1971

Ground Water Management by Streambed Dams for the Upper Big Sioux River Basin

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GROUND WATER MANAGEMENT BY STREAMBED DAMS FOR THE UPPER BIG SIOUX RIVER BASIN

BY

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A thesis submitted
in partial fulfillment of the requirements for the
degree Master of Science, Major in
Civil Engineering, South Dakota
State University

1971

GROUND WATER MANAGEMENT BY STREAMBED

DAMS FOR THE UPPER BIG SIOUX RIVER BASIN

This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable as meeting the thesis requirements for this degree, but without implying that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Thesis Adviser   Date

Head, Civil Engineering Department   Date

ACKNOWLEDGMENTS

The author wishes to express sincere gratitude to Dr. James N. Dornbush and Dr. John R. Andersen, Professors of Civil Engineering, for offering their time, guidance, and assistance throughout this investigation.

Appreciation is also extended to Vern Butler and Jerry Siegel of the East Dakota Conservancy Sub-District for their assistance in providing a portion of the data that was used in this investigation.

This investigation was financed in part by the United States Department of Interior through the South Dakota State University Water Resources Institute as authorized under Public Law 88-379. This investigation was also supported by a Federal Water Quality Administration Training Grant Number 1T1-WP-272.

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INTRODUCTION

In 1964 the Irrigation and Drainage Division Research Committee of the American Society of Civil Engineers defined ground water resource management as (1-94):

> "Ground-water resource management may then be defined as the development and utilization of the subsurface waters, both those that occur naturally and those added by man's activities, and of the subsurface formations for storage, transmission, distribution and treatment, as an integral part of the total water supply-waste disposal system, in such a manner as to maximize the net benefits, social and economic, to the community dependent thereon. In this, quality is of equal importance to quantity."

Ground water in a sense is a renewable resource because some degree of natural recharge occurs in most ground water basins. When pumping exceeds the natural recharge, the resource may be exhausted. South Dakota law does not permit the mining of water, that is, withdrawing more ground water than nature stores each year. Use of ground water up to this withdrawal-replacement balance is permitted. It follows that if more water could be stored in an aquifer, more water would be available for use.

A scheme of ground water management for the Big Sioux River Basin envisions a series of overflow dams on the main channel. These streambed dams with control gates would be capable of raising the water level within the channel by several feet and the accompanying raise in river stage would result in movement of surface water to the adjacent outwash aquifer and would thus prevent the outflow of ground water. The expected result would be more water storage in the channel, but more important, also in the adjacent outwash aquifers where the water would not be subject to evaporation losses and could be developed for irrigation and other beneficial purposes.

Previous studies of the Big Sioux River Basin have demonstrated several important aspects that point toward the desirability and the feasibility of a ground water management plan. The river is known to be deficient in discharge for irrigation, quality control, and water supply during the late summer, fall, and winter months (2-68). The flow that does occur during the late summer, fall, and winter months is sustained almost entirely from ground water sources. With increased emphasis on irrigation development and the push for water law revision in South Dakota, improved water management will be required.

The topography of the Big Sioux River Basin is such that the upper portion of the basin possesses few sites for economical storage of surface water (3-48). The river channel is generally cut through broad and level plains. Therefore, a prime area for a study of ground water management is the Upper Big Sioux Basin, which, for purposes of this study is defined as that part of the Big Sioux Basin between the Watertown and Brookings stream gaging stations.

The United States Corps of Engineers has proposed a series of dams on the Big Sioux River and its tributaries for the purpose of flood control. One of the major structures proposed on the main stem of the Big Sioux is at Flandreau, approximately 10 miles south of the Brookings gaging station. A report on a Bureau of Reclamation study of the Big Sioux Basin stated that the areas below the major dam and reservoir sites could be supplied water for irrigation development from the reservoirs (3-58). In the area between Brookings and Watertown, the only sites for possible surface water development are on minor tributaries and would provide little water for irrigation development in the entire study area (3-48). Therefore, there is a need for more research on developing the ground water for utilization in the study area.

According to the same Bureau of Reclamation report, there are 76,800 acres of arable land in the Basin between Watertown and Flandreau (3-22). The land in the study area has not yet been developed for irrigation to a great extent but in a study conducted by the Department of Economics at South Dakota State University investigating the irrigation development of the Big Sioux River Basin it was concluded that, if adequate water supplies were available, half or more of the arable land in the Big Sioux Basin could be developed profitably for irrigation. It was further concluded that off-farm benefits would also be significant to the area economy (4-98). A ground water management program in the area could possibly help to provide a means for optimum development of the area.

The general objective of this research was to define the problems and to offer possible solutions associated with the development of a ground water management plan for the Upper Big Sioux River Basin. The investigation was primarily an evaluation of existing literature and data. The available information was collected and evaluated for the specific objectives:

1. Determination of the type of information that would be required for the development of an acceptable plan for ground water management in the basin.
2. Determination of the beneficial or adverse effects that may occur in the river basin as a result of raising the ground water table by the use of streambed dams.

A preliminary judgment of the need for and the feasibility of this type of a plan was also made. No actual data were taken nor field measurements made. The collection of such information would be accomplished during future investigations if this analysis indicated that continued study was desirable or feasible.

DESCRIPTION AND HYDROLOGY OF THE UPPER BIG SIOUX RIVER BASIN

The Big Sioux River Basin, which has a drainage area of about 9,750 square miles, is located in eastern South Dakota, northwestern Iowa, and southwestern Minnesota. Of the total drainage area, 69 per cent is located in South Dakota, 15 per cent in Iowa, and 16 per cent in Minnesota (3-2).

The Big Sioux River heads in northeastern South Dakota and flows generally southward to join the Missouri River at Sioux City, Iowa. The Big Sioux has two major tributaries, the Rock River in Iowa and Minnesota and Skunk Creek in South Dakota. The Rock River drains about 1,700 square miles while Skunk Creek drains about 540 square miles (2-5). A map of the Big Sioux River Basin is shown in Figure 1.

The geology of the Big Sioux Basin is generally of glacial origin. The present land surface and geology was shaped by the Wisconsin stage, the last glacier to cover the area. Glacial deposits are usually left as ground moraine, end moraine, or outwash. The ground moraine and end moraine are classed more generally as till and represent the greatest share of the drift in the Basin. Till is a clay matrix with a heterogeneous mixture of silt, sand, and a small percentage of large rock fragments. Outwash, common in the Big Sioux River drainage system's valleys and plains, consists of crossbedded gravel, sand, and silt. Outwash areas are a source of shallow ground water (3-4).

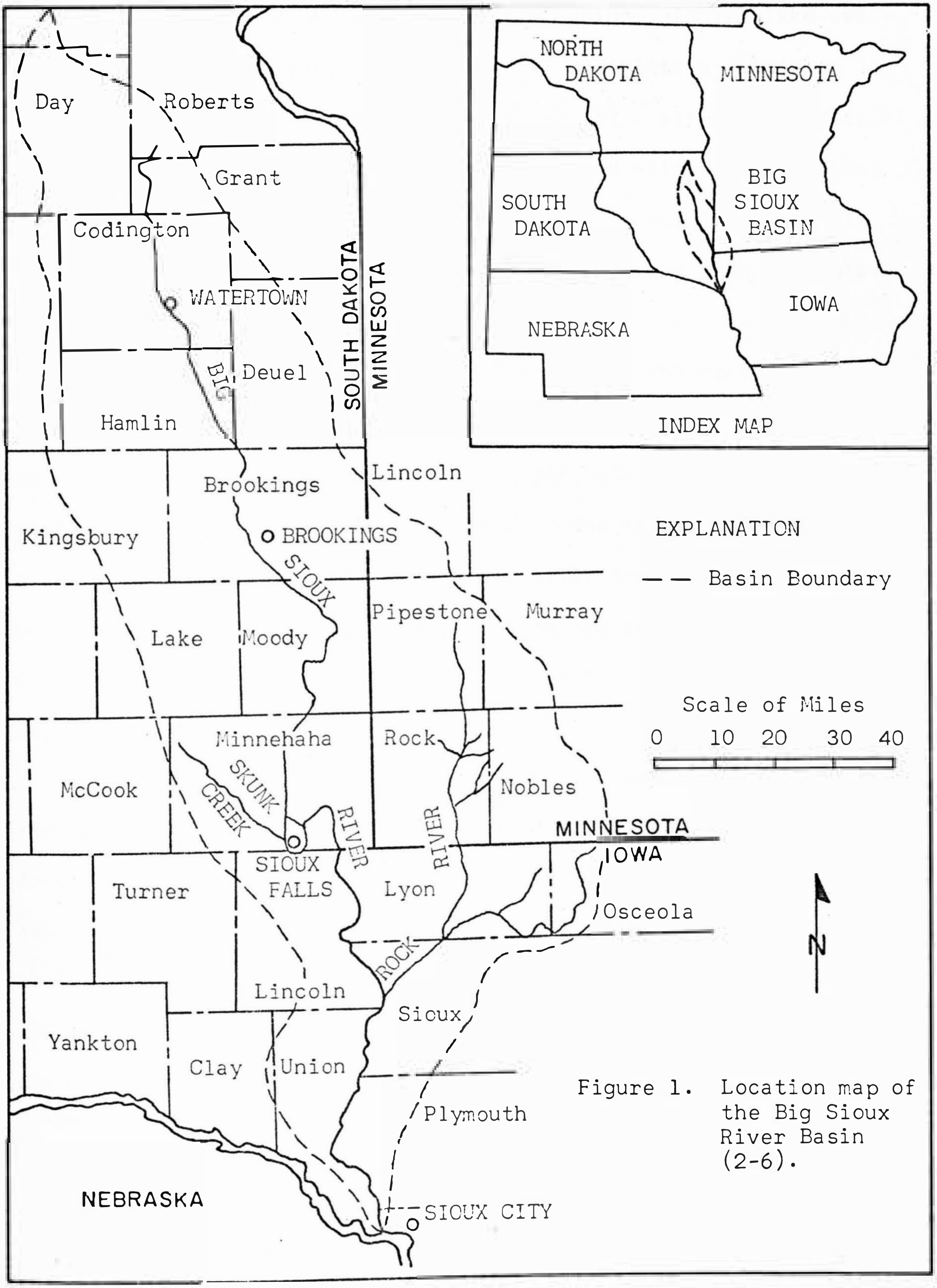

Figure 1. Location map of the Big Sioux River Basin (2-6).

Other geologic deposits in the Basin include glacial lake sediments and alluvial deposits. Glacial lake sediments accumulated in temporary lakes and small depressions in the till areas. The glacial lake sediment consists of fine-grained clay and silt. The alluvial deposits are found along both sides of the Big Sioux River and its tributaries and are deposits of clay, silt, and sand with some gravel (3-5).

Only a portion of the Big Sioux River Basin was considered in this investigation. The main area of interest was that part of the Big Sioux Basin between the Watertown gaging station and the Brookings gaging station. Figure 2 is a map showing the main study area.[1] The area is accessible for study with very little travel. This is an advantage for any future studies that may be needed. The South Dakota Geological Survey has mapped the geology of the entire area and the reports (5)(6) are available for use.

The Corps of Engineers in their flood control studies have considered 11 possible dam sites in the entire Big Sioux River Basin. Of these 11 dams, only two are on the main stem of the river and the others are on tributaries. In the area included in this study there are, according to the Corps of Engineers, only three possible sites, all of which are on minor tributary streams. These streams are Willow, Stray Horse, and Hidewood Creeks (3-48).

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[1]The map of the study area is from a map entitled "Surface and Ground Water Sources and Irrigation Development," revised by the South Dakota Water Resources Commission on July 1, 1969.

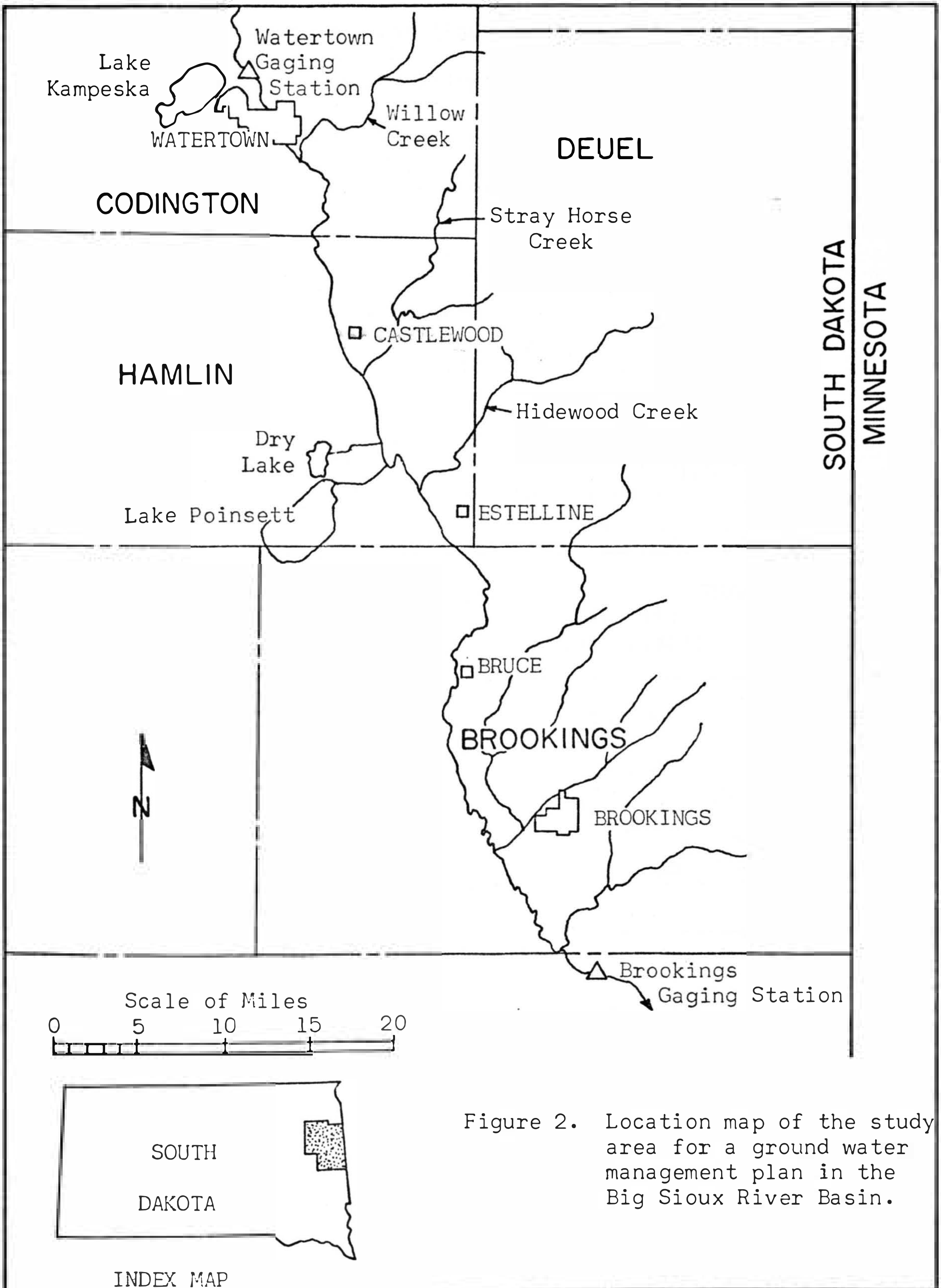

Figure 2. Location map of the study area for a ground water management plan in the Big Sioux River Basin.

Willow Creek joins the Big Sioux River south of Watertown while Stray Horse Creek and Hidewood Creek enter the river between Castlewood and Estelline (see Figure 2). Estimates of the storage capacities of the reservoirs created by the dams are given in Table 1.

Table 1

Estimates of Drainage Area and Storage Capacities at the Possible Surface Water Storage Sites in the Upper Big Sioux River Basin (3-48).

Damsite		Contributing drainage area (sq. mi.)	Reservoir Capacity (acre-feet)	Reservoir Area (acres)
Willow Creek		67	130,000	4,100
Stray Horse		81	130,000	4,600
Hidewood		143	230,000	6,300
	Totals	291	490,000	15,000

In determining the capacities of the reservoirs on the minor tributaries, the Corps of Engineers did not consider physical, social, or economic factors. For example, Interstate Highway 29 would limit the Hidewood reservoir capacity and probably also the Stray Horse reservoir capacity (3-48).

If the river could be regulated by surface reservoirs, a nearly constant flow could be maintained in the stream. During violent rain floods the reservoirs could also serve as settling basins for the silt carried in the runoff, thus preventing the silt from reaching the infiltration areas. Even though snow-melt floods are more uniform and carry less silt than rain floods, the practice of water spreading on an unregulated river may have to be limited to other than flood times (7-292).

The contributing drainage area upstream from the Brookings gaging station is 2,850 square miles (3-35). The area controlled by the three possible reservoirs in the study area is 291 square miles which is only about 10 per cent of the total contributing drainage area. It appears, therefore, that very little stream regulation could occur in the study area.

Figure 3 is a map showing the general relationship of the arable land to the shallow ground water deposits in the study area.[2] The 76,800 acres of arable land in the Basin between Watertown and Flandreau represent about 70.5 per cent of the arable acres in the entire Big Sioux River valley in South Dakota, excluding the Rock River and Skunk Creek valleys (3-22). The Bureau of Reclamation has divided the arable lands into three classifications depending on the land suitability for irrigation development (Appendix A).

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[2]Base map from the South Dakota Water Resources Commission. The general locations of the arable land were obtained from Map No. 1106-602-17 of the Bureau of Reclamation report (3).

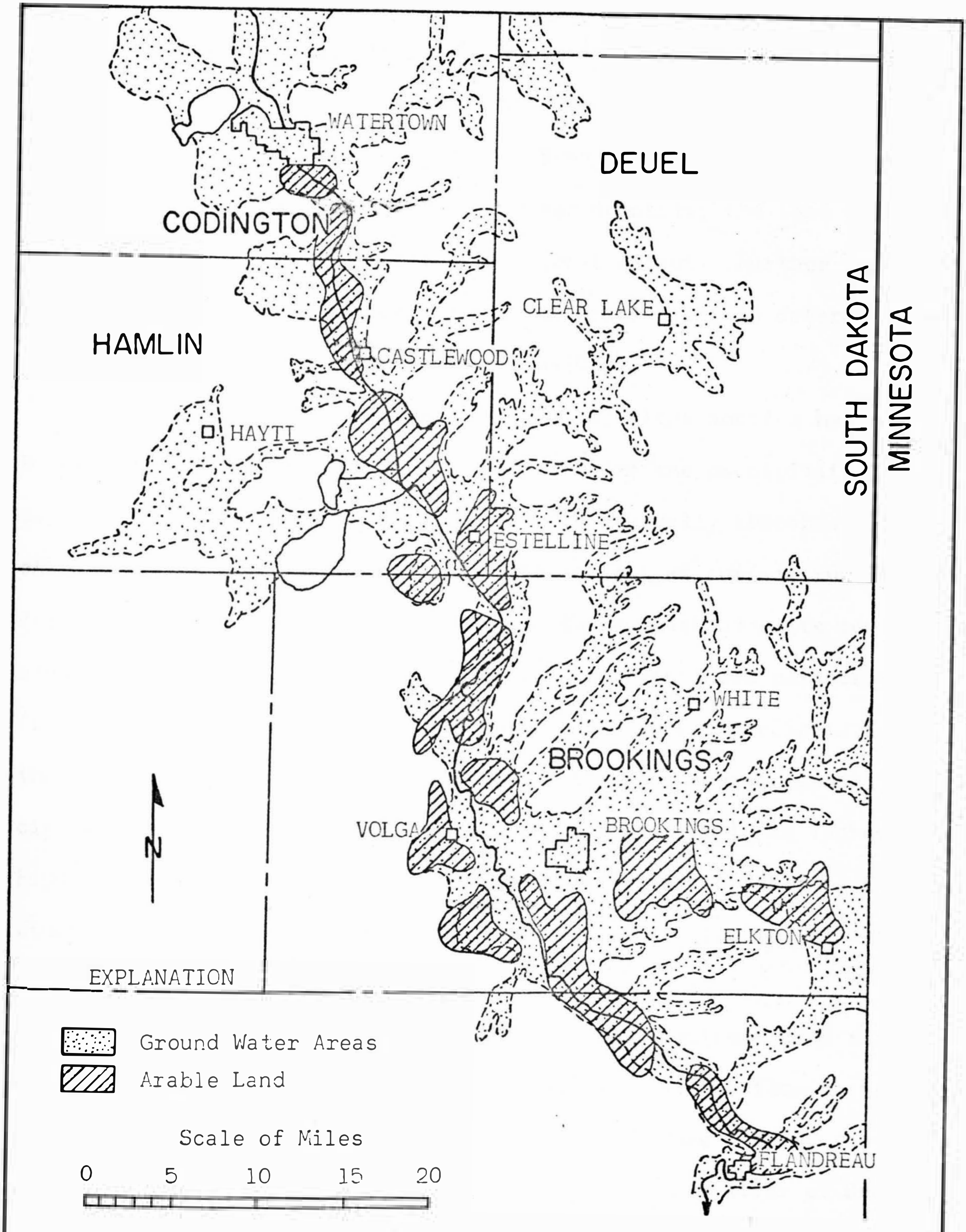

Figure 3. Location map showing shallow ground water deposits and arable land in the Upper Big Sioux Basin.

Figure 3 shows that the arable lands in the Upper Big Sioux Basin are generally located over areas of shallow ground water that could possibly be developed for irrigation. Even though the arable land is suitably located over shallow ground water deposits, the land has not yet been developed for irrigation to a great extent. Further studies would have to be conducted on some of the arable land to determine the feasibility of irrigation development (4-103).

The major source of recharge for the Big Sioux aquifer between Brookings and Watertown is direct absorption of the precipitation that falls on the area. The soil of the area is generally absorbant and only a small amount of the precipitation is lost as surface runoff. Percolation from streams flowing through the outwash deposits contributes a small amount of recharge, especially during flood periods (5-15) (6-18). Figure 4 is a map showing the average annual precipitation in the Big Sioux River Basin. The map shows that the average annual precipitation in the study area generally ranges from 20 to 22 inches. Figure 4 also shows the locations of the precipitation stations in the study area. The stations within the study area are located at Watertown, Castlewood, and Brookings.

The yield of water from the Big Sioux Basin upstream from the Brookings gaging station may be determined by using the flow records from the Brookings gaging station (2-77, 78). Figure 5 shows the seasonal flow-duration relationship for the Big Sioux River at Brookings. The curves illustrate specific percentages of time in which the river flow at Brookings was equalled or exceeded. The 50 per cent

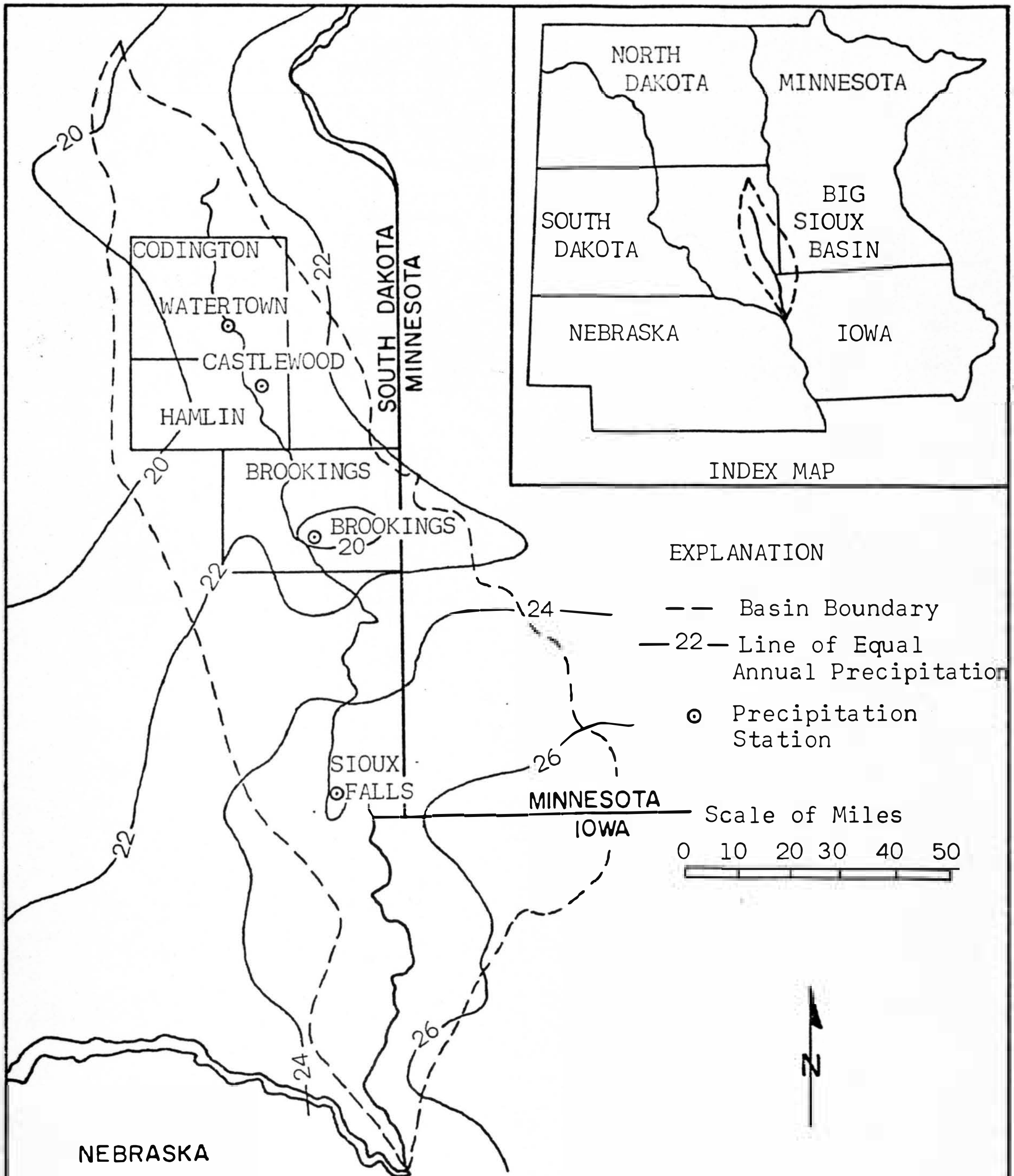

Figure 4. Average annual precipitation in the Big Sioux River Basin (3-6).

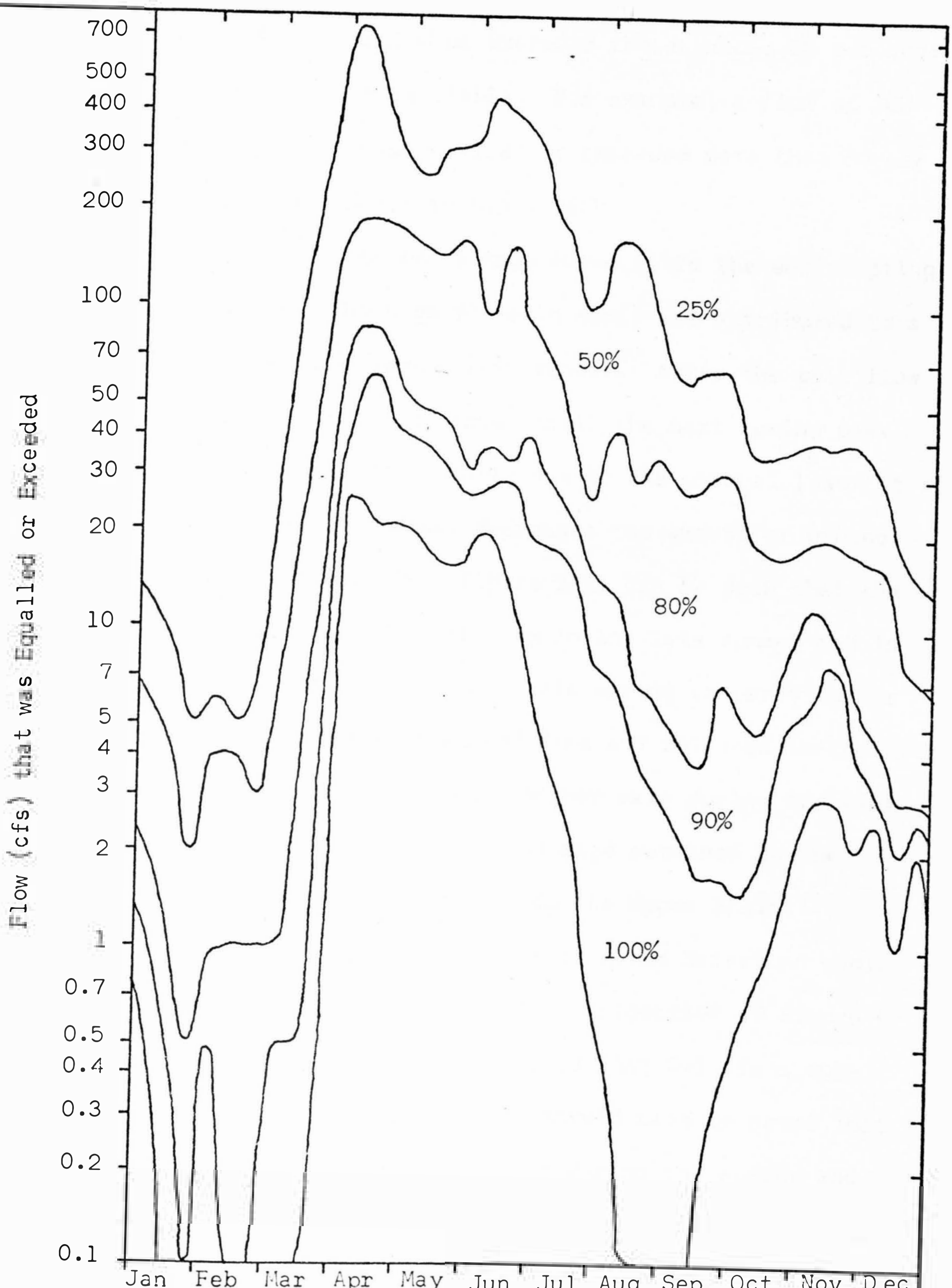

Figure 5. Seasonal flow-duration relationship for the Big Sioux River at Brookings, South Dakota.

line indicates that flow equalled or exceeded those values 50 per cent of the time that records were available. For example, a flow of 100 cubic feet per second (cfs) was equalled or exceeded more than 50 per cent of the time from late March to mid June.

The highest point of each percentage curve is in the early spring months, generally April. The high flows in April are attributed to a combination of snow-melt and spring rain runoff. After the peak flow has subsided, the flows tend to decrease until the next spring peak flow. This general decrease is probably due to the gradual lowering of the ground water table which thereby decreases the amount of ground water flowing into the river. From Figure 5 it can be seen that the river flow has been less than 0.1 cfs only in the late summer and in the winter. If some of the peak flow of late spring or early summer could be stored by the proposed streambed dams and released in the late summer, the flow could be sustained at a higher rate during the late summer. Also the natural and artificial storage retained by the streambed dams could be developed for use in the Upper Basin.

A similar analysis of the flow records from the Watertown gaging station is presented in Figure 6 (2-75, 76). Inspection of Figure 6 shows that the flow at Watertown has been less than 0.1 cfs a substantial portion of the year. However, it should also be noted that there has always been some flow at Watertown during the spring and early summer months. This flow could possibly be stored in the Big Sioux aquifer by streambed dams for beneficial purposes.

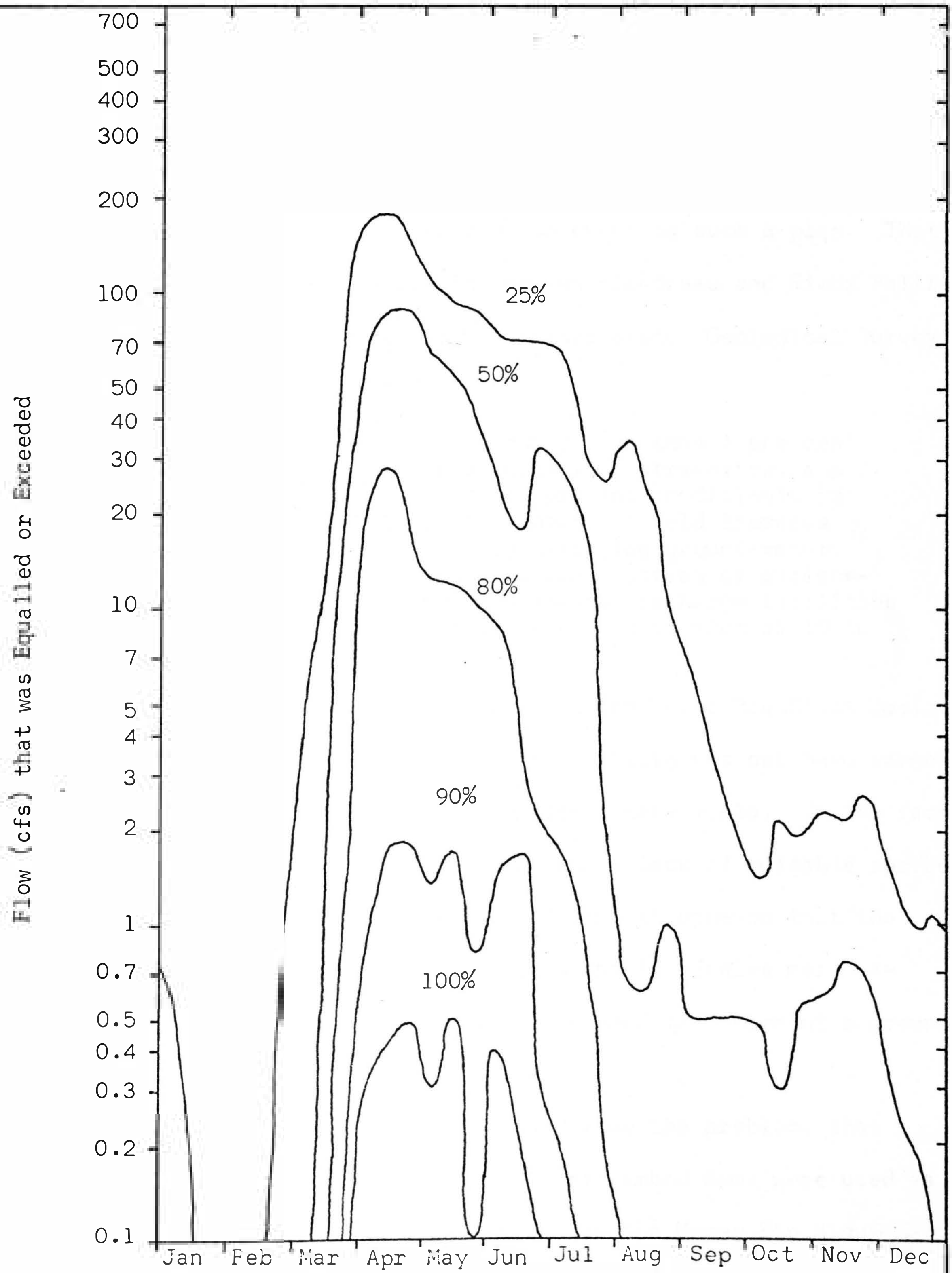

Figure 6. Seasonal flow-duration relationship for the Big Sioux River at Watertown, South Dakota.

Although various factors such as a lack of surface water development sites and a considerable amount of land suitable for irrigation development point toward the desirability of a ground water management plan for the Big Sioux Basin between Watertown and Brookings, a primary concern should be the present need for implementing such a plan. That portion of the Big Sioux River Basin between Flandreau and Sioux Falls has been described by personnel of the United States Geological Survey as follows (8):

> "Within the report area, only slightly more than 1 per cent of the water available from precipitation, streamflow, and ground-water inflow is used. Under present conditions, it is estimated that there could be almost a 5-fold increase in water use without significantly affecting ground-water conditions. Adequate planning, the construction of surface-water control structures, and ground-water recharge facilities could possibly increase potential water use as much as 10 to 15 times present use."

A similar situation appears to exist in the Upper Big Sioux Basin. The ground water usage in the Upper Big Sioux Basin has not been large enough to allow determination of the aquifer's safe yield. In the face of ever increasing demands for more water and a lack of suitable surface sites for water development in the Upper Basin, it appears that the management of the ground water in the Basin should receive more attention even though there may be no pressing need to implement a ground water management plan.

This investigation was undertaken to define the problems that would have to be considered if a series of streambed dams were used as a means of managing the ground water supply in the Upper Big Sioux Basin.

Development of a plan to accomplish ground water management is by no means a simple matter and would probably take a number of years to complete. Although there does not appear to be a pressing need to implement a plan for ground water management, the Upper Big Sioux Basin may well profit from initiating steps to accomplish ground water management.

STREAMBED DAMS FOR GROUND WATER MANAGEMENT

The use of dams for increasing infiltration as part of ground water management has been described in the literature (9)(10)(11). It has been shown that if the flow rate in a channel is controlled, greater recharge from the stream will frequently result (9-81). The basic idea of controlling the flow rate is to increase the time and area over which the water must flow thereby affording greater opportunity for additional infiltration (10-255).

The quantity of recharge from a stream is a function of several variables including the area covered by water, that is, the wetted perimeter and the length of the stream; the amount and duration of stream flow throughout the year; the permeability of the channel and surrounding geologic features; the depth and velocity of flow in the channel; the amount of fine material carried in the stream; the depth to the water table; and the temperature of the water in the stream (12-162).

Works for regulating the flow rate as was envisioned for the Upper Big Sioux River Basin consist principally of small streambed dams. The structural characteristics of the streambed dams may vary from simple temporary structures to more elaborate permanent structures. Tibbetts (11-333) recommended that the dams should not be more than two or three feet high. His reason was that, if the dams are too high, the bottom velocity of the river may be reduced to such an extent that the fine material carried in the stream may be deposited on the streambed causing a subsequent drop in the infiltration rates of the percolation pond.

Temporary structures consist of such things as collapsible rubber dams. These dams are generally installed in such a way that they can be removed or destroyed during periods of high runoff. Removal of the dams would help to prevent channel obstructions with subsequent flooding and damage to the area surrounding the recharge project (9-81). Other temporary structures may be constructed from river bottom materials to withstand low velocity flows. If it is desired, the dams can be protected from the higher velocity flows with brush, wire, riprap, vegetative cover, or other similar methods (9-82).

Permanent structures built on the river bottom would have to be designed to withstand high runoff and the battering from debris that may be carried in the stream (9-82). Tibbetts states that if elaborate, higher structures of concrete are built, their super-structures should be movable to prevent deposition of material during higher runoff flows. It should be noted that high flows may not be necessarily detrimental. High flows may tend to stir up the bed material and may even increase the infiltration rates in the percolation areas (12-162).

The techniques employed in the operation and maintenance of the streambed dams should be varied depending on the location of the projects and the character of the water. Certain problems, such as silt, rodents, mosquitos, maintenance of structures, and maintenance of infiltration rates plague all projects (9-87).

Rodents may cause operation and maintenance problems if they cause leaks in any of the structures associated with ground water management and may, along with mosquitos, become a public nuisance. The rodents can generally be controlled by poisoning or trapping and the mosquitos by fish and chemicals (9-88).

The structures can generally be maintained by routine and systematic checks. The structures should be checked for undercutting and may have to be protected with some form of riprapping. Silt and debris accumulations that may occur near and at the structures may need to be removed (9-88).

SITES FOR EVALUATION OF STREAMBED DAMS IN THE UPPER BIG SIOUX RIVER BASIN

The effectiveness of streambed dams for storage and control of outflow of the ground water remains one of the major questions that needs to be answered concerning a ground water management plan for the Upper Big Sioux Basin as proposed. One of the purposes of this investigation was to recommend areas for evaluating the use of dams if future study was considered worthwhile.

The Boswell Dam

It was considered that the future studies should be conducted in areas that would minimize expenditures and preparation time. The Boswell Dam area northeast of Lake Poinsett appears to be such an area. The principal advantage of the Boswell Dam site for the study of the effectiveness of streambed dams for ground water management is that a dam, that can be controlled, is already in place, thus eliminating the cost of building a similar structure elsewhere for study purposes.

The Boswell Dam is located on the Big Sioux River approximately three miles east and three miles north of Lake Poinsett. The purpose of the dam is to divert flood waters from the Big Sioux River into Dry Lake and thereby into Lake Poinsett. The dam was dedicated October 1, 1929 and was named for W. B. Boswell who worked many years to convince the people of the area to build such a dam. The control gates of the dam are now operated by the South Dakota Department of Game, Fish and Parks. Records of the dates that the gates are closed and then reopened are incomplete.

The geology of the Boswell Dam area is quite extensively known, especially between the river and Dry Lake and Lake Poinsett. The South Dakota Geological Survey (SDGS) has mapped the general geology of the area. In addition, the SDGS along with the East Dakota Conservancy Sub-District (EDCSD) has been interested in the interrelationship of the river stage and the water levels in the lakes and has drilled a network of test holes in this area to study the geology and the ground water in greater detail.

Figure 7 is a map of the Boswell Dam area showing the outwash areas and the locations of present observation sites.[3] For the purposes of this study the primary area of interest is that area north of the dam and the diversion channel. In this area there are presently twelve wells where ground water levels are measured and recorded. Of these twelve wells, there are only two of the wells east of the river. Surface water levels are determined at the dam, at the gates of the diversion channel, and at a bridge two miles north of the dam. These surface and ground water levels are measured and recorded, generally monthly, by the EDCSD. Measurements have been made at most of the surface water stations since 1964 and at most of the wells since 1967.

The availability of the river stage and ground water level records allowed plotting of river stage and ground water elevations on the same day to determine if there was an interrelationship between the two.

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[3]Base map from South Dakota Geological Survey Report of Investigations No. 85 (5-Plate 2). The locations of the observation sites were obtained from the East Dakota Conservancy Sub-District.

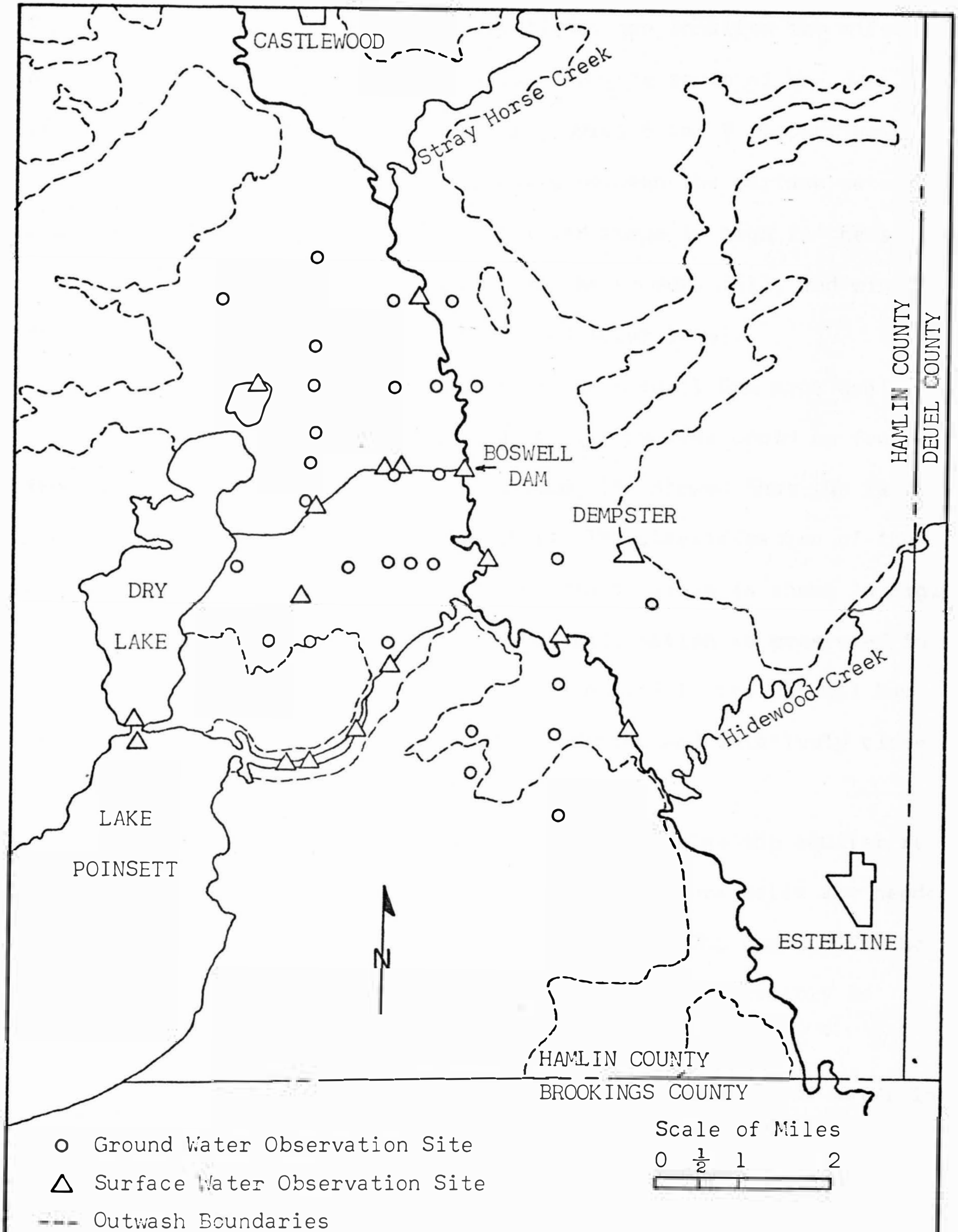

Figure 7. The Boswell Dam area showing outwash areas and locations of observation sites.

Plots were made for two different locations, one location two miles north of the dam and the other location one mile south of the dam. The plots for these locations are shown in Figures 8 and 9 respectively. The graphs show a close interrelationship between the surface water and the ground water in that when the river stage is high in the spring, the ground water table is also high. In the summer, fall, and winter the stream stage is lower as is the ground water level.

The EDCSD has aerial photographs of the Boswell Dam area available for use. Some indication of the land use in the area could be found from them. The Bureau of Reclamation study (3) showed that the land in the Boswell Dam area is generally arable. The classification of the arable land and its relationship to the outwash areas is shown in Figure 10.[4] The Bureau of Reclamation's land classification is presented in Appendix A. Figure 10 shows that the arable land in the Boswell Dam area is nearly all within the outwash boundaries and relatively close to the river.

In order to use the Boswell Dam site to determine the aquifer response to raising the water level in the channel, more wells are needed in the area to determine the ground water levels. The spacing of the additional wells is not known at this time and should possibly be determined in the field.

Some means should also be devised to measure the flow of water in the channel downstream from the dam. Van Den Berg estimated a flow of

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[4]Base map is from maps of the Hayti and Estelline Quadrangles published in 1958 by the South Dakota Geological Survey. The classification of arable land was obtained from unpublished Bureau of Reclamation maps.

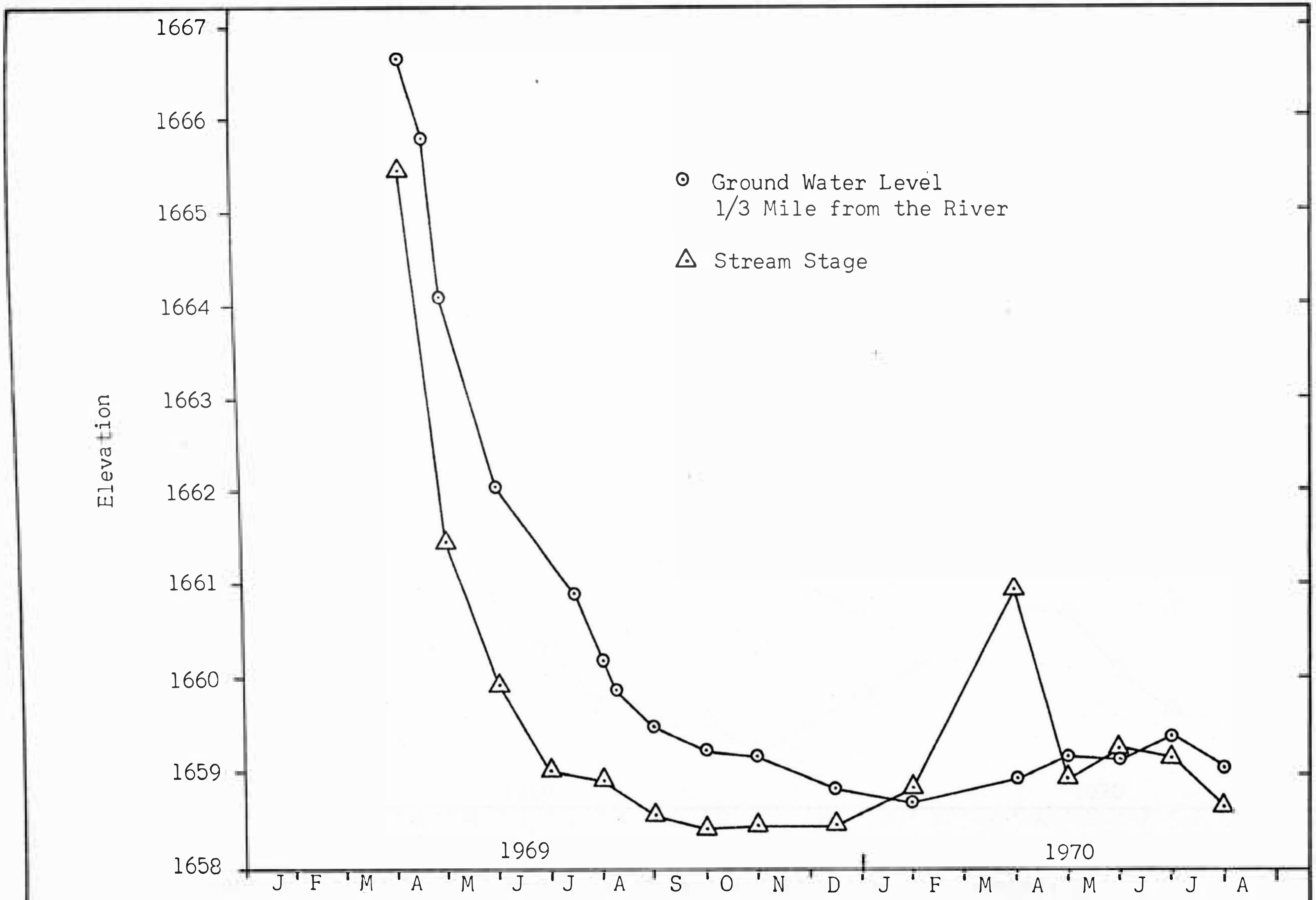

Figure 8. Ground water and surface water elevations at points two miles upstream from Boswell Dam.

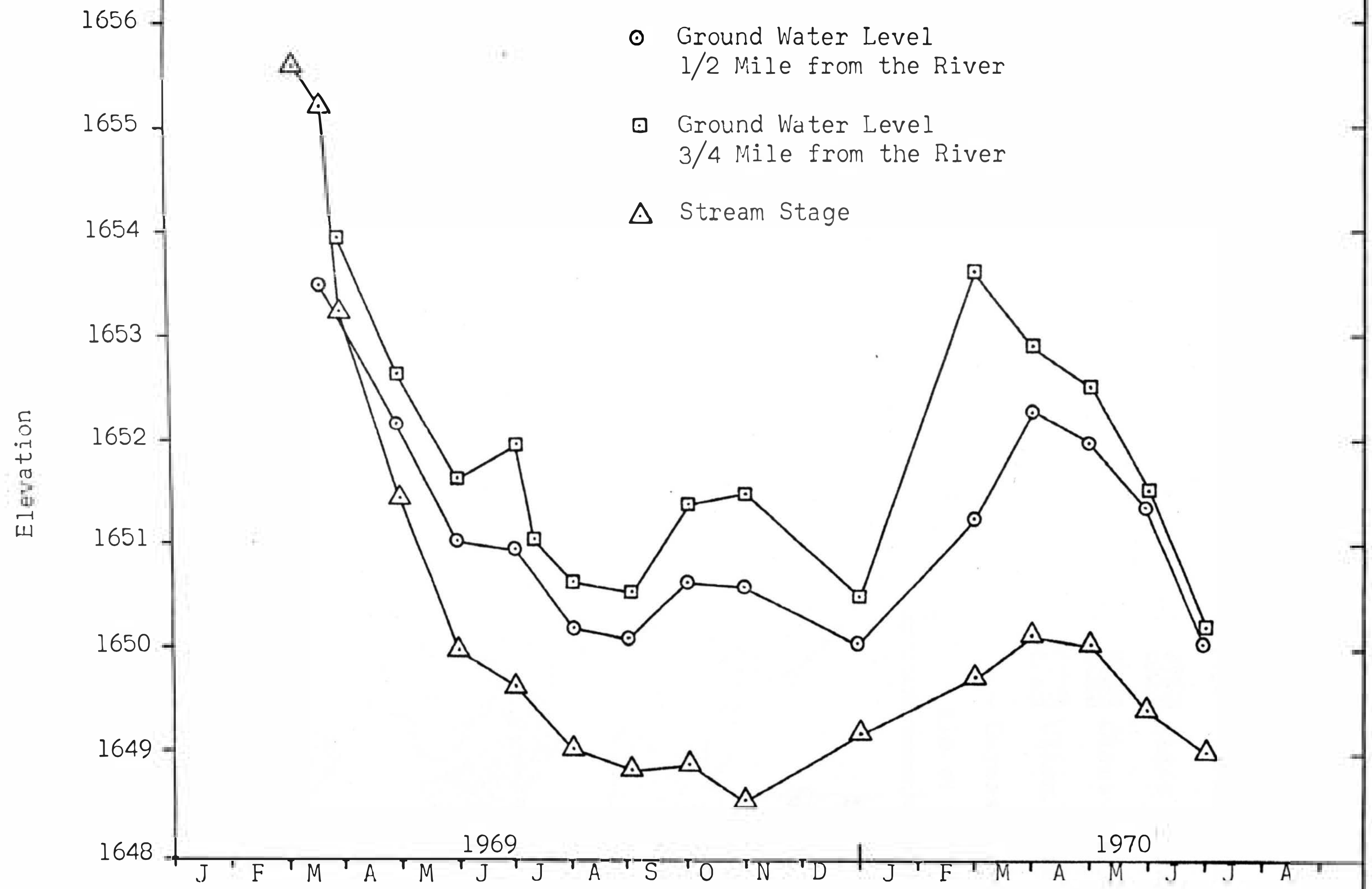

Figure 9. Ground water and surface water elevations at points one mile downstream from the Boswell Dam.

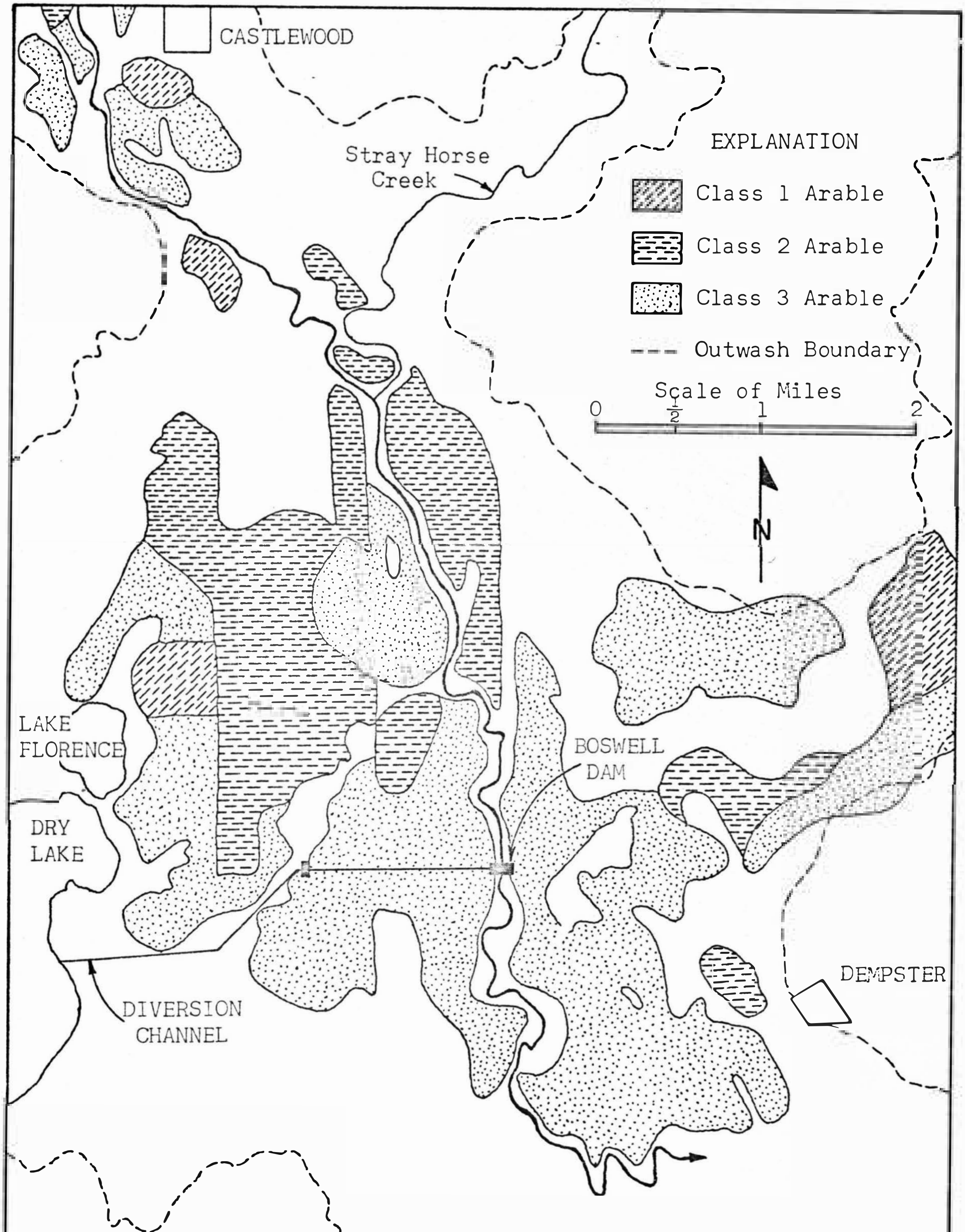

Figure 10. Relationship of arable land to outwash in the Boswell Dam area.

100 cfs below the dam in the spring of the year even with the gates closed (13-36). The Boswell Dam is presently in need of repairs and this may have been the reason that the flow downstream from the dam was great. The repairs needed to make the gates watertight include replacement of the timbers on the bottom of the gates and also the webbing around the gates. This could possibly be simplified by lining the upstream face of the dam with plastic film to make the gates watertight.

Since the dam has been in place for several years, there was a question of siltation in the reach above the dam and a visual inspection of the channel above the dam was made. A large amount of silt was present but there was also a considerable amount of sand and gravel in the channel bed. It is not known if or how much this siltation will affect the infiltration rates in the area. Since the gates are not closed all of the time, high flows that occur when the gates are open may scour the bottom sufficiently to counteract some of the siltation.

The diversion channel from the Boswell Dam to Dry Lake is a disadvantage of the area as a test site. Because of the diversion channel, the area north of the dam is not truly representative of the area that would be affected by a proposed streambed dam. When the gates of the Boswell Dam are closed, the water level will raise in the diversion channel as well as in the river channel (see Figure 10). Therefore, the ground water levels in the area north and west of the dam will be affected by infiltration from the river and the diversion channel.

The most representative indication of the aquifer response to a stream-bed dam would be north and east of the dam and the greatest amount of study should probably be conducted in that area.

Before the dam could be used, legal authority must be obtained. The technicalities involved here are not known and should be investigated. In any case, the owners and the operators of the land in the immediate vicinity of the Boswell Dam would have to be contacted to receive their permission to use their land and to drill wells for study purposes. A map showing the owners and the operators of the land in the immediate vicinity of the Boswell Dam has been made and is presented in Appendix B.

The Agricultural Engineering Research Farm

A second site for possible testing is the Agricultural Engineering Research Farm located approximately 3½ miles south and 1½ miles west of Brookings. This site also presents certain advantages and disadvantages.

The greatest disadvantage of the Agricultural Engineering Research Farm is that some form of temporary dam will have to be constructed at the site. The geology of the area has been mapped by the South Dakota Geological Survey and there are some wells in the area where ground water levels are measured. However, the geologic and the hydrologic characteristics are not as well known in this area as they are in the Boswell Dam area.

Perhaps the greatest advantage of the Research Farm as a test site is that the river flows through the farm. This is an advantage in that the area adjacent to the temporary dam can be studied extensively without the need to receive permission from private landowners.

WATER QUALITY AND AQUIFER RECHARGE IN THE UPPER BIG SIOUX RIVER BASIN

Maintaining the infiltration rate is perhaps the most difficult problem in operation and maintenance of recharge areas. Silt and debris laden water may cause a reduction in the infiltration rates if the silt is deposited on the recharge area. In severe conditions, silt accumulations may have to be removed (9-88).

The American Society of Civil Engineers Manual of Engineering Practice No. 40 states that the allowable silt concentration in waters that may be used for recharge is generally less than 1,000 ppm, with a maximum limit of about 10,000 ppm (9-90). In the Upper Big Sioux Basin there are no sampling stations on the Big Sioux River for which the water is analyzed for suspended sediment. The nearest station where suspended sediment information is available is Dell Rapids, which is about 30 miles south of the study area. Samples taken at the Brookings gaging station should be analyzed for suspended sediment in the future.

The suspended sediment data for Dell Rapids in Water Year 1968 (October 1, 1967 to September 30, 1968) is summarized by months in Table 2. The maximum and minimum concentrations are given for each month in addition to the mean and median concentrations for that month. A survey of Table 2 shows that the maximum sediment concentration determined for Water Year 1968 was 144 mg/l which occurred in April of 1968. Only four of the maximum values exceeded 100 mg/l and only in June of 1968 did the mean and median concentrations exceed 100 mg/l.

Table 2

Suspended Sediment in the Big Sioux River at Dell Rapids, South Dakota, Water Year 1968 (October 1, 1967 to September 30, 1968)*

Month	Number of Samples	Sediment Concentration (mg/l)			
		Maximum	Minimum	Mean	Median
October	31	118	9	45	43
November	27	46	10	23	20
December	21	47	12	24	20
January	6	103	46	70	72
February	18	88	44	57	56
March	6	72	14	32	26
April	30	144	46	92	94
May	28	85	36	57	58
June	22	136	69	107	113
July	29	99	70	84	82
August	5	94	85	87	88
September	30	96	55	72	68

*Compiled from 1968 Water Resources Data for South Dakota, Part 2, Water Quality Records, United States Geological Survey, United States Department of the Interior.

When compared with the American Society of Civil Engineers recommended limits of concentration, it can be seen that the sediment concentrations at Dell Rapids for Water Year 1968 are quite low and theoretically should not create a siltation problem.

The flows in Water Year 1968 were quite low and it is not felt that Water Year 1968 was a representative year of flow in the Big Sioux River. Suspended sediment information for extremes of flow of the Big Sioux River could possibly be obtained from Water Year 1969 data which contains the record floods from the spring of 1969. The data for Water Year 1969 were not available at the time of this study.

Quality control of ground water has not received as much attention as quality control of surface water. Laws and management concepts for the protection of ground water are inconsistent and less advanced than they are for surface water. For example, disposal of waste water from cities and industries to underground strata may be prohibited but not much is usually done to regulate or prohibit subsurface discharges from the millions of septic tanks in our country (1-90). It cannot be overemphasized that the quality of ground water should not be allowed to deteriorate (9-99).

The quality of infiltrating surface water has a great effect on the quality of ground water. The subsurface water may become contaminated by infiltration from polluted streams (10-195). Larger than normal quantities of surface water, and correspondingly larger quantities of dissolved solids, may be induced into an aquifer by pumping wells that are located near a polluted river. Once a body of ground water becomes contaminated it may require several decades or longer for it to return to a usable form because of the slow movement of water through the aquifer. In order to help protect ground water from pollution, surface streams will have to be protected from pollution (9-140). Organic solids may also promote the growth of slimes which could decrease the infiltration rate in an artificial recharge project (14-698).

Not enough is known about the effects of agriculture, and the various farm chemicals used, on the quality of ground water (1-91). In the West maintaining the salt balance in the soil of several irrigated valleys has caused problems in ground water quality. High evaporation losses of irrigation waters tend to accumulate or concentrate the salts in the return water. An accumulation of salts, especially sodium salts, in the soil reduces the soil permeability and thereby hinders further proper irrigation. The salt accumulation may sometimes be removed by sufficiently flooding the area to wash out the accumulation. However, some of the wash water may be returned to the ground water reservoir and would tend to increase the salt concentration in the ground water and gradually make the ground water less suitable for use (9-9).

Table 3 is a qualitative classification of irrigation waters that was included in the South Dakota Geological Survey Report of Investigations No. 85 (5-19). Table 3 includes four critical characteristics for irrigation waters--per cent sodium, boron, chlorides, and sulfates.

Table 4 includes a list of 22 wells from throughout the Upper Basin that have been tested for chemical quality. The sources of data

Table 3 (5)

Qualitative Classification of Irrigation Waters

Classification	Percent Sodium *	Boron (ppm)		Chloride (ppm)	Sulfate (ppm)
		Sensitive Plants	Tolerant Plants		
Class 1 Excellent to Good	0-40	< 0.4	< 1.00	< 71	< 192
Class 2 Good to Injurious	40-70	0.4-1.00	1.00-2.00	71-213	192-576
Class 3 Injurious to Unsatisfactory	70-100	1.00+	2.00+	213+	576+

*Percent sodium refers to the percentage of the sum of the cations sodium, calcium, magnesium, and potassium expressed in milliequivalents per liter.

Table 4

Selected Water Quality Characteristics and Irrigation Classification of Ground Water from Wells Located in the Upper Big Sioux River Basin

Well Number*	Percent Sodium	Boron (ppm)	Chloride (ppm)	Sulfate (ppm)	Irrigation Class.
1	1.2	-	10	30	1
2	7.1	-	5	83	1
3	6.5	-	10	65	1
4	10	-	15	150	1
5	12.5	-	11	64	1
6	15.9	-	18	56	1
7	26.0	-	59	150	1
8	11.3	-	180.0	415.0	2
9	8.6	-	8.0	75.0	1
10	6.5	-	10.0	63.0	1
11	16.5	-	13.0	323.0	2
12	14.5	-	20.0	88.0	1
13	5.2	-	5.0	58.0	1
14	11	0.20	21.0	162	1
15	10	0.09	3.2	84	1
16	9	0.11	11.0	131	1
17	6	0.06	3.2	64	1
18	7	0.06	2.0	89	1
19	4	0.03	3.4	60	1
20	5	0.10	2.2	247	2
21	6	0.10	2.6	184	1
22	7	0.12	16.0	223	2

*For the locations of the wells in the Upper Big Sioux Basin see Appendix C.

and the specific locations of the wells are presented in Appendix C. On the basis of the chemical analysis and the limits for the critical characteristics listed in Table 3, the ground water at each of the wells has been classified for irrigation. The results show that the ground water in the Upper Basin is generally good to excellent for irrigation. Note that the water from only four of the twenty-two wells was below the Class I (excellent to good) classification for irrigation waters and that the water from the four wells meet the restrictions for Class 2 classification and could probably be used for irrigation.

The surface waters of the Upper Big Sioux Basin have also been chemically analyzed. The data for Table 5 has been extracted from a Bureau of Reclamation report (3-27) for the purpose of comparing the surface water quality to the ground water quality in the Upper Basin. From Table 5 it would appear that the surface water is approximately of the same quality as the ground water and should not rapidly degrade the ground water quality to the point of rendering the ground water unsuitable for irrigation.

Table 5

Selected Surface Water Quality Characteristics of the Big Sioux River

Location and Date of Collection	Percent Sodium	Boron (ppm)	Chloride (ppm)	Sulfate (ppm)	Dissolved Solids Residue @ 180 C	Sodium Adsorption Ratio	Specific Conductance μmhos/cm @ 25^{0} C
At Watertown							
June 2, 1960	10.6	0.11	2.2	83	359	0.4	558
March 29, 1962	4.2	0.11	0	14	96	0.1	154
Near Brookings							
June 2, 1960	16.9	0.19	23	209	596	0.8	846
October 11, 1960	13.0	0.14	27	200	590	0.6	866
March 18, 1961	9.9	0.07	7.1	74	276	0.3	418
March 30, 1962	9.3	0.06	0	54	179	0.2	272

POTENTIAL RESULTS OF GROUND WATER MANAGEMENT

According to the American Society of Civil Engineers Manual of Engineering Practice No. 40, a principal benefit derived from using a ground water aquifer as a storage reservoir for surplus surface waters is the great savings in cost of equivalent surface reservoirs and the appurtenant facilities (9-93). This is especially significant in areas where there are few, if any, natural surface reservoir sites (9-93). The Upper Big Sioux River Basin is an area that has few natural surface reservoir sites (3-47).

A ground water management plan must consider the multiple use of all project facilities. These facilities may specifically be designed to recharge and conserve water but they may also serve as wildlife habitat, recreational areas, or generally improve the environment in their areas (1-92).

On August 25, 1970, this author obtained a personal interview with Dr. Donald Progulske, Professor and Head of the Wildlife and Fisheries Sciences Department at South Dakota State University. The nature of the proposed streambed dams was explained to Dr. Progulske and he was asked if he envisioned any wildlife damage or benefit to result from the proposed projects. Dr. Progulske stated that as long as there was no surface flooding of the land he could forsee no damage but only benefit to wildlife. He said that the deeper pools created by the dams should enhance fish propagation and may also be beneficial to the waterfowl of the area.

According to the Economics Department report, a large quantity of the land in the Upper Big Sioux Basin could be economically developed for irrigation, depending upon the availability of an adequate water supply (4-98). If the land were developed for irrigation, the individual irrigators should realize substantial capital gains. On the basis of the possible higher standards of living achieved by the individual irrigators in the area, the entire area economy should benefit. Implementation of a ground water management program could help provide the water required for irrigation development in the Upper Basin.

Herreid (15) and Naughton (16) both concluded that the quantity of flow in the Big Sioux River upstream from Sioux Falls is an important factor in maintaining the water quality in the river downstream from Sioux Falls. Herreid (15) and Rakness (2) reported that the frequency that the intermittent stream category (waste discharge greater than stream flow) would be applicable to the Big Sioux River will increase significantly in future years unless additional dilution water can be provided for the waste discharges. The flow in the Big Sioux River during the late summer, fall, and winter months is sustained almost entirely from ground water. If the natural and artificial storage caused by the proposed streambed dams in the Upper Basin was released in the late summer, the flow in the river could be sustained at a higher rate and the increased flow could provide additional dilution water quality control at Sioux Falls.

It should be realized that all of the results of the proposed method of ground water management may not be beneficial. Maintaining the water table at higher than usual levels may cause some land to become swampy and useless for agricultural crops. Subsurface excavations, such as gravel pits, may become flooded and homes relatively close to the river may be adversely affected by a constantly high water table. The river bank stability might also be affected by the higher water levels in the channel and in the adjacent aquifer. Therefore, the streambed dams should be planned and located to minimize any damages.

ADMINISTRATIVE ASPECTS OF GROUND WATER MANAGEMENT IN THE UPPER BIG SIOUX RIVER BASIN

Effective ground water management cannot be successful when piecemeal management methods are used. In many areas most regulatory agency boundaries are the same as civil boundaries and not the aquifer boundaries. Efficient management can rarely be achieved when several different agencies, each having somewhat different powers and objectives, try to manage a naturally occurring resource (17-640, 641).

It has been suggested that ground water management could best be accomplished locally by the people directly affected (18). In the Western states, including South Dakota, the water users have an important voice in the development and use of the ground water reservoirs because they have established rights to the ground water (9-8). Therefore, a public district organization with broad powers to manage the basin development appears to be the best administrative unit. Up to now the public district has had little experience in the field of ground water management but enough experience has been gained to indicate that it can play a useful role (19-310, 311).

The East Dakota Conservancy Sub-District

A public district organization that appears to have the authority to administer a ground water management plan for the Upper Big Sioux Basin already exists. This organization is the East Dakota Conservancy Sub-District, which was set up under the Water Conservancy District Law (Chapter 61.14 SDC 1960 Supp. as amended) passed by the 1959 South

Dakota legislature. The legislation placed the entire state in a Conservancy District with provisions to create Sub-Districts. At the November 1962 election the people of the Big Sioux River Basin voted to create a Sub-District in the Basin. An eleven man Board of Directors was also elected, eight representing the rural areas and three representing the municipalities.

The East Dakota Conservancy Sub-District is now comprised of $11\frac{1}{2}$ counties in the Big Sioux River Basin (see Figure 11). The purpose of the Sub-District is to give the local people a means to plan, develop, and utilize the water resources of the Basin. The Sub-District has also done much to initiate and coordinate investigations among the many organizations that are interested in water resources development in the Big Sioux River Basin.

Administrative problems that will have to be considered by the management organization before a ground water management plan can be implemented in the Upper Big Sioux Basin include legal considerations, financial considerations, and public relations. The responsibility for the operation and maintenance of any projects will also fall to the management organization.

Legal Considerations

Although many questions will be raised for legal consideration, many of the questions should be solved during the process of formulating the ground water management plan (20-62). Before a management plan can be implemented, the laws of the area must be studied and the plan should be designed to effectively and economically manage the water

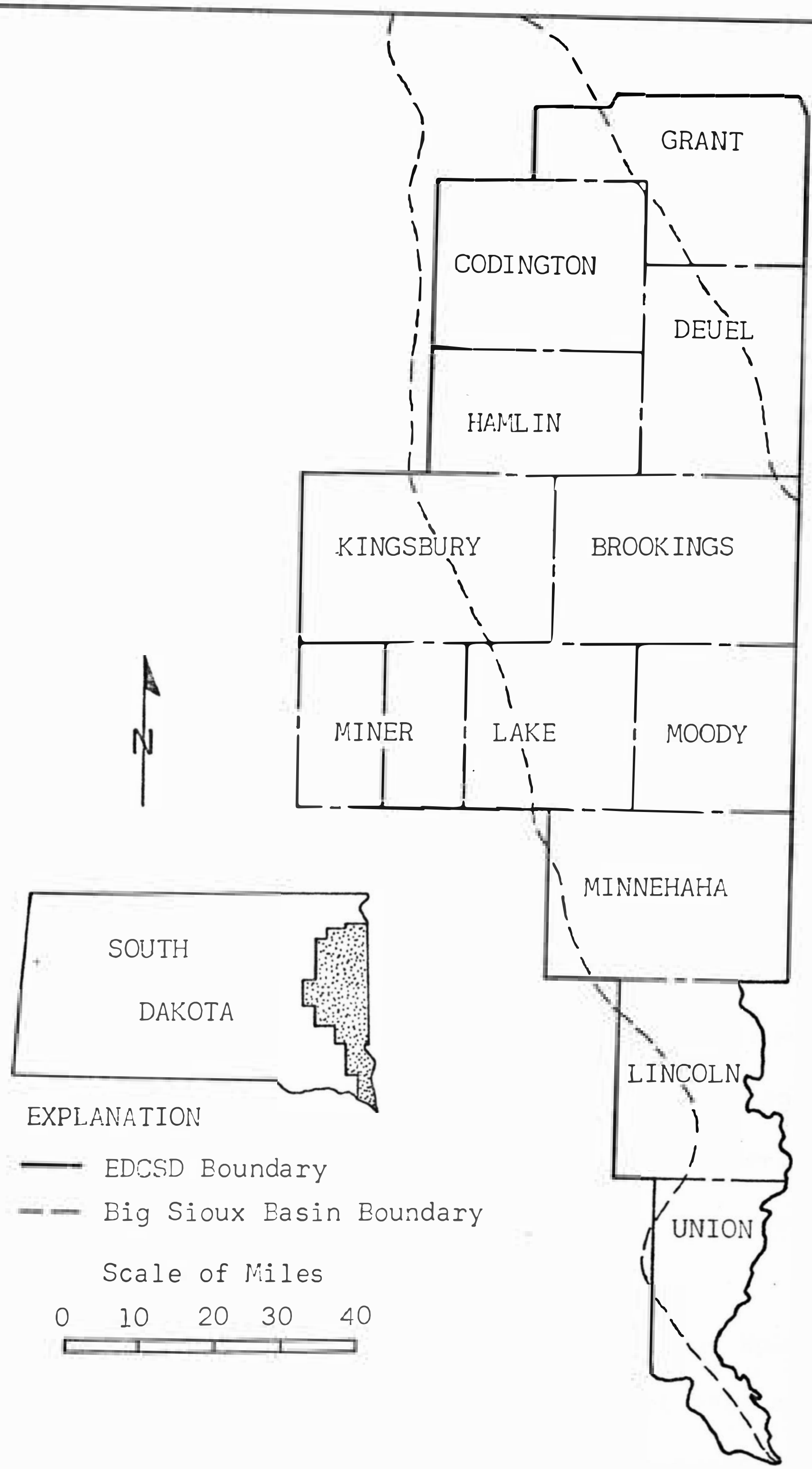

Figure 11. Location map of the East Dakota Conservancy Sub-District and the Big Sioux River Basin in South Dakota.

resources under the law. There may be numerous individual private property rights which interfere with the plan implementation. Before effective management and regulation over the underground resources can be achieved, all interests and rights in the ground water basin must be determined and then acquired and controlled by the management authority. Methods of acquiring, condemning, or otherwise harmonizing these existing rights with the management plan must be devised (1-87). There may be many parties to the action and it may take several years and be very expensive to complete (21).

In seeking the legal authority to use the underground storage space, care must be taken to protect the rights of those who depend on the basin or own land over it (22-99). Any effects of artificial recharge on the Basin and on the people who get their water supply from underground must also be determined. This must be done so that any injury or benefit to the overlying land owners can be determined (20-58). If the organization controls any artificial recharge activities, care must be taken to avoid any conditions that may result in high water table damage. Examples of high water table damage might be swampy land, flooding of excavations, and saturation in underground structures not designed for such conditions. Law suits or adverse claims may result from any such damage (23-1342).

The legal right to use the underground storage space by persons or agencies other than the overlying owners has not been questioned. In the areas where some form of ground water basin management has been attempted, it has been done under existing laws (24-1374). However, some essential ground water management programs may not be implemented because of the possibility of adverse claims and lawsuits with respect to the utilization of the underground storage. Revision and adoption of laws concerning underground storage may be needed (24-1376).

An important legal problem associated with any artificial recharge operation is the identification of the water that has been placed underground (20-58). Most ground water law covers the use of the natural ground water with little reference made to water placed underground by man's activities. The question arises here as to who may claim title to the supplemental water. In most Western states, including South Dakota, unappropriated ground water belongs to the state. If the state recharges water under land it does not own, it is acting in the public's interest as a non-land owning agency (10-304).

There is a close interrelationship between ground water and surface water in the Upper Big Sioux Basin, and, because of the intimacy of the interconnected supplies, there will have to be complete coordination of the legal rights to the use of the supplies (9-123). A check will have to be made on whether a proposed ground water development project will adversely affect surface water usage, and vice versa (25-1155).

Financial Considerations

One of the most controversial questions to answer is how a ground water management and particularly a recharge project is to be paid for. The major costs of a project include land and easements, engineering and construction, and operation and maintenance. These costs must be evaluated to determine the financial feasibility and the economic justification of the project. The cultural development of the area will have a decided effect upon the capital cost of a given project. Financial feasibility refers to the ability of the people who benefit from the program to repay the cost of the projects. Economic justification, expressed as a cost-benefit ratio, allows comparison of alternatives to select the most economical project (9-90).

It is generally conceded that some form of tax must be levied against the project beneficiaries to pay for the project. There are basically three alternatives (26-387):

(1) An ad valorem property tax.

(2) A tax on all ground water withdrawn.

(3) A tax on water pumped in excess of a person's adjudicated rights.

East Dakota Conservancy Sub-District receives its funds from an ad valorem property tax on the Big Sioux Basin. Since the entire Basin may not receive equal benefits of a ground water management program in proportion to property valuations, it may be necessary to devise some means of taxing only the main project beneficiaries. In any case, the merits of each type of tax will have to be weighed and a decision made as to which is the best to finance a ground water management plan for the Upper Big Sioux Basin. The main point to realize is that regardless of the method chosen to finance the plan, the community as a whole will be required to pay about the same amount of money (26-387, 388).

Public Relations

The value of a well formulated and sound public relations program cannot be over emphasized. Most people, both laymen and professional, in government policy making positions do not understand the facets of ground water resources management. The full value of research efforts will not be realized unless all of the potential results and their significance are understood by all those concerned at policy making levels of government (1-95). It will be the responsibility of the management organization to communicate the ideas of ground water management in the political arena to gain acceptance of the use of ground water basins in broad-scale water resources management (27).

Perhaps an even more difficult problem arises with the education of the individual water users and the public as a whole. To receive any benefit from an aquifer, it must be used. Water users generally do not realize that their wells must produce a cone of depression thereby lowering the water table or the wells will not produce water. Many people feel that maximum development of an aquifer by wells is contrary to good concepts of conservation. The limitations of the aquifer should be somehow determined and the people should be told how to best develop the aquifer's potential and then encouraged to use the system to derive its maximum benefits (17-642).

SUMMARY AND CONCLUSIONS

Ground water resource management is the planned utilization of the ground water and the ground water storage capacity to provide maximum benefits to the area concerned. Development of a comprehensive plan to accomplish this objective is by no means a simple matter. Specific problems that may be encountered in the plan formulation include a possible lack of geologic and hydrologic information in certain areas; setting up an organization with adequate powers; operation and maintenance of projects; maintenance of ground water quality; legal problems; development of a means of financing a ground water management program; and development of a public relations program.

Basic to any ground water management program is a complete knowledge of the geologic and hydrologic characteristics of the basin. The geologic and hydrologic characteristics govern the physical aspects of the program, including site selection and the need for, and size of, projects for the management of ground water. The Upper Big Sioux Basin geology was formed by glaciers and the general geology of the area has been studied and mapped. The geologic studies of the Upper Sioux Basin show that glacial outwash deposits are common in the Big Sioux River valley and that the outwash deposits are a source of shallow ground water.

The Big Sioux River valley upstream from Flandreau represents 70.5 per cent of the arable land in the Big Sioux valley in South Dakota, excluding the Rock River and Skunk Creek tributaries. The arable land in the Upper Big Sioux Basin has not been developed for irrigation to a great extent as yet, even though the arable lands in the area are generally located over areas of shallow ground water.

There are no major sites on the main stem of the Big Sioux River in the Upper Basin for artificial storage reservoirs for surface water. The only sites available for man-made storage reservoirs are on minor tributaries and would provide limited water for over-all Upper Basin irrigation development.

The degree to which irrigation development could occur in the Upper Big Sioux Basin under the present conditions is not known because the safe yield of the Upper Big Sioux aquifers is not known. The ground water usage in the area has not been large enough to allow determination of the aquifer's safe yield.

Since the quantity of surface water available for artificial recharge could be a limiting factor in the need for, and size of, ground water management projects, an evaluation should be made of the quantity, quality, and character of the water supply to be utilized. The yield of water from the Big Sioux Basin upstream from the Brookings gaging station can be determined by studying the flow records from the Brookings gaging station. Analysis of the flow records from the Watertown gaging station shows that there has always been some flow entering the north end of the study area in the early spring months that could possibly be stored in the Big Sioux aquifer.

The major source of recharge for the Big Sioux valley aquifer is precipitation. However, artificial recharge of aquifers can often be accomplished efficiently and economically by use of the main stream channel bed. If the flow rate in the channel is controlled, greater recharge from the channel will frequently result. Streambed dams would provide a means for regulating the flow rate in the stream by controlling the flow velocity and also increasing the area of streambed covered by water. The streambed dams may serve a dual purpose by holding ground water in the aquifer that would otherwise be lost downstream if the dams were not present.

Care must be taken in velocity control by the streambed dams so that the velocity is not reduced to an extent that an extreme amount of silt is deposited in the stream channel. The dams should be movable or controllable so that highly silt-laden waters are not allowed to deposit their loads on the infiltration area. Records of the silt concentrations in the Big Sioux River in the Upper Basin are not available but silt concentrations should be measured in the future. The nearest point at which some silt records are available is Dell Rapids. An indication of the silt loads in the Upper Basin could perhaps be obtained from the Dell Rapids records.

An organization must be set up with adequate power to effectively manage the system. Education programs to gain public support of ground water management should be established and a suitable method of financing a management program will have to be determined. An interpretation of the laws and water rights in the Big Sioux Basin will have to be made to determine the legality of a management program. The responsibility may fall to the State Legislature to revamp the State's water laws to provide for ground water management.

The information needed for development of a ground water management plan must be collected for a number of years prior to and after implementing a management plan. There should be a continuous study of the area, its land uses, and geology; constant measuring and recording of data; and control of all factors possible to provide optimum development of the water resources.

Specific conclusions drawn from this investigation include the following:

1. Although the general geology of the Upper Big Sioux Basin is known, more specific geologic studies of the area would probably have to be undertaken before a plan for ground water management could be fully developed and implemented.
2. Because there are few sites for artificial storage of surface water in the Upper Big Sioux Basin, use of the ground water aquifers for storage of surface waters may serve as an alternative to high priced surface storage sites.
3. The quality of the shallow ground water in the Big Sioux aquifers is generally good to excellent for irrigation. The quality of the surface water available for infiltration appears satisfactory and would probably not degrade the quality of the shallow ground water.
4. A ground water management plan may help to provide the necessary water for future irrigation development in the Upper Big Sioux River Basin.
5. Additional dilution water for water quality control downstream from Sioux Falls may be provided in the late summer, fall, and winter months

by releasing the natural and artificial storage retained by the proposed streambed dams in the Upper Big Sioux Basin.

6. Controllable streambed dams on the Upper Big Sioux would probably provide an over-all benefit to wildlife by providing deeper pools for fish propagation and possible waterfowl enchancement.

7. Because there is a definite interrelationship between ground water levels and surface water levels in the Boswell Dam area, the Boswell Dam appears to be an excellent site for a preliminary evaluation of the feasibility of streambed dams as a means of accomplishing ground water storage and controlling ground water outflow.

8. The East Dakota Conservancy Sub-District is an organization that would probably have the authority to administer a ground water management program for the Upper Big Sioux River Basin.

9. The Big Sioux River Basin in its present state of development does not need an extensive ground water management plan. However, in the face of ever increasing demands for water and a lack of suitable surface sites in the Upper Sioux Basin for water development, it appears that the management of the ground water in the Basin should receive more attention as an alternative for increasing the available supply of water during water short periods, such as late summer, fall, and winter. Because it may take a number of years to formulate a plan for effective and efficient management, the Basin may well profit from the initiation of a program to study ground water management.

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APPENDIX A

United States Bureau of Reclamation

Arable Land Classification

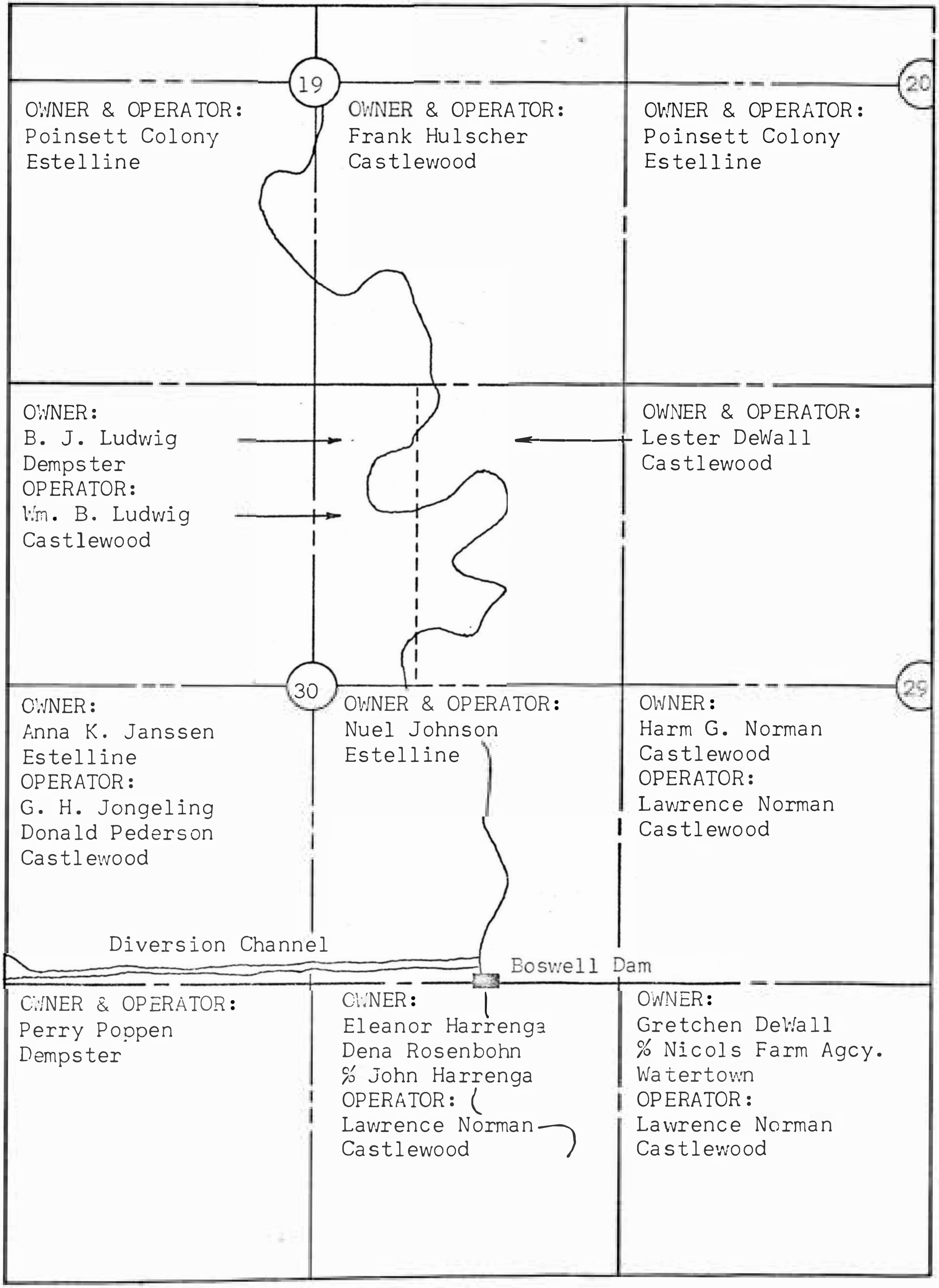
The Bureau of Reclamation in their study of the Big Sioux River Basin recognized four land classifications: Class 1, Class 2, Class 3, arable, and Class 6, non arable. The Bureau's description of each land class is as follows (3-21):

> Class 1, arable: Lands in this class are highly suitable for irrigation farming and are capable of producing a wide range of crops at reasonable cost.
>
> Class 2, arable: Lands in this class are of moderate suitability for irrigation farming and are measurably lower than Class 1 in productive capacity. They are adapted to a somewhat narrower range of crops, more expensive to prepare for irrigation, or more costly to farm.
>
> Class 3, arable: Lands in this class have restricted suitability for irrigation because of more extreme deficiencies in soil, topography, or drainage.
>
> Class 6, nonarable: Lands in this class do not meet the minimum requirements of Class 3, arable, for reasons of extreme deficiencies in one or more factors of soil, topography, or drainage.

A more comprehensive description of the U. S. Bureau of Reclamation general land classification specifications can be obtained from Water Resources Engineering by Linsley and Franzini (28-379).

APPENDIX B

Land Owners and Operators in the Boswell Dam Area


19
20
OWNER & OPERATOR:
Poinsett Colony
Estelline
OWNER & OPERATOR:
Frank Hulscher
Castlewood
OWNER & OPERATOR:
Poinsett Colony
Estelline
OWNER:
B. J. Ludwig
Dempster
OPERATOR:
Wm. B. Ludwig
Castlewood
OWNER & OPERATOR:
Lester DeWall
Castlewood
30
29
OWNER:
Anna K. Janssen
Estelline
OPERATOR:
G. H. Jongeling
Donald Pederson
Castlewood
OWNER & OPERATOR:
Nuel Johnson
Estelline
OWNER:
Harm G. Norman
Castlewood
OPERATOR:
Lawrence Norman
Castlewood
Diversion Channel
Boswell Dam
OWNER & OPERATOR:
Perry Poppen
Dempster
OWNER:
Eleanor Harrenga
Dena Rosenbohn
% John Harrenga
OPERATOR:
Lawrence Norman
Castlewood
OWNER:
Gretchen DeWall
% Nicols Farm Agcy.
Watertown
OPERATOR:
Lawrence Norman
Castlewood

APPENDIX C

Locations of and Sources of Water Quality Data
for Selected Wells in the Outwash Areas
of the Upper Big Sioux River Basin

Well Number*	County	Location
1	Codington	Sec 27, T118N, R53W
2	Hamlin	Sec 22, T115N, R52W
3	Hamlin	Sec 24, T114N, R52W
4	Brookings	Sec 1, T112N, R52W
5	Codington	Watertown Well #2
6	Hamlin	Estelline Well #1
7	Hamlin	Castlewood Well #2
8	Brookings	Sec 2, T111N, R51W
9	Brookings	City of Aurora
10	Brookings	City of Bushnell
11	Brookings	Sec 12, T110N, R49W
12	Brookings	City of Volga
13	Brookings	Sec 1, T111N, R51W
14	Codington	Sec 28, T116N, R52W
15	Hamlin	Sec 27, T115N, R52W
16	Hamlin	Sec 6, T113N, R51W
17	Hamlin	Sec 23, T113N, R51W
18	Brookings	Sec 30, T112N, R50W
19	Brookings	Sec 36, T111N, R51W
20	Brookings	Sec 8, T109N, R50W
21	Moody	Sec 25, T108N, R49W
22	Hamlin	Sec 7, T114N, R51W

*The water quality data for the wells were obtained from several sources: wells 1 through 7 from page 17 of reference 5, wells 8 through 13 from page 16 of reference 6, and wells 14 through 22 from pages 36 and 37 of the 1966 South Dakota Water Resources Commission Observation Well Report.