a narrow flood plain. South of this point the river flows southeasterly in a broader, more mature flood plain in which the valley becomes wider and deeper and the bluffs become more rounded.

B. Main Stem Hydrology/Hydraulics

1. Description of Flooding

The flooding on the Des Moines River was the most severe and had the greatest impact on the City of Des Moines. Plate 32 shows the total monthly precipitation for May, June, July and August in 1993 vs. the average total precipitation for the same period at the Des Moines National Weather Service rainfall gage. The record rainfall that persisted in the basin resulted in overtopping the levees and inundating the city's water treatment plant. The residents were without drinking water for three weeks. The storm that was responsible for this event began at 9 p.m. on July 8 and ended on July 9 at 1 a.m. During that five-hour period, 6.5 inches of rain fell on an already swollen Des Moines River basin. Flash flooding occurred on the Raccoon River, a tributary to the Des Moines River that has its confluence in the City of Des Moines. This compounded the severity of the flooding in Des Moines. The operation of the two reservoirs that are located on the Des Moines River and the impact that they had on the flooding are discussed in detail in Sections D and E, Reservoir Regulation.

Major floods on the Des Moines River basin have been recorded since the early 1900s. Generally, the floods are a result of heavy rainfall during the summer months and snowmelt in the spring and late spring. Some of the more notable events are discussed below. A summary of the top five floods of record for the Des Moines River main stem gaging stations is shown in Table 10.

a. Flood of 1938

During two periods in 1938, heavy rainfall caused flooding in the upper Des Moines River basin. In the first period, September 5-8, rain amounting to nearly 6 inches saturated the soil. The second period September 11-14, had a somewhat lesser amount of rain which fell on the saturated soil causing extensive flooding.

b. Flood of 1947

June of 1947 had temperatures below average and precipitation in the upper basin that occurred on 19 of the 30 days. This resulted in monthly precipitation that ranged from 8 to 12.5 inches.

c. Flood of 1951

In March of 1951, the temperatures were cold and there was a record amount of snowfall. Late in the month, rain and warm weather hastened the snowmelt resulting in flooding.

d. Flood of 1953 and 1954

The Floods of June 1953 and June 1954 were caused by exceptionally heavy rainfall. Most of the rainfall in 1953 occurred west of the Des Moines River basin, and only the West Fork Des Moines River at Estherville had a flood of significance. In June 1954, the center of the heavy rain was near the eastern boundary of the basin, with an eight-day total exceeding 12 inches. Record peak discharges occurred on the East Fork and on the main stem downstream as far as Des Moines.

e. Floods of 1961, 1962, 1965 and 1969

The Floods of 1961, 1962, 1965 and 1969 were caused by similar conditions as those that produced the 1951 Flood. They were primarily caused by snowmelt compounded by rainfall.

Table 10
Des Moines River
Main Stem Top 5 Floods of Record

Station	Flood Stage (feet)	Date 1	Stage 1	Date 2	Stage 2	Date 3	Stage 3	Date 4	Stage 4	Date 5	Stage 5
Estherville	7.0	4/12/69	17.68	4/10/65	15.61	6/8/53	15.53	6/30/93	15.38	5/10/93	14.36
Humbolt	7.0	4/14/69	15.40	7/13/93	15.22	4/8/65	13.90	4/13/65	13.43	6/18/84	12.50
Fort Dodge	10.0	6/23/47	19.62	6/21/65	19.28	4/8/65	17.79	4/1/93	15.81	7/14/93	15.73
Stratford	14.0	4/2/93	25.68	7/11/93	25.64	6/19/64	24.08	6/5/91	23.31	8/26/79	23.22
S.E.14thSt Des Moines	23.0	7/11/93	34.29	4/10/65	29.72	6/19/84	28.46	7/2/86	28.16	6/7/91	27.00
Tracy	14.0	6/14/47	26.50	6/6/47	25.80	5/31/03	25.00	7/12/93	24.16	4/11/65	23.17
Ottumwa	10.0	7/12/93	22.15	5/31/03	22.00	6/7/47	20.20	6/15/47	20.10	5/24/44	17.50
Keosauqua	25.0	6/1/03	37.85	6/10/05	33.80	7/13/93	32.66	6/14/17	28.70	8/3/15	28.60
St Francisville	18.0	8/19/86	35.03	7/15/93	32.02	3/14/79	30.15	1/19/73	28.22	6/16/47	26.98

2. Stream Data

Stage hydrographs for selected stations along the main stem of the Des Moines River show the period beginning March 1 and ending September 30, 1993. Plate 33 shows the hydrograph for the gage at Fort Dodge, Iowa. The first flooding that occurred at Ft. Dodge began at the end of March. The event lasted for about 1-2 weeks reaching a peak stage of 15.81 feet on April 1. This event was the fourth highest during the period of record. Flooding began again in June and continued throughout July. In August, after the river dropped below flood stage, another storm occurred and for a few days the water levels exceeded the 10 foot flood stage.

The hydrograph for the gage at Stratford, Iowa, is shown on Plate 34. At Stratford, flooding began at the end of March. The flood of record stage was 25.68 feet on April 2. The river remained above flood stage through the end of May except for a short period of time where it fell to about 12 feet. Flood stage is 14 feet. The river rose again in June and remained above flood stage until early August. On July 11, the second highest flood of record (25.64 feet) occurred. For the months of April through September of 1993 the runoff depth near Stratford, Iowa, was 21.9 inches. The mean runoff depth for the months of April through September for the period of record (72 years) was 3.47 inches.

The hydrograph of the S.E. 14th Street gage in Des Moines, Iowa, (Plate 35) shows flood stages beginning in early April and remaining until the middle of May. One month later, the levels again rose above flood stage. The flood of record stage was 34.29 feet on July 11, 1993. The river dropped below the flood stage for most of August, then crested again in late August and remained above flood stage into September for approximately one week.

The hydrograph for the gage at Tracy on the main stem of the Des Moines River is shown on Plate 36. The stage went above the flood level of 13 feet in March and remained there for about two weeks. The river stage remained above flood stage from mid-May through the end of September. The peak stage of 24.16 feet for this event occurred on July 12 and ranked fourth highest for the period of record.

The hydrograph for the Des Moines River at Ottumwa is shown on Plate 37. By mid-May and for most of June the river stages were 1 to 2 feet above flood stage. In July the river rose significantly and on July 12 a new flood of record occurred (22.15 feet). The stage remained well above the 10-foot flood stage through July, August and September.

Plate 38 shows the hydrograph for the Des Moines River at Keosauqua, Iowa. Flooding began at this location in July. July 13, the stage reached 32.66 feet which is the third highest flood of record. Flood stage is 25 feet. For the months of April through September 1993, the runoff depth at Keosauqua, was 20.65. The mean runoff depth for the months of April through September for the period of record (23 years) was 5 inches.

The hydrograph for the St. Francisville, Mo., gage on the Des Moines River is shown on Plate 39. The flood stage of 18 feet was exceeded on numerous occasions from March through September. In July the river stage was consistently above flood stage, and July 15, the peak stage of 32 feet was reached. The flooding continued through the months of August and September.

The operation of the two reservoirs that are located on the Des Moines River and the impact that they had on the flooding are discussed in detail in Sections D and E, Reservoir Regulation. Table 11 summarizes the stage reduction to the stations along the main stem of the Des Moines River. It compares the observed peak stages and discharges to the stages and discharges that would have occurred without the two reservoirs.

3. Hydraulics

Profiles along the main stem of the Des Moines River from the Red Rock Dam to the mouth are shown on Plates 40 and 41 . In addition to the water surface profiles for the 1993 event, the 1947, 1959, 1961, 1962, 1965, 1969 and 1984 profiles are also shown for various reaches of the river. Plate 40 shows that along this reach of the Des Moines River, the 1993 Flood ranked between first and second highest on record. Plate 41 shows that the 1993 event ranked between second and third highest. Plate 42 shows the water surface profile from the Red Rock Dam to the Saylorville Dam. Plates 43 and 44 show the water surface profile from Saylorville to the Stratford gage.

Table 11
Stage Reductions on the Des Moines River
From Operation of Saylorville and Red Rock Dams

	Observed		Reconstituted		
Station	**Stage (feet)**	**Flow (cfs)**	**Stage (feet)**	**Flow (cfs)**	**Reduction (feet)**
2nd Ave	31.5	55,000	34.2	66,000	2.7
SE 14th St	34.3	116,000	34.7	122,000	0.4
Tracy	24.2	109,000	25.5	146,000	1.3
Ottumwa	22.1	112,000	23.9	140,000	1.8
Keosauqua	32.7	111,000	35.4	134,000	2.7
St.Francisville	32.0	120,000	33.1	138,000	1.1

C. Tributary Hydrology

1. Description of Flooding

a. East Fork Des Moines River

The East Fork Des Moines River has its source in Martin County, Minn., and it flows southeasterly for approximately 120 miles and enters the Des Moines River. It has a slope of 2.6 feet per mile. The gaging station on the East Fork Des Moines River is located at Dakota City, Iowa, where the area of the watershed is 1,308 square miles. The 1993 flooding that occurred on the East Fork Des Moines River was the second highest on record. The peak occurred on April 1, 1993, and the maximum stage reached was 23.35 feet. The flood of record occurred on June 21, 1954 and the peak was 24.02 feet. Other notable floods are as follows: 23.13 feet in 1965; 21.71 feet in 1979; and 21.00 feet in 1991. Flood stage is 20.0 feet.

b. Boone River

The Boone River has its source in Hancock County, Iowa, and it flows southwesterly and joins the Des Moines River approximately 24 miles upstream from Boone, Iowa. Its length is about 100 miles, and it drains a watershed with an area of 900 square miles at Webster City, Iowa. The average slope of the Boone River is 3 feet per mile. The 1993 Flood ranked fifth for the Boone River with a river stage of 15.32 feet on April 1. The other events that ranked higher are as follows: 19.1 feet in 1918; 18.55 feet in 1954; 16.0 feet in 1932; and 15.91 feet in 1965. Flood stage at Webster City is 10 feet.

c. Beaver Creek

Beaver Creek is a tributary of the Des Moines River. The gaging station is located at Grimes, Iowa, where the drainage area is 358 square miles. The flood of record for Beaver Creek at Grimes occurred on July 10. The peak river stage reached was 16.58 feet, which is 6.58 feet above flood stage. Plate 45 shows the hydrograph for the period March 1 through September 30 for the gage at Grimes. The other significant events that occurred on this tributary are as follows: 14.73 feet in 1986; 14.69 feet in 1974; 14.05 feet in 1960; and 14.04 feet in 1966.

d. Raccoon River

The Raccoon River basin is in west central Iowa. It covers 3,629 square miles and includes parts of 14 counties. The North Raccoon River flows in a southeasterly direction for almost the length of the basin. It drains almost two-thirds of the Raccoon River basin before entering the Raccoon River at river mile 230. The Raccoon River flows into the Des Moines River in Des Moines at river mile 201. The Middle and South Raccoon Rivers drain nearly one-third of the basin. Table 12 is a summary of the top five floods of record for the Raccoon River basin. Plate 46 shows the hydrograph for the Raccoon River at Van Meter. The flood of record occurred on July 10, 1993 at Van Meter, Iowa, cresting at 26.34 feet, 13.34 feet above flood stage. The Van Meter stream gage recorded a peak flow of 70,200 cfs on July 10. This flow exceeded the previous flood-of-record (79-year period-of-record) of 41,200 cfs. For the months of April through September 1993, the runoff depth at Van Meter, was 17.3 inches. The mean runoff depth for the months of April through September for the period of record (77 years) was 3.8 inches. Plate 47 shows the water surface profile of the Raccoon River from the mouth to river mile 233.

Table 12
Raccoon River Basin Top 5 Floods of Record

Location	Flood Stage (feet)	Date 1	Stage 1	Date 2	Stage 2	Date 3	Stage 3	Date 4	Stage 4	Date 5	Stage 5
N. Raccoon Sac City	N/A	6/17/90	20.14	9/1/62	18.12	3/23/79	18.02	7/11/93	17.55	3/31/93	17.5
North Raccoon Jefferson	10.0	6/23/47	22.3	6/22/54	19.52	3/31/60	19.43	7/10/93	19.20	6/19/90	18.63
Middle Raccoon Bayard	N/A	7/9/93	29.02	6/30/86	24.7	8/14/86	20.24	4/30/84	19.99	7/2/83	19.79
Middle Raccoon Panora	N/A	7/9/93	20.04	6/30/86	15.5	5/19/74	14.80	6/10/53	14.3	7/3/73	13.56
S. Raccoon Redfield	14.0	7/2/58	29.4	7/10/93	26.98	7/1/86	25.15	9/6/58	25.12	6/12/47	24.3
Raccoon Van Meter	13.0	7/10/93	26.34	7/1/86	22.69	7/3/58	21.77	7/4/73	21.74	6/14/47	21.40

The storm that was responsible for the flood of record on the Raccoon River at Bayard, Iowa, and Van Meter and the Middle Raccoon River at Redfield, Iowa, also was responsible for the flooding in the City of Des Moines. The National Weather Service station at Coon Rapids recorded 4 inches of precipitation between 9 p.m. and 11 p.m. on July 8. This exceeds the 100-year rainfall frequency for a two-hour period at this location. From 9 p.m. to 2 a.m., on July 8 and 9, 6.5 inches of rain fell exceeding the 100-year frequency for a six-hour period. Plate 48 shows the total isohyetal map of rainfall for this event.

e. South River

The South River has its source in Clarke County, Iowa, and flows northeasterly to its confluence with the Des Moines River approximately 19.7 miles downstream from Des Moines, Iowa. Its length is approximately 55 miles and it drains an area of about 590 square miles. The average slope of the river is 7.3 feet per mile. The July 6, 1993, peak stage of 30.02 feet ranked fourth for the South River gage at Ackworth, Iowa. Flood stage is 19 feet. The other notable events were as follows 32.85 feet in 1981; 32.68 feet in 1990; 32.00 feet in 1982; and 29.07 feet in 1974.

f. Whitebreast Creek

Whitebreast Creek is located approximately 148.6 miles upstream from the mouth of the Des Moines River. It has a drainage area of 590 square miles. The 1993 Flood ranked third near Dallas, Iowa, with a peak stage of 30.20 feet occurring on July 6. Flood stage is 22.0 feet. Other events that ranked in the top five are as follows: 33.45 feet in 1982; 31.18 feet in 1992; 28.87 feet in 1962; and 26.73 feet in 1982.

g. English Creek

English Creek is located 137 miles upstream from the mouth of the Des Moines River. Its watershed area is 430 square miles. The flood of record occurred on July 5, 1993 with a stage of 27.88 feet at Knoxville, Iowa. The second highest stage was on July 12, 1993 at 24.41 feet. The third highest occurred on August 19, 1993, with a peak of 23.39 feet. The other two notable events were 23.06 feet on July 9, 1993; and 21.78 in 1991.

h. Cedar Creek

Cedar Creek is located 127 miles upstream from the mouth of the Des Moines River. The area of the watershed is 374 square miles at Bussey, Iowa. Of the top five floods of record, the 1993 Flood ranked third. The peak stage reached 28.53 feet on July 5, 1993. Other events of significance were as follows: 34.61 feet in 1982, 33.2 feet in 1982, 28.30 feet in 1981; and 28.2 feet in 1963. Flood stage is 18.0 feet.

D. Reservoir Regulation - Saylorville Reservoir

1. Pre-Flood Conditions

As discussed in detail in Section III, a colder than normal growing season in 1992 followed by a wet fall, led to above normal soil moisture conditions at the onset of winter. Subsequently, a cold cloudy winter which limited early snowmelt, created conditions which increased the potential for spring flooding. That potential was realized in late March, when rainfall, combined with rapid snowmelt, produced widespread flooding across the State of Iowa. The Des Moines River basin above Saylorville Lake was no exception. March 26 marked the last day the lake level was at the normal conservation pool, elevation 836.0-836.5 feet NGVD.

2. Reservoir Operation

a. March / April / May

Inflows steadily increased throughout the remainder of March and into early April with a peak average daily inflow of 45,700 cfs being recorded on April 3. Inflow-outflow-pool elevation hydrographs for the months of March through September are shown on Plates 49 through 55. In accordance with Schedule A of the reservoir regulation plan, Table 14, reservoir releases were held below 13,000 cfs to prevent exceeding the downstream control stage of 23 feet at S.E. 14th Street in the City of Des Moines. High discharges on the Raccoon River, which flows into the Des Moines River above S.E. 14th Street, were the major factors responsible for limiting releases. By April 5, the pool had climbed to elevation 875.0 feet. At this level, reservoir operation is guided by Schedule B of the regulation plan shown on Table 14. This schedule of the regulation plan calls for downstream constraints to be relaxed as dam safety becomes a consideration.

Consequently, reservoir outflows were increased to 16,000 cfs. However, reservoir inflows continued to exceed outflows. April 21, the reservoir had risen to elevation 880.4 feet as inflow to the reservoir approached 30,000 cfs. Pool forecasts indicated that the pool would exceed elevation 884.0 feet, the crest of the emergency spillway. Therefore, outflows were increased to 21,000 cfs. Nevertheless, April 23, water began flowing over the emergency spillway peaking four days later April 27 at elevation 886.16 feet. Reservoir releases continued to be maintained at 21,000 cfs until May 16 when the reservoir fell below elevation 875.0 feet, signaling a return to normal flood control operation and a gradual reduction in reservoir releases to 12,000 cfs by the end of the month.

b. June

By June 3, Saylorville Reservoir had fallen below elevation 866 feet as relatively little precipitation occurred during May. However, the return of rainy weather combined with wet antecedent soil conditions and above normal base flows, once again increased reservoir inflows. June 17, water flowed over the emergency spillway for the second time in 1993. The peak inflow for the month of 35,900 cfs occurred June 18. Releases were again increased to 21,000 cfs and were maintained at that level until the reservoir climbed to elevation 889.0 feet June 21. At that time, releases were adjusted as directed by Schedule C, shown on Table 14. This schedule of the regulation plan takes effect when inflow forecasts indicate that the remaining storage capacity in the reservoir will be exceeded. Upon reaching elevation 889.0 feet, reservoir releases are increased so that at full flood control pool, elevation 890.0 feet, the conduit is fully open. As a result, releases were increased to a maximum discharge of 28,500 cfs, causing the reservoir to peak at elevation 889.35 feet at noon June 21. Subsequently, discharges gradually receded to 21,000 cfs as the pool fell below 889.0 feet.

c. July

On June 30, slow moving storms once again produced widespread rainfall averaging 1 to 2 inches over the Des Moines River Basin above Saylorville. With the pool already between elevation 887 feet and 888 feet, inflow forecasts indicated that the pool would exceed elevation 890.0 feet. Accordingly, releases were again increased in compliance with Schedule C in order to hold the pool below elevation 890.0 feet. The pool reached elevation 889.46 feet on July 5. Combined conduit and spillway discharge totaled 31,400 cfs. During the next few days, the pool fell slowly as reservoir outflows exceeded inflows. Outflows tapered off slowly as well, until July 9, when 3 to 4 inches of rain covered a broad area above the reservoir. By midnight on July 9, the reservoir had exceeded elevation 890.0 feet. Reservoir releases were increased from 34,500 cfs to 37,900 cfs. No further increases in discharge were made in order to minimize flood damage in the City of Des Moines.

However, by 6 a.m. on July 11, the total discharge from the reservoir had climbed to 39,200 cfs due to increased head on the spillway. Earlier, that same morning, the levee protecting the Des Moines Waterworks was overtopped as the Raccoon River reached record levels. In order to aid flood fighting efforts in Des Moines at S.E. 6th Street and at the abandoned IPALCO power plant federal levee T-wall, at 11 a.m. discharges from Saylorville were decreased to 34,800 cfs, a reduction of 4,400 cfs.

Over the next few days, a constant discharge of 11,500 cfs through the conduit was maintained as flow over the spillway increased as the pool rose. On July 13, the pool climbed to a peak elevation of 892.03 feet, 107.6 percent of flood control capacity. The corresponding outflow from the reservoir was 43,500 cfs, while inflow was at 47,100 cfs.

Following the peak, discharges slowly decreased as the pool fell. As the Raccoon River receded, reservoir releases were gradually increased in order to reduce pool levels without causing additional flooding downstream. A peak outflow of 44,500 cfs was recorded on July 18. By July 22, the falling pool had caused a significant reduction in spillway discharges. In order to maintain outflows and keep the pool falling, the sluice gates of the conduit were set at their maximum opening. The reservoir fell below the emergency spillway crest at midnight on July 29. Outflow was recorded at 21,700 cfs. The reservoir continued to be operated with the conduit completely open throughout the remainder of July and into early August, when outflows were reduced to slow the rate of fall in the pool to reduce the potential for bank sloughing in the reservoir.

d. August / September

For the remainder of August and September, the reservoir was operated with a goal of lowering the pool to the conservation level as soon as possible while limiting the decrease in pool elevation to less than two feet per day to minimize bank erosion. In order to achieve that goal, reservoir outflows had to be maintained near 16,000 cfs for a good portion of the month of September as inflows remained high. Outflows from the reservoir during September ranged from a peak of 16,700 cfs in early September to below 10,000 cfs on September 30. Finally, on October 8, the reservoir returned to the fall conservation level of 838.5 feet. Table 13 summarizes the significant events that occurred at Saylorville Lake during the Flood of 1993.

Table 13
Significant Events During 1993 Flood Regulation at Saylorville Lake

Date	Pool Elevation	Remarks
April 23-30	886.2 feet	Water over spillway
June 3	865.7 feet	Receded after spring flood
July 9	890.0 feet	Exceeded full flood pool
July 11	891.2 feet	Followed plan until July 11
July 13	892.0 feet	Adjusted releases to control for 28.0 feet, 2nd Ave gage
July 18	891.6 feet	Max. release 44,500 cfs
July 22	889.8 feet	Conduit fully open
July 29	884.0 feet	Lake level below spillway
August 2	880.7 feet	Back on regulation plan

Table 14
Saylorville Reservoir
Regulation Plan

Regulation	Reservoir	Condition	Operation
A. Normal Flood Control Operation–pool elevation between 836 - 875 feet NGVD (Max. daily change of outflow is 3,000 cfs.)	Steady or rising or falling	I - 16 Dec thru 20 Apr	Maintain permanent pool level 836 feet NGVD (except as described in para 7.03 of this regulation manual) by releasing inflow up to 16,000 cfs limited by conduit capacity and balance the storage in accord with Lake Red Rock, releasing not less than 2,000 cfs, except as limited by A-II.
		II - 16 Dec thru 20 Apr– discharge at S.E. 14th Street in Des Moines above or forecasted to exceed 30,000 cfs (stage of 23 feet.)	Release not less than 2,000 cfs to control flow at S.E. 14th Street insofar as possible below 30,000 cfs, and balance the storage in accord with Lake Red Rock, if Saylorville Pool level is below 860.0 feet NGVD.
		III - 21 Apr thru 15 Dec	Maintain permanent pool level 836 feet NGVD (except as described in para 7.03 of this regulation manual) by releasing inflow up to 12,000 cfs and balance the storage in accord with Lake Red Rock, if pool level is below 860.0 feet NGVD releasing not less than 2,000 cfs , except as limited by A-IV.
		IV - 21 Apr thru 15 Dec – discharge at S.E. 14th Street in Des Moines above or forecasted to exceed 30,000 cfs (stage of 23 feet.)	Release not less than 2,000 cfs to control flow at SE 14th Street insofar as possible below 30,000 cfs, and balance the storage in accord with Lake Red Rock, if Saylorville Pool level is below 860.0 feet NGVD.
		V - Any date, if Beaver Creek flow is above or forecasted to exceed 10,000 cfs.	Release inflow up to a minimum of 2,000 cfs.

Table 14
Saylorville Reservoir
Regulation Plan
(continued)

Regulation	Reservoir	Condition	Operation
B. Intermediate Magnitude Flood Operation	Rising	I - Any date, reservoir is rising and forecasted to exceed 875 feet NGVD.	When predictions indicate that anticipated runoff will product a peak reservoir elevation between 875 feet and 884 feet NGVD. If operated under Schedule A, the schedule listed below will be adapted with the purpose of minimizing releases. 21 Apr - 15 Dec / 16 Dec - 20 Apr Pool Elev / Outflow / Outflow 875 / 12,000 / 876 / 12,000 - 13,000 / 16,000 877 / 12,000 - 14,000 / 16,000 878 / 12,000 - 15,000 / 16,000 879 / 12,000 - 16,000 / 16,000 880 / 12,000 - 17,000 / 16,000 - 17,000 881 / 12,000 - 18,000 / 16,000 - 18,000 882 / 12,000 - 19,000 / 16,000 - 19,000 883 / 12,000 - 20,000 / 16,000 - 20,000 884 / 12,000 - 21,000 / 16,000 - 21,000 Schedule C will be adopted when predictions indicate runoff will cause pool elevation to exceed elevation 884 NGVD when operated under the above schedule.
	Falling	II - Any date after reservoir elevation has peaked and pool elevation is between 884 feet and 875 feet NGVD.	Hold outflow to maximum rate reached in Schedule B-I above until elevation 875 NGVD is reached; then follow Schedule A.

Table 14
Saylorville Reservoir
Regulation Plan
(continued)

Regulation	Reservoir	Condition	Operation
C. Large Magnitude Flood Operation	Rising	I - Any date, reservoir elevation is rising and above or forecasted to exceed elevation 875 feet m.s.l.	When predictions indicate that anticipated runoff from a storm or snowmelt will appreciably exceed the storage capacity remaining in the reservoir, when operated under Schedule A or Schedule B, release rates will be made in accordance with the following schedule:

21 Apr - 15 Dec Pool Elev ft, N.G.V.D.	21 Apr - 15 Dec Outflow cfs	16 Dec - 20 Apr Outflow cfs
875	12,000	16,000
876	13,000	16,000
877	14,000	16,000
878	15,000	16,000
879	16,000	16,000
880	17,000	17,000
881	18,000	18,000
882	19,000	19,000
883	20,000	20,000
884	21,000	21,000

Above 884 feet m.s.l., gradually close the conduit to release combined spillway and conduit flow of 21,000 cfs up to elevation 889 feet m.s.l.

Above 889 feet m.s.l., open the conduit gates gradually to achieve fully open condition at pool elevation of 890 feet m.s.l., corresponding to a flow of 42,000 cfs.

Allow the pool to rise with uncontrolled spillway and conduit discharge above 890 feet m.s.l.

Regulation	Reservoir	Condition	Operation
	Falling	II - Any date after reservoir elevation has crested and pool elevation is above 890 feet m.s.l.	Maintain maximum conduit and spillway flow.

Table 14
Saylorville Reservoir
Regulation Plan
(continued)

Regulation	Reservoir	Condition	Operation
		III - Any date after reservoir elevation has crested and pool elevation is between 889 feet NGVD and 890 feet NGVD.	Reduce combined spillway and conduit discharge from 42,000 cfs at elevation 890 feet NGVD to 21,000 cfs at elevation 889 feet NGVD, by operation of conduit gates, releasing not less than the estimated inflow to the reservoir.
	Steady, rising or falling	IV - Any date after reservoir elevation has crested and pool elevation is between 889 feet NGVD and 875 feet NGVD.	Maintain a flow of 21,000 cfs until elevation 884 feet NGVD is reached, then maintain full conduit flow until elevation 875 feet NGVD is reached, then follow Regulation Schedule A.
D. Drought Regulation for Water Supply and Water Quality	Any date reservoir elevation is below elevation 836.0 feet NGVD.	Pool above elevation 827	Release all water supply and water quality demands
		Pool is between elevation 827.0 and 826.0	Release 100 percent of water supply, maintain 175 cfs at dam, and 245 at S.E. 14th street
		Pool is between elevation 826.0 and 825.0	Release 100 percent of water supply, maintain 150 cfs at dam, and 220 at S.E. 14th street
		Pool is between elevation 825.0 and 824.0	Release 100 percent of water supply, maintain 125 cfs at dam, and 195 at S.E. 14th street
		Pool is between elevation 824.0 and 823.5	Release 100 percent of water supply, maintain 100 cfs at dam, and 170 at S.E. 14th street
		Pool is between elevation 823.5 and 819.0	Release 100 percent of water supply; no water quality releases made
		Pool is between elevation 819.0 and 816.0	Release 75 percent of water supply; no water quality releases made
		Pool is below elevation 816.0	Release 50 percent of water supply; no water quality releases made

3. Runoff vs. Storage Volume

A comparison of runoff into Saylorville Lake versus the volume of runoff that was stored or evacuated in a given month is given in Table 15. At full flood control pool elevation 890.0 feet, the reservoir has the capacity to store 1.89 inches of runoff. For the period March 1 through September 30, runoff to Saylorville Lake totaled 23.90 inches. This is 11 times the storage capacity available at full flood control pool and more than six times the normal cumulative inflow of 3.88 inches of runoff. As one can see, the Flood of 1993 was the result of successive events which occurred over a period of months. The one-day peak inflow had a frequency of once in 20 years (5 percent) while the 30- and 90-day peak inflows approached once in 140 years (0.7 percent), and the 120-day peak inflow was a 200 year (0.5 percent) event.

Table 15
Saylorville Reservoir
Runoff vs. Storage Utilized in Inches

Date	Total Runoff	Storage Utilized	Incremental Change in Storage
March 31, 1993	1.28	0.36	+0.35
April 30,1993	4.60	1.56	+1.20
May 31, 1993	2.80	0.80	-0.76
June 30, 1993	4.25	1.78	+0.98
July 31, 1993	6.37	1.46	-0.32
August 31, 1993	2.99	1.22	-0.24
September 30,1993	1.58	0.17	-1.05

4. Sedimentation

The most recent sediment surveys that were used to determine reservoir storage at Saylorville Reservoir were conducted in 1983-84. The 1993 Flood impact to reservoir storage cannot be determined at this time.

5. Problems and Lessons Learned

Discrepancies between tailwater discharge estimates and combined conduit-spillway discharges at Saylorville Lake, were noted during the 1993 Flood. In some instances, discharge measurements gathered at the tailwater gage loacted downstream of Saylorville Dam at Fisher Bridge varied significantly from combined spillway-conduit discharges determined from stage-discharge ratings. The discrepancy most likely is explained by difficulties encountered when measuring discharge at the tailwater gage. Flow over the road and through road culverts made accuracy difficult, if not impossible, to achieve. This discrepancy presented an obvious complication to reservoir operation. Ratings of outflow structures should be more stable than tailwater discharge estimates. In the future it may be advantageous to base reservoir discharge computations on flow through the gates and over the spillway.This could be achieved by installing instrumentation on the sluice gate so that gates settings as well as pool elevations would be available for satellite transmission to the District Water Control Center allowing consistent computation of reservoir outflows.

Another problem which occurred during the flooding in July, involved communication between the Corps of Engineers (COE), the National Weather Service (NWS), the City of Des Moines and the Des Moines Waterworks. Although reservoir operation prevented catastrophic damage along the Des Moines River in the City of Des Moines, concerns have been raised about the effectiveness of the transmission of Raccoon River forecasts to waterworks personnel who were unaware of the seriousness of the situation. Due to the magnitude of the event and the corresponding rapid increase in flows on the Raccoon River, it is unlikely that earlier warning of the approaching flood would have prevented the levee at the Waterworks from overtopping. Measures have been taken to provide for better communication in the future between the Corps, the NWS, the city and public facilities located in the floodplain. Additionally, the Des Moines Waterworks has upgraded levee protection at the Waterworks and is considering the possibly of building a second water treatment facility at another location in the city.

E. Reservoir Regulation - Lake Red Rock

1. Pre-Flood Condition

Pre-flood conditions above Lake Red Rock were much like those in the upper Des Moines River basin above Saylorville Lake. However, snowmelt runoff began to occur in early March. The meteorology Section III of this report gives a detailed analysis of those conditions.

2. Reservoir Operation

a. March

Increasing inflow to the reservoir caused the pool to rise to a peak elevation of 751.3 feet on March 10. As indicated in Schedule A of the Red Rock Reservoir Regulation Plan, Table 17, releases are permitted to be increased to a maximum of 30,000 cfs when the pool rises above elevation 750 feet provided downstream constraints are not violated. Accordingly, the release was increased to 28,000 cfs the following day which caused the pool to begin to recede. Outflows were gradually reduced to match inflows as the pool fell. By March 25, the pool was again at the normal conservation level, elevation 742.0 feet. Inflow-outflow-pool elevation hydrographs for the months of March through September are shown on Plates 56 through 62.

b. April

The pool remained near the conservation level until March 31 when 1.5 inches of rain fell at the reservoir. Inflow increased to 47,400 cfs. But, releases had to be reduced from 26,000 cfs to 18,000 cfs to offset high flows on Cedar Creek at Bussey. The rise in flow on Cedar Creek had caused the Des Moines River at Ottumwa and Keosauqua to climb above the respective stage constraints of 10.8 feet and 19.6 feet for non-growing season operation. This reduction in release achieved the intended objective and reduced those stages. However, inflows remained near

30,000 cfs throughout the month of April causing the pool to steadily rise. Yet, early in April, releases again had to be reduced as the Mississippi River was forecast to exceed a stage of 20 feet at Quincy, Ill. When this occurs, Schedule A directs releases to be reduced to not less than 5,000 cfs with the intention of holding the Mississippi River stage at Quincy, Ill., below 20 feet. April 6, the release was reduced to 5,000 cfs and held at that flow for two days before being increased to 15,000 cfs. This increase is triggered when the pool reaches elevation 757.0 feet. Reservoir releases were held at 15,000 cfs until April 12 when the release was increased to 25,000 cfs. Releases were held between 25,000 and 27,000 cfs for the remainder of the month, with the exception of April 21-23. April 21 between 1 and 2 inches of rain fell below the reservoir, causing the river to rise above control stages at Ottumwa and Keosauqua. From the April 21-23, outflows were maintained at 20,000 cfs. April 30, the pool reached elevation 767.00 feet, the peak for the month of April.

c. May

Inflows continued to rise in the month of May due to high releases from Saylorville Lake and rainfall affecting tributary streams which flow into the reservoir. May 1 growing season constraints take effect at Ottumwa and Keosauqua, downstream of Red Rock. Accordingly, releases were reduced from 25,000 cfs to 22,000 cfs to comply with growing season operation requirements. Normally, releases would be reduced to 18,000 cfs. However, when the pool is above elevation 760 feet, outflows are maintained at 22,000 cfs. May 7 more than an inch of rain fell, both above and below the reservoir. Inflow increased to 55,700 cfs, the peak for May. Outflows, however, were further reduced to 19,000 cfs to relieve flooding downstream. But, May 9 forecasts indicated that the reservoir would exceed elevation 775 feet as inflows remained above 40,000 cfs. Subsequently, outflows were increased. By noon May 11, the pool rose above 775 feet, and the release was increased to 30,000 cfs. Releases were held near 30,000 cfs for the remainder of the month. The pool reached a peak elevation of 777.35 feet on May 16, but had gradually receded to 774.85 feet by midnight May 31.

d. June

Although releases from Saylorville Lake kept inflow to Lake Red Rock above average during June, relatively little rainfall occurred early in the month. Therefore, the pool receded slowly, falling to 773.27 feet by June 13. As the pool fell, outflow was also reduced reaching a low of 22,000 cfs. However, June 19, 2.54 inches of rain were recorded at the dam and rainfall amounts of 1 to 2 inches were common throughout the basin. This resulted in outflows being increased to 30,000 cfs by June 21 as the pool rose above elevation 775.0 feet. The pool continued to climb and reached elevation 778.68 feet at midnight June 30.

e. July

Releases were held at 30,000 cfs until July 1, when at 1 p.m., all of the sluice gates controlling the low level conduits were closed because the gated spillway would have to be utilized to pass outflow from the dam as the capacity of the conduits are limited to 38,000 cfs. At this time, outflow was increased to 35,000 cfs. At 4 p.m. another gate opening was made to increase outflow to 40,000 cfs. This increase was in compliance with Schedule B of the regulation plan, Large Magnitude Flood Operation. This schedule of the regulation plan takes effect anytime forecasts indicate that the remaining storage capacity in the reservoir will be exceeded if operated under Schedule A. Under Schedule B, downstream constraints no longer apply as dam safety becomes the primary concern. The following day, outflows were increased further to 45,000 cfs as the pool had risen above elevation 779 feet. Releases were held near 45,000 cfs until July 5.

July 5, 3.57 inches of rain fell at the reservoir, with many locations above and below the reservoir receiving more than 2 inches. Inflow to the reservoir increased from a daily average of 51,800 cfs, to 100,400 cfs. By midnight July 5, the outflow had been increased to 65,000 cfs as the pool climbed to elevation 780.89 feet. The inflow remained above 100,000 cfs the following day as another 1 to 2 inches of rain fell above the reservoir. July 7, the outflow was increased to 70,000 cfs. Rain continued to fall almost daily, keeping inflow high. As the pool rose, outflow from the dam continued to be increased. However, releases were below those prescribed in the regulation plan to aid floodfighting efforts in downstream communities.

A peak inflow of 134,900 cfs occurred July 11. By 6 p.m. that evening the pool had risen to elevation 782.08 feet. At 7 p.m., the release from the dam was increased to 100,000 cfs, still well below the release called for in the regulation plan. According to the plan, the outflow should be increased to 130,000 cfs when the pool reaches elevation 782 feet. However, levees downstream protecting the Ottumwa Waterworks plant and the City of Eddyville were saturated and were in danger of being breached or overtopped.

The pool climbed to a peak elevation of 782.68 feet at 6 a.m. July 13. At this elevation the reservoir is at 112 percent of flood control capacity. Although no further gate openings were made, the release from the reservoir peaked at 104,500 cfs as a result of increased head on the spillway. Consequently, the gates of the spillway were maintained at the same openings letting outflow recede naturally as the pool fell until July 19 when the pool reached 780 feet. From July 19 - July 22, several gate closures were made which gradually reduced the outflow from 102,000 cfs to 87,000 cfs.

On the afternoon of July 22, the District Water Control Section was notified by the Lake Red Rock Project Manager that several steel cables used to lift the tainter gates had broken on gates number 1 and 5, the outside gates. Upon conferring with structural engineers in Design Branch, it was decided that those two gates should be closed completely to relieve tension on the remaining cables. At 4 p.m., gates 1 and 5 were completely closed and settings on gates 2, 3 and 4 were adjusted to pass the same flow that had been released prior to the incident. After further consultation with the structural engineers the following day, it was decided that gates 2 and 4 should each be set to their maximum opening of 45 feet and that gate number 3 should be closed off entirely in addition to gates 1 and 5. The reasoning behind this decision was to have an extra gate in reserve, in case an emergency increase in release was required or cables failed on gates 2 or 4. Further cable failures were unlikely as an emergency construction contract was let to install dawgs on gates 2 and 4 which would carry the gate load, thus eliminating tension on the cables. Therefore, July 28 a second deviation from the regulation plan was requested. This deviation would allow the pool to be drawn down 10 feet below the normal conservation pool level to elevation 732 feet allowing contractors to safely replace the damaged tainter gate cables. The deviation also allowed downstream constraints at Ottumwa and Keosauqua, Iowa and Quincy, Ill., to be violated in order expedite drawing the pool down and avoid moving the altered gates. Approval was received July 30.

f. August / September / October

For the remainder of July and until August 11, no gate changes were made. Gates 2 and 4 were kept at their maximum opening of 45 feet. However, outflows continued to decline as the pool receded, reducing head on the spillway. By 6 a.m. August 11 the pool had fallen to 761.28 feet. Outflow at that elevation was 40,200 cfs. In order to keep the pool falling, operation of the conduits was reinstituted in addition to the spillway tainter gates. As the pool continued to fall, sluice gate openings on the conduit were gradually increased to offset the reduction in outflow due to the decrease in head on the spillway. September 14 the tainter gates on the spillway were completely closed and flow was released exclusively through the conduits. By this time the pool had fallen to elevation 746 feet and the outflow was 30,000 cfs with the sluice gates of the conduits set at their maximum opening. As the pool neared the target elevation of 732.0 feet, outflows were gradually reduced. October 11 the pool reached elevation 732.46 feet with a corresponding outflow of 13,300 cfs. Table 16 summarizes the significant events that occurred at Red Rock Reservoir.

Table 16
Significant Events During 1993 Flood Regulation at Red Rock Reservoir

Date	Pool	Remarks
July 5	780.9 feet	Operated on plan until 7/5. Outflow at 65,000 cfs. Heavy rain over Des Moines Basin.
July 6	781.1 feet	Major flood fight downstream (Eddyville and Ottumwa) raise levee heights and save Water Treatment Plant.
July 11	782.3 feet	Maximum inflow 134,900 cfs
July 13	782.7 feet	Reservoir crested. Outflow raised to 104,500 cfs.
July 18-22	778.2 feet	Failed cables discovered. Three tainter gates closed / two fully opened. All sluice gates closed.

Table 17
Red Rock Reservoir Regulation Plan

Regulation Schedule	Reservoir Stage	Condition	Operation
A. Normal Flood Control Operation	Rising	I. 16 December thru 01 May	Maintain permanent pool level 734 by releasing inflow up to 22,000 cfs then, permit pool level to rise with uncontrolled outlet discharge until elevation 750 is reached (corresponds to uncontrolled outlet discharge of 30,000 cfs) then continue to release 30,000 cfs as pool continues to rise, except as limited by Conditions A-II , and Schedule B.
	Rising	II. 16 December thru 1 May. Stage at Ottumwa or Keosauqua above or forecasted to exceed 10.8 feet and 19.6 feet, respectively.	Release not less than 5,000 cfs to control flow to those discharges at respective stations insofar as possible except as limited by Schedule B.
	Falling steady or rising.	III. 1 May thru 15 December. Reservoir at or above permanent pool elevation 734 (736; 15 Sep - 15 Dec), but lower than elevation 775.	Release 18,000 cfs until reservoir recedes to permanent pool level, after which it shall be held at that level insofar as possible without exceeding release of 18,000 cfs (22,000 if pool above 760) except as limited by Conditions A-IV, and Schedule B.
	Rising	IV. 1 May thru 15 December. Stage at Ottumwa or Keosauqua above or forecasted to exceed 7.5 feet (8.7 feet if pool higher than 760) or 17.6 feet (18.4 feet if pool higher than 760) respectively including release in condition A-III.	Release not less than 5,000 cfs to control flow to those discharges at respective stations insofar as possible except as limited by Schedule B.
		V. Any date, stage at, above or forecasted to exceed 18.5 feet on Mississippi River gage at Burlington, Iowa, or, 20.0 feet on Mississippi River gage at Quincy, Illinois.	During period corresponding to time Mississippi River is above forecast stages provided reservoir inflow is greater than 5,000 cfs, release not less than 5,000 cfs until reservoir elevation 757.0 is reached; then provided (a) reservoir inflow is greater than 15,000 cfs release not less than 15,000 cfs until reservoir elevation 765.0 is reached or (b) if reservoir inflow is between 5,000 cfs and 15,000 cfs release the inflow; then, if the operation (a) was followed and at elevation 765.0, provided (c) reservoir inflow is greater than 25,000 cfs until reservoir elevation 775 is reached, or (d) if reservoir inflow is between 15,000 cfs and 25,000 cfs release the inflow; then if the operation (c) was followed release not less than 30,000 cfs, except as limited by Schedule B.

Table 17 (continued)

Regulation	Schedule	Condition	Operation
B. Large Magnitude Flood Operation	Rising, Falling	Any date, reservoir elevation is above or forecasted to exceed elevation 775.0	When predictions indicate that anticipate runoff from a storm will appreciably exceed the storage capacity remaining in the reservoir when operated under Schedule A, release rates will be made in accordance with the following schedule: Pool Elev. Outflow cfs 775 30,000 776 35,000 777 40,000 778 45,000 779 50,000 780 60,000 780.5 80,000 781 100,000 781.5 115,000 782 130,000 783 130,000 784 130,000 785 130,000 785 Open spillway tainter gates as necessary to maintain reservoir elevation 785 until uncontrolled spillway and outlet conduit discharge prevails, then allow reservoir to continue risin with uncontrolled spillway & outlet conduit discharge.
C. Drought Regulation for Water Quality	Any date reservoir is below elevation 734.0 feet NGVD.	Pool above elevation 727.0	Release 300 cfs.
		Pool between elevation 726.0 and 727.0	Release 290 cfs.
		Pool between elevation 725.0 and 726.0	Release 275 cfs.
		Pool between elevation 724.0 and 725.0	Release 250 cfs.
		Pool between elevation 723.0 and 724.0	Release 225 cfs.
		Pool between elevation 722.0 and 723.0	Release 200 cfs.
		Pool between elevation 718.0 and 722.0	Release 175 cfs.
		Pool between elevation 713.0 and 718.0	Release 150 cfs.
		Pool below elevation 713.0 feet.	Release 100 cfs.
D. Flash Flood Operation	Rising, Steady or Falling	1 April thru 30 Oct. Reservoir elevation at or below 757.0 and flows at Ottumwa at, above or forecasted to exceed 30,000 cfs.	Release no less than 500 cfs to control flows at Ottumwa insofar as possible for a maximum period of 48 hours.

3. Runoff vs. Storage Volume

As in the case of Saylorville Lake, the Flood of 1993 resulted from a series of storm events which occurred over a period of months. However, short intervals between storms allowed little time to evacuate stored runoff. At full flood control pool, elevation 780 feet, the reservoir has the capacity to store 2.26 inches of runoff. Table 18 compares runoff into Lake Red Rock with the volume of runoff that was stored or evacuated in a given month. For the period of March 1 to September 30, runoff into Lake Red Rock totaled 22.38 inches. This is nearly ten times the storage capacity available at full flood control pool and more than five times the normal cumulative runoff of 4.3 inches for this period. The 10 and 30-day peak inflows for 1993 had an estimated frequency of once in 1,000 years (0.1 percent chance exceedance).

Table 18
Lake Red Rock
Runoff vs. Storage Utilized in Inches

Date	Total Runoff	Storage Utilized	Incremental Change in Storage
March 31, 1993	1.20	0.13	+0.13
April 30,1993	2.88	1.18	+1.05
May 31, 1993	3.16	1.76	+0.58
June 30, 1993	2.83	2.14	+0.38
July 31, 1993	6.70	1.46	-0.68
August 31, 1993	3.21	0.49	-0.97
September 30,1993	2.40	0.00	-0.49

4. Sedimentation

The most recent sediment surveys that were used to determine reservoir storage at Lake Red Rock were conducted in 1983-84. The impact of the 1993 Flood on reservoir storage cannot be determined at this time.

5. Problems and Lessons Learned

As in the case of Saylorville Lake, when outflows exceeded any previously observed, discrepancies between discharge derived from theoretical stage-discharge ratings and tailwater ratings were noted. Because discharge measurements conducted at the tailwater were inconsistent with measurements downstream at Tracy, Iowa, the outflows computed from the structural spillway rating were determined to be the most accurate and consistent. This discrepancy initially caused some confusion as inconsistent data was released to the public. However, once it was determined that the stage-discharge rating curve would be used for discharge computations, the problem was alleviated. From a public relations standpoint, no significant problems occurred. The deviation which allowed constraints at Ottumwa and Keosauqua to be violated so that the pool could be drawn down to allow replacement of the tainter gate cables was well coordinated with the public, state and local agencies. Likewise, good communication between field and water control personnel proved beneficial to flood fighting efforts and prevented levee failures in the Cities of Ottumwa and Eddyville.