APPENDIX F

Big Sioux aquifer recharge study at Sioux Falls *

* This appendix contains the entire text but does not contain the appendices.

FINAL REPORT

BIG SIOUX AQUIFER RECHARGE STUDY AT SIOUX FALLS

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INTRODUCTION

Scope of This Report -- This report is not inteneded to be a detailed treatise on aquifer recharge. Instead, it is an effort by the chairman of a multi-agency task force, created in 1977, to make a pilot aquifer recharge study, to document the group's efforts, and to summarize the conclusions drawn from this experience.

Basis for Study -- On June 22, 1977, a Citizens Water Advisory Committee appointed earlier by the Sioux Falls City Commission submitted a written report to the Commissioners.[1] The Committee's first short-term recommendation was that, "Immediate steps be taken by the city to initiate programs of annual recharge of the aquifer." The Committee further recommended that additional study be made to determine the most effective means of recharging the Big Sioux Aquifer.[2]

On June 10, 1977, John Velehradsky, Chief - Planning Division, Omaha District - Corps of Engineers (Corps), wrote to the East Dakota Conservancy Sub-District (EDCSD), U.S. Geological Survey (USGS), and City of Sioux Falls (C-SF) noting that the Corps was evaluating alternative sources of supplemental water supply for Sioux Falls as part of the Corps' Upper Big Sioux River and Eastern South Dakota Water Supply Study.[3] He proposed a multi-agency evaluation of artificial recharge and offered $5000 of Corps' funds to initiate the effort.

Representatives of the Corps, USGS, South Dakota Geological Survey (SDGS), and C-SF met with the EDCSD Board of Directors on July 21, 1977 and decided to jointly pursue a well-planned research program to evaluate the possibility of recharge of the Big Sioux River Aquifer north of Sioux Falls.[4]

These actions were taken because artificial recharge had been a popular concept in most discussions of alternatives for Sioux Falls' future water supply. In addition, the Sioux Falls Water Advisory Committee had hired Ed Lacey, a well driller/inventor from Trent, South Dakota, to run some preliminary recharge tests. The Committee felt that these test results warranted more intensive evaluation using pilot tests in a section of the city's wellfield.

Formation of Task Force and Pilot Study Proposal -- Initial task force participants were Carter Laing, Corps; Jerry Siegel and Wendell Wischer, EDCSD; John Powell and Ed LeReux, USGS; Merlin Tipton and Assad Barari, SDGS; Les Hash, Tom Molohan and Vern Winegarden, C-SF; and Gerald Moore, EROS Data Center.

It should be noted that Rick Miner, Paul Ziemba and Alan Johnson were later Corps participants as were Neil Koch and John Little with the USGS. In addition, John Wiersma, James Dornbush and Walter Hu, Engineering Professors at South Dakota State University, provided input. John Madden, DeWild Grant Reckert and Assoc. (DGR), as consultant to C-SF, assisted the task force with various technical aspects of the project.

All committee meetings were held at the Water Purification Plant in Sioux Falls. A brief summary of actions of the task force in planning and trying to implement the study follows.

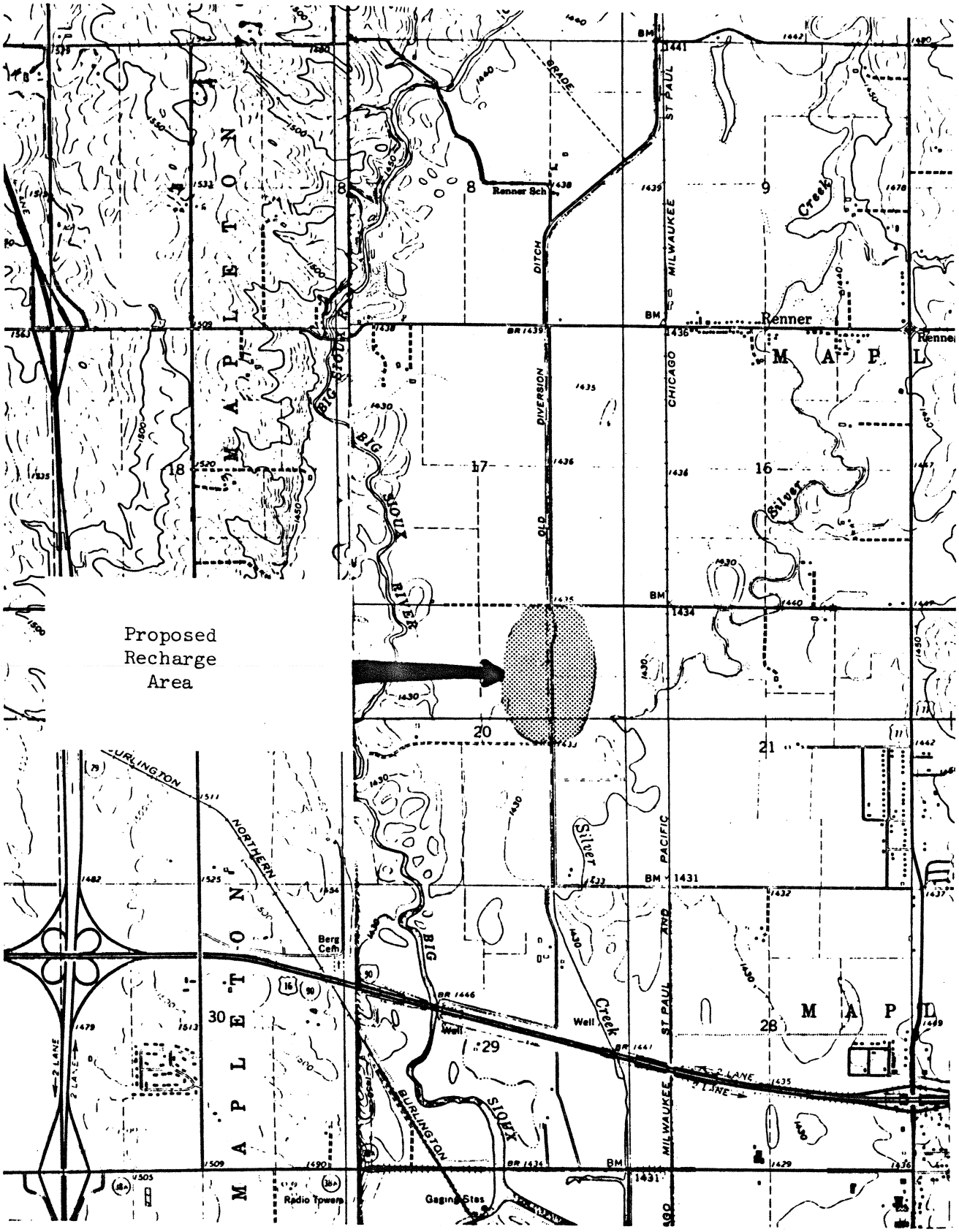
At the initial meeting, on August 4, 1977, Jerry Siegel was appointed task force chairman. Three possible pilot recharge sites in the Sioux Falls area were evaluated using maps and field inspections. A section of a drainage channel north of the city between the Big Sioux River and Silver Creek was tentatively selected as the best site. The task force decided to secure the following information: (1) maps showing location and capacity of all city wells; (2) the location of all existing observation wells; (3) sediment data from the Dell Rapids gauging station; (4) a detailed bibliography on past aquifer recharge efforts in the United States; and (5) a copy of the Silver Creek Watershed Improvement Plan.

At the second meeting, on September 1, a number of articles on artificial recharge were reviewed and the general concept of diverting Big Sioux River water via pipeline as the source of recharge was developed. The task force decided to ask the Sioux Falls Water Advisory Committee and two townships to participate in the task force, if they desired.

At an October 4 meeting, the task force learned from John Hatch, S.D. Division of Water Rights, that a temporary water permit was needed to run the proposed pilot recharge tests. In addition, the permit to divert Big Sioux River flows for the proposed Slip-Up Creek Project would be senior to any artificial recharge permit.

On October 27, Les Hash reported that water levels in their older wells in the airport area had risen six to eight feet recently when water began flowing again in the Big Sioux River. A rough cost estimate of $23,500 was made to install and operate a four-cell recharge system. A final site location was made along 160 acres owned by the C-SF in the NE½ of Section 20 (see Figure 1). Carter Laing was authorized to finalize a proposal for submission to the Corps' Missouri River Division Office in Omaha with a request for $15,000 of Corps' funding. By late December, the task force received word that the Corps had tentatively approved a $15,000 grant.[5]

Figure 1. Location Map of Proposed Artificial Recharge Test Area.



Final Study Proposal -- The general proposal agreed on by the task force and finalized by Carter Laing is summarized below:

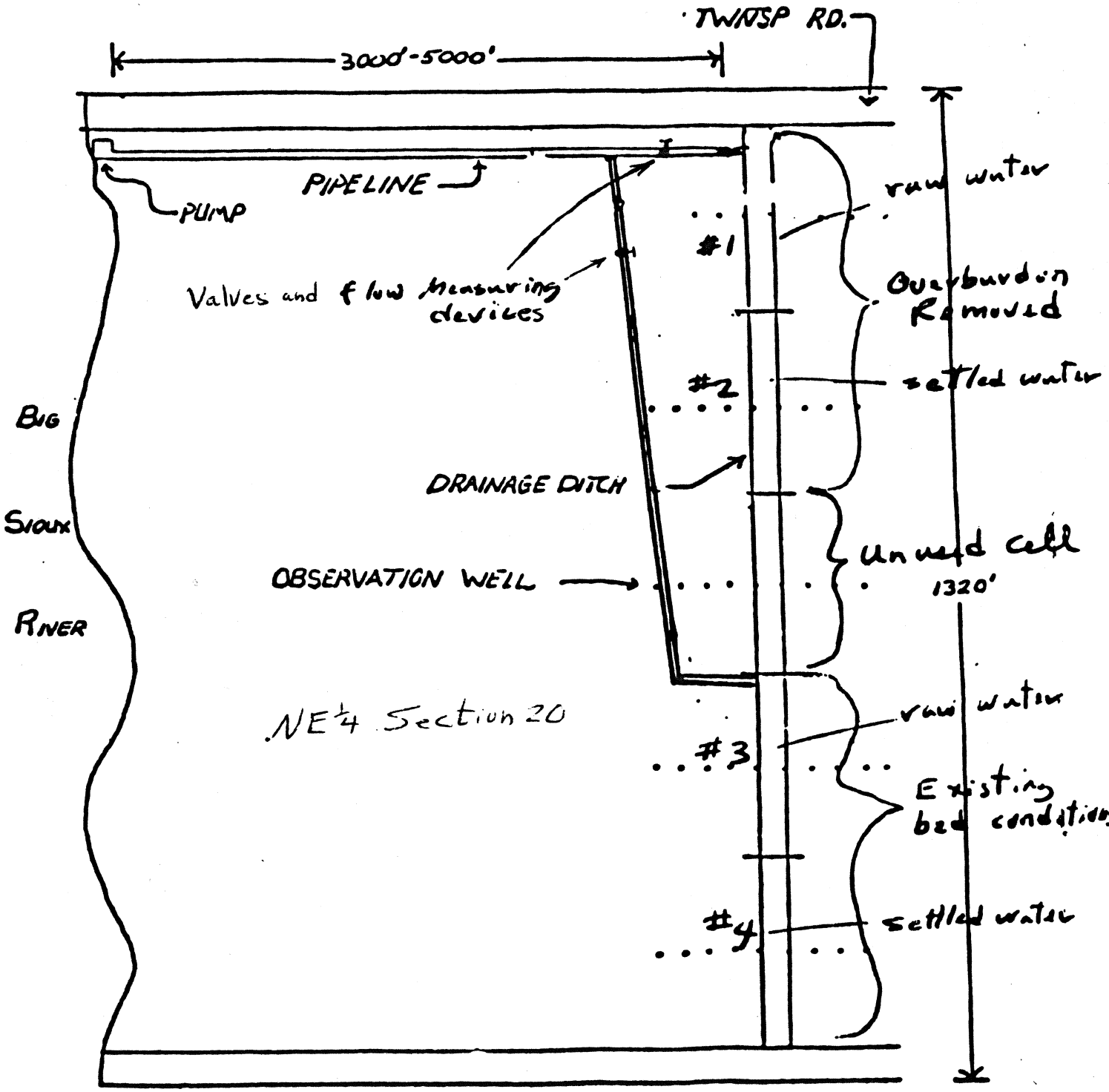
Materials for constructing the pits, power costs, and other direct costs would be financed by the Corps grant. The C-SF would provide equipment and labor to construct the pits and would be in charge of actual operation of the recharge tests.

The project called for construction of two two-cell recharge pits in a one-fourth mile reach of the old drainage ditch north of Sioux Falls between Silver Creek and the Big Sioux River, along land owned by the C-SF. The recharge tests would be conducted essentially as follows: Water would be diverted from the Big Sioux River to the drainage ditch by means of an irrigation pump and a T-ed pipeline which would allow metered discharge of water into the recharge test area at two separate points. Water would be impounded in the drainage ditch by means of six channel structures filled with flow measurement devices. The six channel structures would form four recharge impoundments. The first two impoundments would be prepared for the recharge tests by removal of 12 to 18 inches of soil from the drainage ditch bottom. The third and fourth impoundments would be left in their natural state. The first cell of each series would thus receive raw Big Sioux River surface water, whereas the second cell would receive better quality water with most of the suspended solids removed in the first cell (see Figure 2).

A total flow of about 600 gpm would be pumped into the recharge impoundment and allowed to infiltrate into the aquifer. The quantity of surface flow into and out of each recharge pit would be accurately measured. The quantity of water which infiltrated the recharge area would be determined by use of the continuity equation. The rate of recharge into the aquifer would be monitored by about 50 observation wells placed in five parallel rows in a semi-logrithmic pattern perpendicular to the drainage ditch. At least one row of wells would extend from Silver Creek to the Big Sioux River. Water would be applied to the recharge site in a cyclical manner during the critical phase of testing and in a continuous manner during the second phase of testing. Recharge tests would be run as soon as there was a combination of the following two conditions: (1) the water level in the recharge area was low enough to conduct reliable recharge tests, and (2) there were still sufficient flows in the Big Sioux River to allow diversion.

All participating agencies would assist in data collection for the first few days of the recharge tests. After that period, the C-SF would read the observation wells and river stage gauge on a regular basis in the manner approved by the other participating agencies. Data evaluation would be conducted to determine the rate of flow from recharge water into the aquifer under the variable conditions experienced during the recharge test.

Figure 2. Sketch Diagram Showing General Layout of Proposed Four Cell Recharge System.



Attempted Implementation of Project -- The committee met again on January 10, 1978 and approved the final study work plan. It was apparent, however, from the rising watertable that the pilot tests would be difficult to conduct during 1978. The task force felt strongly that the average water level in the recharge area should be at least five feet below the top of the gravel outwash material before reliable information could be secured from artificial recharge tests. The SDGS agreed to install the needed observation wells as soon as weather permitted. The Corps issued a three-party contract with the C-SF and EDCSD on May 4, 1978.

The task force met again, May 24, 1978, to finalize detailed plans for recharge cell size and location and the location and placement of observation wells. John Madden of DGR was authorized to survey the location and elevation of the observation wells, once installed (see Figure 3). The SDGS installed the observation wells in early June, 1978. High water levels continued through 1978 and early 1979, however, and prohibited the running of pilot recharge tests.

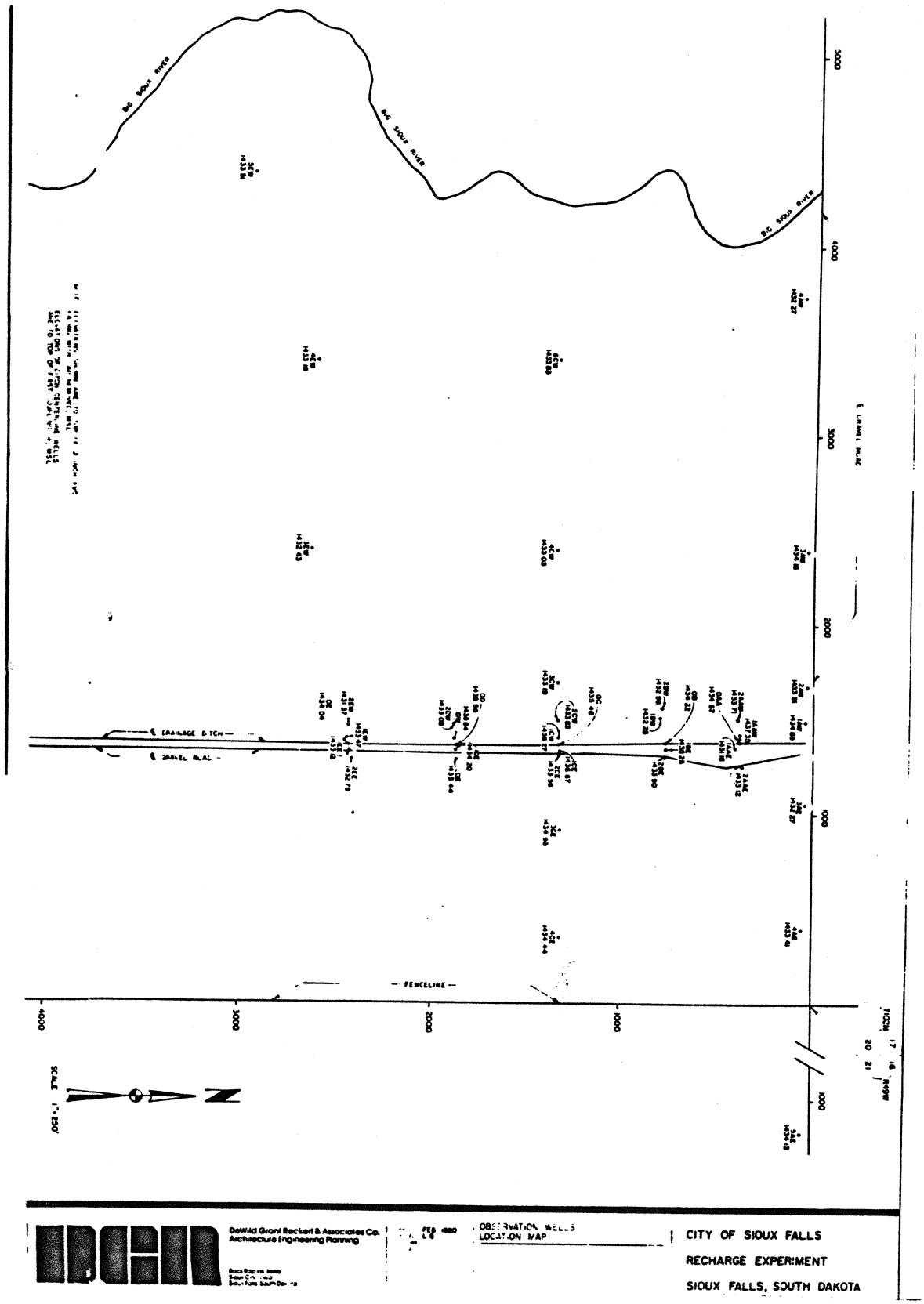
During late summer of 1979, water levels began to drop. On September 13, the task force met to update the proposed recharge project and determine whether to proceed with the pilot tests. Updated costs estimates prepared by DGR for purchase and fabrication of the channel structures were reviewed. Total costs had risen from $31,000 to $41,031.93. The task force asked the Corps to consider providing additional funds needed due to the rise in costs resulting from time delays.

The task force decided to purchase the materials and fabricate the structures so they would be ready to install once water levels were favorable. The Corps modified the three-party contract on October 12 so a $10,000 payment could be made upon installation of the observation wells and delivery of the assembled channel structures. The channel structures were fabricated by DGR and C-SF personnel. Water levels rose again, however; further delaying the actual tests.

On March 18, 1980, EDCSD billed the Corps for $10,000. A $1,428.40 payment was given to SDGS for installation of the observation wells and $7,706.11 to DGR for surveying, preparing cost estimates, and purchasing and partially assembling the channel structure materials.

The task force met April 22, 1980 to review the possibility for conducting tests during 1980. Although the aquifer and river were essentially full, the committee decided to apply for a temporary water permit in case water levels dropped later. A temporary permit for Sioux Falls to divert 0.865 mgd, as long as there was a 50 cfs by-pass flow, was approved June 10 by the State Division of Water Rights. On August 12, DGR noted that water levels might not drop the desired 5 feet below the top of the aquifer by the end of the year. The temporary recharge permit expired December 31, 1980.

Figure 3. Detailed Location Map of Observation Wells Installed by the S.D. Geological Survey for the Sioux Falls Aquifer Recharge Project.



On February 10, 1981, DGR billed the C-SF and EDCSD for $1242.12 of unpaid engineering services and materials and noted that high water levels precluded testing that spring. DGR was paid $865.49 remaining from the $10,000 Corps grant received earlier, leaving an unpaid bill of $376.63.

Task Force Chairman Jerry Siegel corresponded with the C-SF stating that no further expenses should be incurred until additional funds were secured.[6] He began pursuing funds through the Corps' Sec. 22 and Eastern South Dakota Water Supply Study programs. In late 1981, a strong request was made for a $15,000 allocation of Eastern South Dakota Water Supply Study funds for FY1982. The Corps indicated they might become available and asked for detailed cost estimates. The following breakdown was made for the remaining $5000 grant plus $15,000 of new funds.[7]

Purchase and installation of water delivery equipment	--	$13,000
Purchase and installation of flow measurement devices	--	1,000
Pumping power costs	--	1,000
Data interpretation and report preparation	--	5,000
Total	--	$20,000

This estimate continued to assume that the C-SF would honor an earlier commitment to get the site ready for testing and record most of the data, and that the EDCSD, SDGS and USGS would supervise the installation of equipment and the collection and analysis of data. On June 11, Mr. Siegel met with the Corps and learned that they were in the process of allocating the $15,000 to the aquifer recharge budget. Water levels remained high during 1982, however, and the recharge tests were further delayed.

During early 1982, the USGS was finalizing preparation of a digital model of the main Big Sioux River Aquifer in Minnehaha County, north of Sioux Falls. The task force shifted its efforts temporarily toward use of the digital model to analyze the potential for artificial recharge north of Sioux Falls. Several trips were made to Huron to consult with Neil Koch, who was responsible for preparation of the model. A discussion of these analyses is contained in the Analysis and Discussion section of this report.

During 1983, water levels remained high. Alan Johnson replaced Rick Miner as the Corps official responsible for the project. In late 1983 (November 7), the Corps processed payment for $372.63 engineering services which had been provided by DGR. Alan Johnson advised Task Force Chairman Jerry Siegel that the $15,000 allocation of Eastern South Dakota Water Supply Study funds for the recharge project would likely be lost if the tests could not be run during 1983.

In early 1984, it became apparent to everyone involved that reliable recharge tests at the selected site could not be achieved unless drought conditions returned. Alan Johnson advised Jerry Siegel, in an April 18 telephone conversation, that the $15,000 of additional Corps funding had reverted and asked him to utilize the $5627.37 remaining to summarize the efforts of the task force and to make a realistic appraisal of the potential for artificial recharge of the Big Sioux River Aquifer near the Sioux Falls wellfield area.

USGS and C-SF water officials were consulted. C-SF officials indicated they did not wish to prepare the final report but offered to provide water level data for their wellfield and to review the draft report. The EDCSD entered into a cooperative agreement with the USGS to provide $1000 of Corps funds for USGS analysis of flow records at the Dell Rapids gauging station.

SUMMARY OF EXPENDITURES FROM $15,000 CORPS FUNDING

Engineering Services - DeWild Grant Reckert & Assoc.		$ 4,847.37
Purchase of Channel Structure Materials		4,096.86
Installation of Observation Wells - SDGS		1,428.40
Preparation of Final Report - EDCSD		3,627.37
Flow Analysis -- Dell Rapids Gauging Station - USGS		1,000.00
	Total	$15,000.00

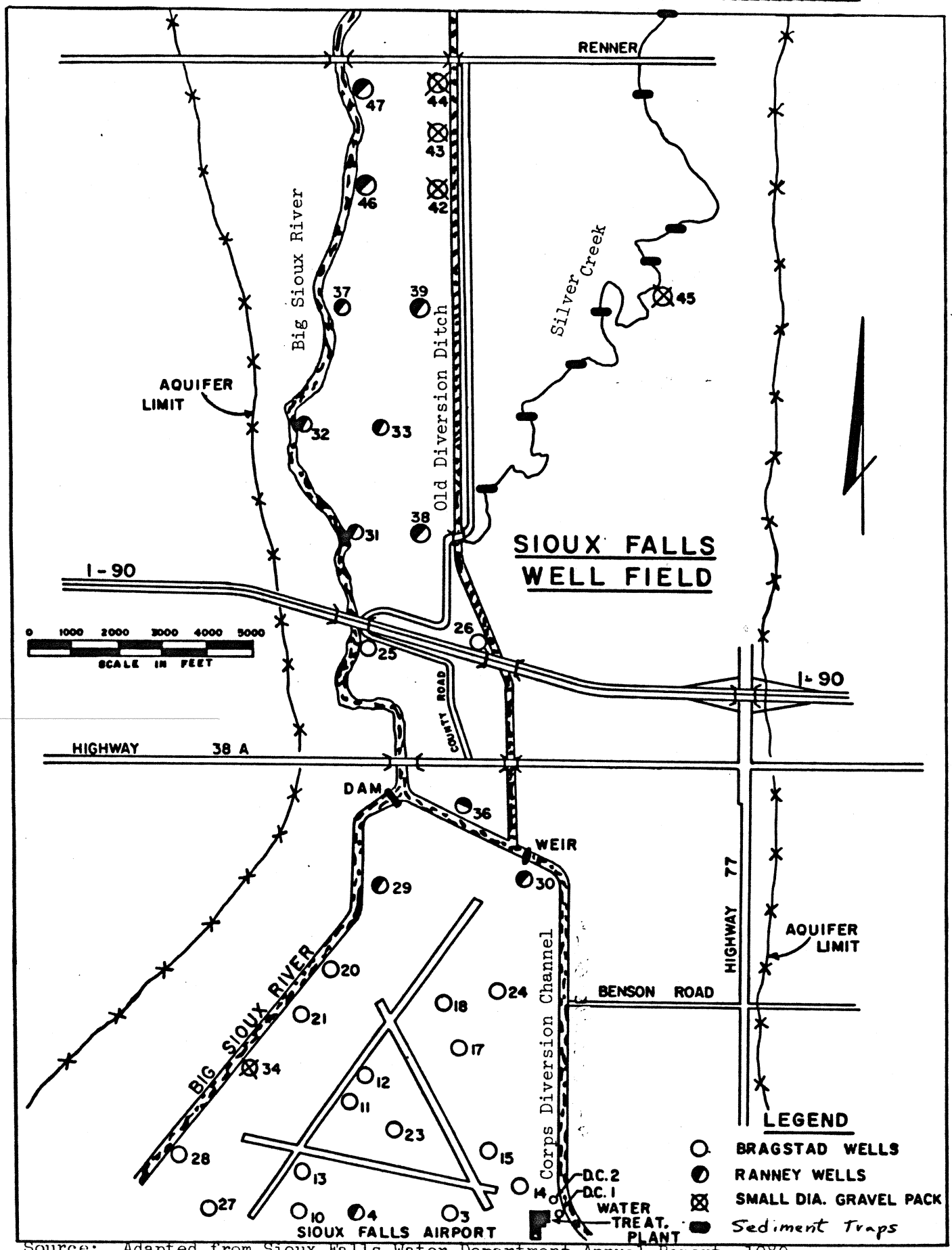
ANALYSIS AND DISCUSSION

The Artifical Recharge Paradox -- The fact that efforts to run aquifer recharge tests were frustrated for seven years because the aquifer water level never dropped more than five feet below the top of the sand and gravel, leads to an important conclusion. Natural recharge of the Sioux Falls wellfield area through precipitation and flooding plus infiltration through the bed of the Big Sioux River, Silver Creek and the old diversion ditch, and the flood diversion channel constructed by the Corps of Engineers is very efficient.

The favorable location of Sioux Falls' municipal wells in relation to the Big Sioux River, the old diversion channel and Silver Creek is shown in Figure 4. As a part of the Silver Creek PL566 Watershed Project, a series of over 25 sediment traps was constructed in the Silver Creek stream bed. Figure 4 notes the location of seven of these traps which lie in the wellfield area. Seven upstream dams, in conjunction with these traps, inadvertently provide effective artificial recharge of the northern portion of Sioux Falls' wellfield.

As long as there is flow in the Big Sioux River, it appears that the adjacent aquifer will be replenished. This was dramatically demonstrated in 1977. A severe drought occurred during 1975-1977 and water levels in Sioux Falls wells and the surrounding aquifer area dropped sharply. A number of experts predicted that it would take a major flood to bring the water level in the wellfield back up.

Figure 4. Location Map of Sioux Falls Municipal Wells and Sediment Traps Constructed as Part of the Silver Creek PL566 Watershed Project*



Source: Adapted from Sioux Falls Water Department Annual Report, 1980.

No major flood occurred during 1977. Yet, by late 1977, aquifer levels in the wellfield had risen to the high levels they were at in the spring of 1973 before the drought began (see water level charts for four wells in Appendix I).

During normal water years, it would be wasteful or foolish for Sioux Falls to pump water from the Big Sioux River to artifically recharge the aquifer near the wellfield for a number of reasons: (1) Power costs for pumping are expensive, (2) Mother Nature is recharging the wellfield very efficiently herself, (3) most of the time, the bulk of water would end up flowing naturally back to the river, and (4) if excess water were placed in the aquifer (creating high water-table conditions), surrounding farmers could sue for crop damages.

Even following abnormally dry summers, high river flows usually occur the following spring and replenish the aquifer. Thus, pumping river water to recharge the aquifer most years would involve wasted energy and money. The only scenario in which artificial recharge would make economic sense would be when an extended dry period occurred and the river level dropped to the point that it was not recharging the aquifer naturally. When that occurs, however, the city could very well face restrictions on diverting river water for recharge because of downstream water right considerations.

This brings us to the heart of the artificial recharge paradox for the city. When hydrologic conditions are such that the aquifer water level has dropped to the point where pumping Big Sioux River water to recharge the aquifer would be a reasonable economic gamble, there would not likely be enough flow in the river to allow diversion for artificial recharge. It must be remembered that the river and aquifer are not separate systems operating independently. They are closely inter-related parts of the same system.[8]

The remaining subsections contain additional information dealing with the artificial recharge paradox.

Digital Model Evaluation of Aquifer Recharge above Sioux Falls -- In 1982, as noted earlier, the task force decided to utilize the hydrologic digital model being finalized for the Big Sioux River Aquifer above Sioux Falls[9] to make an assessment of the potential and impacts of diverting Big Sioux River water for artificial aquifer recharge. Project Manager Neil Koch agreed to make the desired computer runs. Task force members Les Hash, Assad Barari, and Jerry Siegel met with him to reivew and discuss his results.

Using the model, water was pumped to the recharge site at a constant rate of 870 gpm or 1.94 cfs for four 30 day recharge periods. The model estimated the amount of the recharge water that would return to the river during these periods. In addition, the model was used to predict the amount of water that would return to the river during three 30 day recovery periods.

The outputs of the model run are summarized as follows:

Total water delivered during 120 day recharge period	150,336,000 gallons
Water returned to river during 120 day recharge period	24,429,600 gallons
Recharge water remaining in aquifer after 120 day recharge period ...	125,906,400 gallons
Water returned to river during 90 day recovery period	30,067,200 gallons

Thus, during the 120 day recharge and 90 day recovery period, the model predicted that 54,496,800 gallons out of 150,336,000 gallons delivered to the aquifer, or 36%, would return to the river.

Streamflow Analysis at Dell Rapids Gauging Station -- Daily streamflow data from the gauging station on the Big Sioux River near Dell Rapids for May 1, 1948 through October 24, 1983 are contained in Appendix II.

As noted earlier, the S.D. Board of Water Management determined that 50 cfs must be bypassed for any diversions from the Big Sioux River. Table I contains a listing of the dates when Big Sioux River flow at the Dell Rapids gauging station was less than 50 cfs. As the table shows, diversions of Big Sioux River flows for artificial recharge of the Sioux Falls wellfield would have been restricted during extended periods of most dry years. And, as noted earlier, diversion during normal years would have been wasteful.

A duration hydrograph prepared by the U.S. Geological Survey for the period 1954-1983 is shown in Figure 5. The hydrograph shows the percent of time which discharges were equaled or exceeded during any given time period. The 50 cfs bypass requirement has been superimposed on the diagram. Even though the hydrograph shows that 50 cfs is exceeded over 50% of the time between mid-March and early August, it is during the extended dry periods (when flow would most likely be less than 50 cfs) that artificial recharge would be beneficial.

Table 1. Dates When Big Sioux River Flow at Dell Rapids Gauging Station was Equal To or Less Than the 50cfs By-Pass Requirement

Water Year 1948*

12/18-2/25
7/18
7/19
7/21-7/25
8/13
8/14
8/19-9/2
9/5-9/10
9/12-9/30

Water Year 1949

10/1-3/23
7/25
7/28
7/29
8/1
8/2
8/7-8/11
8/17-9/20
9/27-9/30

Water Year 1950

10/6
10/8-10
10/13
10/15
10/16-17
10/20-2/23
3/5-3/26

Water Year 1951

1/11-1/14
1/18-2/10
2/28-3/18

Water Year 1952

11/2
11/4-3/10

Water Year 1952

12/4
12/11-2/8

Water Year 1954

10/17-11/5
11/13-3/1
3/6-3/9
5/23-5/26
6/1-6/17
6/25-9/30

Water Year 1955

10/1-3/24
3/29-3/30
5/21-6/3
6/6-6/22
7/5-7-12
7/19-8/7
9/9-9/30

Water Year 1956

10/1-3/21
8/16-8-22
9/3-9/19
9/22

Water Year 1957

10/1-10/30
11/19-2/24
3/5
3/8-3/22
7/1-9/30

Water Year 1958

10/1-3/6
4/7-5/4
5/6-5/27
7/1-7/6
7/8-9/30

Water Year 1959

10/1-3/28
7/22-8/24

Water Year 1960

10/2-2/20
7/20-8/3
8/10-8/22
8/31-9/30

Water Year 1961

10/1-3/25

Water Year 1962

12/9-3/15

Water Year 1963

12/8-3/11
7/18-9/30

Water Year 1964

10/1-3/14
3/18-3/31
8/16
8/18
8/31-9/18

Water Year 1965

11/26-12/11
12/19-2/8
7/7-7/17
8/3-8/19
8/30
9/4-9/10
9/17-9/30

Water Year 1966

10/1-11/10
11/12-2/29
8/6-8/25
9/3-9/30

Water Year 1967

10/1-10/22
10/24-3/17
3/20-3/22
3/30-4/2
5/23
5/26-6/24
7/15-9/30

Water Year 1968

10/1-10/15
12/7-12/10
12/13-4/2

Water Year 1969

12/9
12/21-12/25
8/24
8/28-9/30

Water Year 1970

10/1-10/9
10/24
10/27
12/17
12/20-2/17
2/20-2/23
7/28-9/30

Water Year 1971

10/1-10/29
12/17-12/19
12/28-3/11

Water Year 1972

7/17-9/28
9/30

Water Year 1973

10/1-10/8
10/18-2/19
6/24-9/30

Water Year 1974

10/1-4/7
6/3-9/30

Water Year 1975

10/1-2/26
3/5
5/24-9/30

Water Year 1976

10/1-3/9
5/11-6/17
7/14-9/30

Water Year 1977

1/9-3/12
9/28-29

Water Year 1978

10/13-3/17

Water Year 1979

1/29-3/13
9/14
9/16-9/30

Water Year 1980

10/1-3/7
5/9-9/30

Water Year 1981

10/1-2/22

Water Year 1982

None

Water Year 1983

None

*Water Year - begins October 1 and runs through September 30 of the following year.

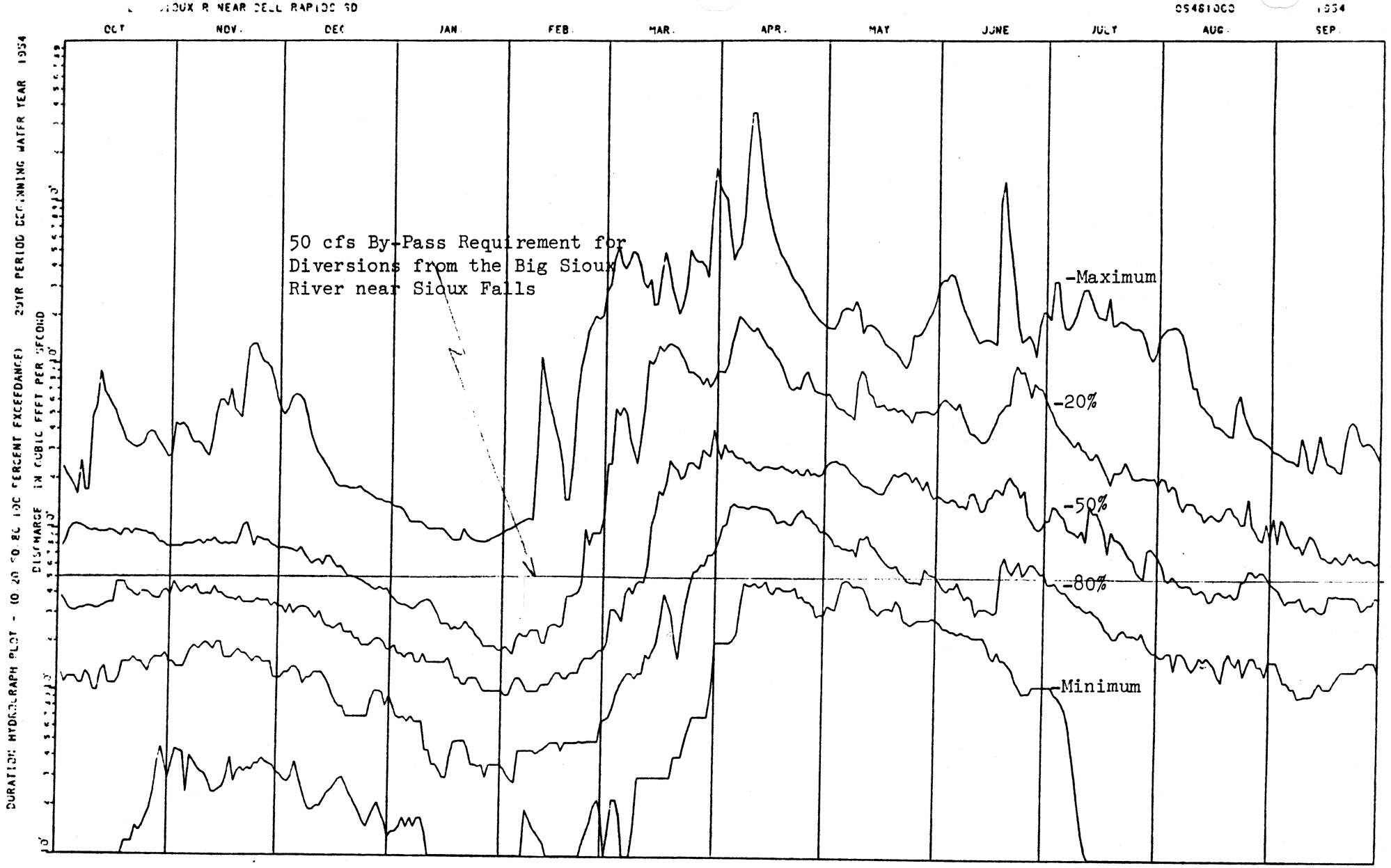


Figure 5. Duration Hydrograph for the Period 1958-1983, Big Sioux River Gauging Station near Dell Rapids, South Dakota.

REFERENCES

1 Report of the Citizens Water Advisory Committee to The City Commissioners, Sioux Falls, South Dakota, submitted June 22, 1977, p. 12.

2 Ibid, p. 15

3 10 June, 1977 Letter from John E. Velehradsky, Chief - Planning Division, Omaha District Corps of Engineers, to Jerry L. Siegel, Manager-Treasurer, East Dakota Conservancy Sub-District.

4 Minutes - East Dakota Conservancy Sub-District - July 21, 1977, pp. 1 and 6.

5 20 December 1977 Letter from Carter Laing, U.S. Corps of Engineers - Omaha District to Task Force Members.

6 March 3, 1981 Letter from Jerry L. Siegel, Manager-Treasurer, East Dakota Conservancy Sub-District, to Les Hash, Manager, Sioux Falls Water Department.

7 April 14, 1982 Letter from Jerry L. Siegel, Manager-Treasurer, East Dakota Conservancy Sub-District, to Rick Miner, U.S. Corps of Engineers - Omaha District.

8 The Big Sioux Aquifer Water Quality Study, First in a Series, East Dakota Conservancy Sub-District, 1983, pp. 6-8.

9 A Digital-Computer Model of The Big Sioux Aquifer in Minnehaha County, South Dakota, U.S. Geological Survey Water-Resources Investigations 82-4064, Prepared in cooperation with the East Dakota Conservancy Sub-District, the South Dakota Department of Water and Natural Resources, and Minnehaha County

10 Annual Report of Sioux Falls Water Department, 1980, p. 4.