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The 1970's: A Decade of Growth in South Dakota Irrigation

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SUMMARY

South Dakota ranks twentieth in the nation in its irrigated acreage. Depending on how "irrigation" is defined, South Dakota has between 450,000 and 500,000 acres of irrigated land. About 375,000 acres has been developed under State-issued permits by private individuals and groups. An additional 66,450 acres comprise the Belle Fourche and Angostura Federal Irrigation Projects, although in any one year not all of this land is necessarily irrigated. About 52,300 acres of "dry draw, spreader" irrigation involves the intermittent backing up of water behind dams in small creeks for occasional irrigations by farmers and ranchers in the West River Region. Finally, about 15,000 acres are irrigated under vested water rights originating before 1907 and by Indian tribes. The primary source of ambiguity in the irrigation statistics for South Dakota is whether "dry draw, spreader" irrigation is included in the count.

The most distinctive features of South Dakota's irrigation are as follows.

1. Between 1969 and 1978, the area irrigated in South Dakota increased by over 2.3 times. This was a faster relative rate of development than that in any of the other nine Great Plains states (Colorado, Kansas, Nebraska, Montana, New Mexico, North Dakota, Oklahoma, Texas, and Wyoming), and was second only to that in Georgia in the nation.
2. Between 1969 and 1979, the total privately-developed irrigated area in South Dakota increased at a compound annual rate of almost 18 percent. The annual growth rate was highest in the Missouri Mainstem Region (22 percent) and lowest in the West River Region (11 percent). The pace of irrigation development

in the State was most rapid between 1974 and 1977 when strong farm commodity prices and drought were commonly experienced.

3. Between 1970 and 1979, the compound annual growth rate in privately-developed surface irrigation in the State was 13 percent. For irrigation from groundwater sources, the growth rate was 22 percent per year. Even with this unusually rapid rate of groundwater development during the 1970's, the percentage of ~~total~~ on-farm pumped irrigation water from groundwater sources for South Dakota (about 55 percent) is relatively low compared to all other Great Plains states except for Montana (13 percent groundwater). The percentage for the other states ranges from 61 in Wyoming to 97 in Kansas, and averages 85 for the Great Plains states as-a-group and 78 throughout the U.S.

4. Between 1969 and 1979, the percentage of the irrigated area covered by State-issued "permits" that was actually under irrigated production in South Dakota increased from less than 25 to more than 35. This upward trend reflects changes in both the regulations surrounding the granting of permits and the perspectives of farmers concerning their applying for irrigation permits.

5. In 1982, irrigation water was distributed on about 87 percent of South Dakota's total irrigated area by pressurized sprinklers. This percentage far exceeds the 31 percent average for the Great Plains states as-a-group. Further, in no other Great Plains state, except North Dakota, does more than one-half of its total irrigated area involve sprinkler water distribution.

6. Center pivot systems dominate South Dakota and North Dakota irrigation to an extent that no other irrigation method dominates in any other Great Plains state. In 1982, about 70 percent of the irrigated area in each of these states involved center pivot water distribution. In no other Great Plains state, was the percentage greater than 35.

Two features of the 1970's undoubtedly help to explain the dominance of center pivot irrigation in the Dakota's. This was a time when both (a) the relative rate of expansion of irrigation in the Dakota's exceeded that in the other Great Plains states and (b) the center pivot technology became well-developed and was readily available on the market.

7. In 1982, 80 percent of South Dakota's irrigation systems were electrically-powered. Electricity is the dominant power source for irrigation in Colorado, Montana, North Dakota, and Wyoming as well. In Kansas, New Mexico, Oklahoma, and Texas, however, natural gas is the most common energy source.

8. In 1982, the average irrigation application in South Dakota was 15 inches. This is less than the average of 21 inches for the Great Plains states as-a-group, and less than one-half the amount applied in either New Mexico or Montana. One probable explanation for differences in water application rates undoubtedly involves the mechanism by which the payment for irrigation water is made.

In states like South Dakota where the vast majority of irrigation water is distributed under pressure powered by privately-owned pumps, the payment for irrigation water is

essentially volumetric. The more water applied, the greater is the charge to the irrigator for his water. In states like New Mexico or Montana which have mainly publicly-supported surface irrigation and fixed per acre charges for water, on the other hand, irrigators do not have economic incentive to monitor carefully the amounts of irrigation water applied.

9. The principal crop grown under irrigation in the Dakota's--corn--covers about one-half the total irrigated area in each state. Of the great Plains states, the ratio is higher only in Nebraska (two-thirds). Corn accounts for slightly less than one-third of the irrigated areas in fourth and fifth ranking Colorado and Kansas and for as little as two percent of the irrigated areas in Wyoming and Montana.

THE 1970's: A DECADE OF GROWTH IN SOUTH DAKOTA IRRIGATION

by Donald C. Taylor

INTRODUCTION

Irrigation was practiced in the United States as early as 1,000 B.C. when the Hohokam Indians built canals to irrigate crops in the Salt River Valley of Arizona. During the 16th and 17th centuries, Spanish settlers and missionaries established modest irrigation works in the same general area. They introduced new irrigation techniques and practices which had been employed for centuries in their homelands.

The modern history of irrigation in the U.S. began as pioneers moved in the mid-1800's into the arid and semi-arid west. Many of the settlers adopted and built upon the Spanish-American irrigation techniques. The development of irrigation initially involved the diversion of water onto the level valley lands immediately adjacent to streams. Over time, more elaborate control structures (e.g., dams and reservoirs) and larger networks of conveyance and distribution channels were introduced so that lands more distant from the streams could be irrigated. The successful development of deep-well drilling equipment and power-driven centrifugal pumps gave farmers increased access to supplies of surface and groundwater for irrigation development (ITFR, 1979).

Underlying these developments were national policies to settle people and support irrigation development in the West. The Federal Reclamation Act of 1902 and the Federal Flood Control Act of 1944 were the principal pieces of legislation that provided public support for irrigation development in the U.S.

Irrigation development in South Dakota: an overview

In South Dakota, irrigation was initially introduced on small, isolated tracts of land in western areas of the State. The pioneer irrigators often found it advantageous to form mutual groups known as ditch companies. By the beginning of the 20th century, several simple gravity-diversion structures had been established along tributaries to the Cheyenne River such as Rapid Creek, the Redwater River, and the Belle Fourche River. These structures enabled the irrigation of approximately 26,000 acres of low benchlands along the rivers. A smaller total area was developed by individuals and private groups in other river basins west of the Missouri River (USGS, 1964, 224).

The data in Table 1 provide a picture of the pace of irrigation development in South Dakota over nearly the past century. The most rapid relative rate of irrigation development took place during the final decade of the 19th century when the acreage nearly tripled. The irrigated area continued to expand thereafter--especially with the completion in 1914 of the federally-supported Belle Fourche Project in west central South Dakota[1/]--until 1919. Over the next 25 years, the irrigated area in South Dakota dropped--from 90,000 acres in 1919 to 52,895 acres in 1944. The interest and involvement in irrigation rebounded following the depression, however, and by 1954 an area equal to that in 1919 was again irrigated.

Since 1944, the area irrigated in South Dakota has increased without interruption. The most marked decade-to-decade increase in irrigated area took place between 1969 and 1978 when 193,000 additional acres were placed under irrigation in South Dakota. The 130 percent increase in irrigated area represented by this increment between 1969 and 1978 greatly overshadows the 30 percent increase in irrigated area for the U.S. as-a-whole (Jensen, 1980, 5).

The purpose of this paper is to examine the nature of the rather "explosive" development of irrigation in South Dakota during the 1970's. The dominant force underlying this development has been the effort of individuals and private groups. This contrasts with public support which was the dominant propelling force in the earlier development of irrigation in much of western United States.

Sources of data used in the study

The major data-set upon which this paper is based is that reported by the Office of Water Rights (OWR) in the South Dakota Department of Water and Natural Resources. Each year since 1968, the OWR has requested individual irrigators in South Dakota to complete a questionnaire reflecting their use of irrigation during each crop season.[2/] A main reason for conducting the survey is to obtain information that will enable a determination of whether "licenses" should be granted on land for which irrigation "permits" have been issued.[3/]

Examples of the information covered in the questionnaires are permit and actually irrigated areas for both surface water and groundwater sources, types of systems for distributing irrigation water, types of energy used for pumping irrigation water, the frequency and duration of irrigation water applications, and the acreages of individual crops raised under irrigation.

The questionnaires cover the area within the State for which irrigation permits have been issued. This includes all irrigation in the State except for that undertaken (1) in the Belle Fourche and Angostura Federal Irrigation Projects, (2) via "dry draw, spreader" irrigation, (3) under "vested" water rights originating before 1907,[4/] and (4) by Indian tribes. Only the first two categories--which involve federal irrigation projects and the somewhat sporadic backing up of water in small watercourses by farmers and ranchers

behind simple dams in the West[5] --involve substantial acreages. A reasonable, interpretation of the OWR questionnaires is that they cover that part of the State's irrigation which is privately developed and rather intensively used. The term "privately-developed" is used in this manuscript as short-hand for the irrigation covered by the OWR data.

Each year the OWR summarizes the data reported by the individual irrigators. Beginning in 1973, the data have been summarized for each of the State's 14 river drainage basins.[6] Prior to that, either data on only part of the State had been summarized or the data that were summarized were not shown separately for the individual river drainage basins.

In this paper, the OWR data are reported beginning with the earliest year for which they are available--usually 1969 or 1970, but sometimes 1968. The most recent year for which the data are summarized is 1979,[7] and hence observations in the basic data-set terminate with 1979.

Data included in this paper which are not from the OWR annual summaries are shown by source.

South Dakota's river drainage basins

In this paper, South Dakota's 14 river drainage basins are divided into three regional categories: The Missouri Mainstem Region (including the chain of man-made lakes: Oahe, Sharpe, Lake Francis Case, and Lewis and Clark), the basins east of the Missouri Mainstem which are termed the East River Region and those west of the Missouri Mainstem which are termed the West River Region. The component river drainage basins comprising the East and West river regions are (Figure 1):

--West River: Bad, Belle Fourche, Cheyenne, Grand, Little Missouri, Moreau, Niobrara Tributaries, and White; and

--East River: Big Sioux, James, Minnesota Tributaries, Red Tributaries, and Vermillion.

The entire State, except for a small section in the extreme northeast, is drained into the Missouri River. The unglaciated area west of the Missouri River is drained by generally eastward and northeastward flowing streams. From north to south, these are the Grand, Moreau, Cheyenne (into which the Belle Fourche River drains from the west), Bad, and White Rivers.[8/] Most of the glaciated eastern part of the State is drained by the southward-flowing James, Vermillion, and Big Sioux Rivers. The balance is drained northerly by the Red River or southeasterly by the Minnesota River.

Factors that critically influence the development of irrigation in any region include the region's human, water, land, and climatic resources. Selected data on these various factors for the three regional divisions in the State, and the component river drainage basins, are provided as a back-drop for interpreting the results of the analysis in this report.[9/]

Human resources. About one-fourth of South Dakota's total population in 1970 lived in the West River Region (Table 2). The 77,491 population in the Cheyenne River Basin was more than double that in either the second or third ranking Belle Fourche and White river basins. At the other extreme, the 370 people residing in the Little Missouri River Basin constituted less than 0.1% of the State's total population.

In 1970, about 13 percent of the State's population resided in the Missouri Mainstem Region, and about 61 percent resided in the East River Region. The two most populous East River basins--the Big Sioux and James--accounted for almost one-half of the State's total population in 1970.

Of the State's total population, about 38 percent is estimated to be rural. The proportion of rural people in the West River and Missouri Mainstem regions--41 percent--is slightly higher than that in the East (36 percent).

Most of the river basins experienced losses in both their total and their rural populations between 1950 and 1970. The river basins experiencing the greatest total population reductions (all greater than 20 percent) were the Big Sioux Coteau, Red Tributaries, Missouri Coteau, and the Grand. On the other hand, the Cheyenne, Belle Fourche, and Big Sioux river basins all experienced a substantial growth (ranging from 12 to 45 percent) in their total populations. This growth is associated with population increases in certain key towns and cities in the river basins, namely, Rapid City in the Cheyenne Basin; Belle Fourche, Spearfish, and Sturgis in the Belle Fourche Basin; and Sioux Falls and Brookings in the Big Sioux Basin.

The Cheyenne and Belle Fourche river basins experienced some growth in their "rural" populations between 1950 and 1970. This growth, however, was associated with increasing numbers of rural residents living in close proximity to towns and cities. In all other river basins, the rate of reduction in rural population was greater than that for the total population. This reflects relatively rapid off-farm migration rates. The river basin which experienced the greatest proportional loss of rural population is Moreau (59 percent loss).

Water resources. Data are presented on the areas drained within each river basin and the quantities and qualities of the water available in the various river basins.

Nearly one-half of the total drainage area in South Dakota is in the West River Region (Table 3). The two rivers in the West having the largest drainage basins are the Cheyenne and White, with each accounting for over 10 percent of the State's total drainage area. The area drained in the East River Region represents nearly one-third of the State total. The area drained by the

Missouri Mainstem is slightly more than that for the James River. Together these two rivers drain almost 40 percent of the total State.

"Surface water availability" is defined in the South Dakota Water Plan (DNRD, 1977) to include annual average stream flows for each river, including the amounts of water stored in large reservoirs for four of the rivers (Table 3). Judged from this standpoint, the Missouri River dwarfs all of South Dakota's other rivers, accounting for over 87 percent of the State's total. The rivers west of the Missouri account for more than twice as much surface water as those east of the Missouri.

"Aggregate water-use," as used in the South Dakota State Water Plan (DNRD, 1977), covers irrigation, industrial and municipal, stock-water, and rural domestic uses, as well as pond and lake evaporation and recreational uses (Table 3). Judged in this light, the Missouri River accounts for about one-half the State's aggregate water-use, the rivers east of the Missouri for about 30 percent, and the rivers west of the Missouri for about 20 percent. Next to the Missouri, the Big Sioux River ranks a strong second in its aggregate water-use.

In the data on water-use by consuming sector, no account is taken of evaporation which accounts for 73 percent of the State's "aggregate water-use" and recreation which accounts for five percent of the State's "aggregate water-use". The amount of water lost through evaporation is not controlled by man. Water used in recreation is not withdrawn or consumed.

For the State as-a-whole, about 64 percent of the total water consumed is for irrigation, 22 percent is for industrial and municipal purposes, 11 percent is for livestock, and two percent is for rural domestic use (Table 4). Regional variations in these percentages are considerable. For example, over 75 percent

of the water in the Missouri River and the rivers as a group in the West River Region is used for irrigation, whereas less than 40 percent of the water in the rivers in the East River Region is used for irrigation. This outcome arises because of a much greater use of water for municipal and industrial purposes in the East River Region. A somewhat larger proportion of water is also used for livestock in the East than elsewhere in the State.

The quality of any natural water source depends on the materials that are dissolved and suspended in it. Because the climate, topography, streamflow, and water management practices differ markedly from one part of the State to another, the quality of water in the State's various streams and aquifers is also widely variant. Attention is given to water quality in surface sources and then in groundwater.

Dissolved solids in streams are generally least abundant in the extreme eastern part of the State (the majority of the Vermillion, Big Sioux, and Minnesota Tributaries river basins), immediately along the Missouri River, west of the Missouri in the south (the Niobrara Tributaries and White river basins), and in the Black Hills region (Figure 2). At the other extreme, they are greatest in the central part of the State just west of the Missouri where precipitation is less and hence the dissolved solids become more concentrated over time. This includes much of the Upper Cheyenne River Basin, the northern two thirds of the Bad River Basin, and parts of the Missouri, Moreau, and Belle Fourche river basins. The only area in the East River Region with "above-average" dissolved solids is that immediately along the James River.

Patterns of variation across the State in suspended sediment concentration in streams (Figure 3) are much simpler than those for dissolved solids. Levels of concentration are low (less than 2,000 milligrams per liter) throughout

the Missouri Mainstem and East River regions, as well as in the Black Hills area and the majority of the Niobrara Tributaries River Basin. Suspended sediment concentration is high (more than 5,000 milligrams per liter), on the other hand, west of the Missouri in the Bad, Cheyenne, Belle Fourche, and northern part of the White river basins. The concentrations are high in these areas because of high erosion resulting from locally steepened topography, shallow soils, and low resistant types of bedrocks (USGS, 1975, 225).

The main potential water quality problems with groundwater involve high levels of sodium or total salt content. Since the adverse effects on the suitability of groundwater for irrigation depend, in part, on the sodium-total salts balance, simple correlations between levels of either sodium or total salts and the suitability of groundwater for irrigation cannot be made. Further, within individual aquifers, the levels of sodium and total salts are highly variant. Thus, while total salts and especially sodium are problematic in certain parts of the State, broad statements concerning regional variations in groundwater quality are not warranted.

The Division of Water Quality in DWNR is currently undertaking--with support from the U.S. Corps of Engineers--an extensive study of the State's aquifers. A report on groundwater quality in Eastern South Dakota is near completion (as of September 1983). Samples of water from some 500 wells in the West are being collected and analyzed. The results of these detailed studies will augment currently available information on groundwater quality (USGS, 1975, 206-214; Nelson and Siegel, 1983).

Land resources and use. The soils in the extreme eastern part of the State--within the Big Sioux, Vermillion, Minnesota Tributaries, Red Tributaries,

and the eastern edge of the James river basins--are generally loamy and silty textured, deep, and well-drained (Figure 4). Those in the southern half tend to be less rolling than those in the northern half. Some of the loess hills and ridge areas such as those in Lincoln County, however, are exceptions.

The majority of soils in the James and Missouri river basins are deep and well-drained. Soils in the Missouri River Basin tend to be silty and most of those in the James River Basin are loamy. Soils in the central part of the James River Basin, however, are clayey. Most of the Missouri River Basin has a more rolling topography than does the James River Basin.

The non-glaciated soils which comprise the West River Region tend to be less deep than those elsewhere in the State. Most are well-drained. Except for the southern part of the White River Basin, the West River Region tends to be more uneven in its topography than elsewhere in the State. In the northern part of the West--covering the Grand, Moreau, Little Missouri, and part of the Upper Cheyenne river basins--the plain is also moderately to steeply "dissected".[10/]

Land use varies considerably from one region to another in the State (Table 5). This reflects differences in land and water resources and climate. In the East River drainage basins, from three- to four-fifths of the total land area is in cropland, and one-quarter or less is commonly in pasture and rangeland. In the West River Region, on the other hand, only one-fifth or less of the total land area is cropped,[11/] and three-fifths or more is in pasture and rangeland. The Missouri Mainstem Region is intermediate, with cropland comprising 42 percent of its total area and pasture and rangeland 47 percent.

The major crops grown in the East River Region are "corn and sorghum" and "oats and barley" (Table 6). These two groupings constitute from 45 percent (Red Tributaries) to 77 percent (Vermillion) of the cropland in the different

East River basins. Except for the Vermillion River Basin, in which the area of "corn and sorghum" is double that of "oats and barley", the proportions of land devoted to these two groups of crops in each basin are roughly the same. About 15 percent of the cropland in the James and Red Tributaries river basins is in wheat; from 10 to 15 percent of the cropland in each of the East River basins is in alfalfa; from 16 to 17 percent of the cropland in the Big Sioux, Minnesota Tributaries, and Red Tributaries river basins is in flax; and nearly 10 percent of the Vermillion Basin is in soybeans.

In the Missouri Mainstem Region, about one-third of the cropped area is in "corn and sorghum", and about one-fifth is in each of "oats and barley", wheat and ~~barley~~ alfalfa.

In the West River Region, about two-fifths of the cropland in the Bad and Grand river basins is in wheat; about one-third of the Moreau Basin is in wheat. Alfalfa and hay together comprise over 50 percent of the cropped area in the Belle Fourche, Cheyenne, and Niobrara Tributaries river basins. The White River Basin is more diversified, with 20 to 25 percent of the cropland in each of wheat, hay, and alfalfa and 13 to 15 percent is in each of "corn and sorghum" and "oats and barley".

Climatic Resources. Levels of precipitation are highest in the southeastern corner of the State, where they average between 24 and 25 inches per year (Figure 5). As one movest northwest across the State, precipitation generally becomes less. In the northwestern corner of the State, for example, only about 14 inches of precipitation is received annually.[12/]

Annual precipitation in the Missouri Mainstem Region varies from less than 18 inches in the northwest to more than 24 inches in the extreme south. Except for the northwestern part of the James River Basin, precipitation levels in the East River Region average more than 20 inches per year. In the East, the Vermillion River Basin is most favored with rainfall, and the James River Basin is least favored. In the West River Region, the Niobrara Tributaries

River Basin generally receives more than 20 inches of rainfall annually. The other West River drainage basins most commonly receive between 14 and 18 inches of precipitation per year.

Patterns of variation across the state for precipitation during the April-September normal growing season are roughly the same as those for total annual precipitation (Figure 6). Across-the-state differences in precipitation during the growing season, however, are somewhat less than for total annual precipitation.

Most of South Dakota's agricultural area has a growing season ranging in length from 125 to 140 days (Figure 7). In the extreme northwestern part of the State (covering the Little Missouri Basin and the extreme western parts of the Grand and Moreau basins) and in the northeast (covering small parts of the James and Big Sioux basins), however, the growing season is shorter.

Two areas in South Dakota have definite above-average growing seasons. One, which extends across the eastern half of the State in the south, covers the southern parts of the Missouri Mainstem Region and the James, Vermillion, and Big Sioux drainage basins. The second area extends west from Pierre in both northerly and southerly directions, and covers approximately one-half of the Bad River Basin and parts of the White and Missouri drainage basins.

To conclude, the geographic bounds on temperature zones in the State do not generally correspond very closely with those for the drainage basin areas. Exceptions--in which the growing season in more than one-half of a drainage basin area is atypically short or long--are the following:

--A below-average length of growing season, Little Missouri River Basin; and

--An above-average length of growing season, the Bad and Vermillion river basins.

IRRIGATED AREA

Actual irrigated area

The rapid rate of growth in irrigation in South Dakota during the 1970's was noted above. In this section, attention is drawn to those regions and river basins in South Dakota in which the growth in privately-developed irrigation has been most rapid. The extent of irrigation in South Dakota is also compared with that in other Great Plains states.

In 1970, the Missouri Mainstem Region accounted for about 25 percent of the 93,900 acres of total privately-developed area irrigated in South Dakota (Table 7). The remaining privately-developed irrigated area was split about evenly between the East and West River regions. Among the individual river basins, the Missouri and the James involved by far the largest irrigated areas, followed by the Belle Fourche, Big Sioux, and White.

The total privately-developed area irrigated in South Dakota in 1979 is 377,192 acres (Table 7). The "non-privately developed area"[13/] irrigated in the State is estimated to be 133,700 acres (Table 8). The largest categories of "non-private" irrigation are 66,400 acres in the Belle Fourche and Angostura Federal Irrigation Projects and 50,500 acres of "dry draw, spreader" irrigation. Since little detailed information is available on "non-private" irrigation, the "non-private" irrigated areas have probably changed relatively little over the past decade, and much of the "non-private" irrigated area is not farmed intensively (the federal irrigation projects are a partial exception), the discussion in the text (unless otherwise indicated) is oriented around only the OWR data covering privately-developed irrigation in the State.

In 1979, about 35 percent of the privately-developed area was in the Missouri Mainstem Region, about 23 percent was in the West River Region, and 43 percent was in the East River Region. The James and Big Sioux river basins

ranked second and third behind the Missouri in irrigated area, accounting for 13 percent of the State total, respectively. Collectively, these three river basins accounted for over two-thirds of South Dakota's total irrigated acreage in 1979.

The changes in the privately-developed irrigated area between 1970 and 1979 are also summarized in Table 7. For the State as-a-whole, the area irrigated in 1979 was over four times the size of that in 1970. The area irrigated in the West was 2.5 times in 1979 what it was in 1970. In the East, the growth-multiple was 4.5 times and in the Missouri River Basin it was 5.6 times. Of the total increase in privately-developed irrigation during the 1970's, 44 percent was in the East River Region, 38 percent was in the Missouri Mainstem Region, and 18 percent was in the West River Region.

In absolute terms, the James, Big Sioux, and Vermillion river basins ranked second, third, and fourth--behind the Missouri River Basin--in expansion of privately-developed irrigated area during the 1970's. Their shares of the State's overall growth during the decade were 19, 15, and eight percent, respectively. The river basin in the West experiencing the largest area increase was the White, but its growth accounted for only five percent of the State's overall growth.

In relative terms, the greatest expansion of private irrigation during the 1970's--namely, a more than five-fold increase--took place in two "large" river basins and three "small" basins. The two "large" basins are the Big Sioux and Vermillion. The "small" basins are the Minnesota Tributaries, the Niobrara Tributaries, and the Little Missouri. At the other extreme, the river basins experiencing the least growth during the 1970's--namely, less than a doubling in their privately-developed irrigated acreage--are the Belle Fourche and Moreau basins.

In Figure 8, a semilog or ratio chart,[14/] information on the time-path of growth for the privately-developed irrigation in the three regional areas and the State as-a-whole is shown. Differences in the slopes of the functions representing the various regions and the State reflect directly differences in the rates of growth involved.

Over the period 1969 to 1979, the total privately-developed irrigated area in South Dakota increased at a compound annual rate of almost 18 percent.[15/] The annual growth rate was highest in the Missouri Mainstem Region (22 percent) and lowest in the West River Region (11 percent). The rates of growth in the irrigated area cultivated in the Missouri Mainstem Region were highest between 1968 and 1970 and again between 1974 and 1977. The most rapid rates of growth in the river drainage basins west and east of the Missouri Mainstem Region were during the latter period. Two of the main stimuli underlying the spurt of growth in private irrigation during the mid-1970's were a strengthening in farm commodity prices and the drought experienced at that time.

In Table 9, the pace of irrigation development in South Dakota is compared with that in other states in the Great Plains region. The states are listed in accordance with their national ranking in 1978. Six of the U.S.'s top ten states in irrigated area in 1978 are from the Great Plains: Texas-second, Nebraska-third, Colorado-fifth, Kansas-sixth, Montana-seventh, and Wyoming-tied for tenth. South Dakota was tied for twentieth. The Great Plains states as a group accounted for 48.4 percent of the total acres irrigated in the U.S. in 1978 (USDA, 1981, 419).

In the 25 years between 1944 and 1969, the area irrigated in the Great Plains states more than doubled (Table 9). For the U.S., the irrigated area increased about 90 percent (USDA, 1981, 419). Over one-half the increase in

the Great Plains region was in Texas. Nebraska and Kansas together accounted for just over one-third of the Great Plains increase. South Dakota, on the other hand, accounted for less than one percent of the increase in irrigated area in the Great Plains states. In terms of the relative increase in irrigated area between 1944 and 1969--as reflected by the ratio of the 1969 acreage to the 1944 acreage--Missouri ranked first, Oklahoma second, Georgia third, Kansas fourth, and South Dakota ninth out of the U.S.'s 20 top states in irrigation.

Between 1969 and 1978, the total area irrigated in the Great Plains increased by another 29 percent (Table 9). This represents about the same growth rate as that for irrigation throughout the U.S. (USDA, 1981, 419). Over one-half of the increase in the Great Plains took place in Nebraska. The increase of 193,000 acres in South Dakota accounted for 3.5 percent of the increase in the Great Plains. Relatively speaking, however, the 2.3-fold expansion of irrigated area in South Dakota during the 1970's was greater than that for any other Great Plains state, and second only to that in Georgia out of the U.S.'s 20 top states in irrigation (USDA, 1981, 419).

The striking development of irrigation in South Dakota in the 1970's is further illustrated in Table 10. Between 1969 and 1978, the number of irrigated farms in South Dakota increased by over 80 percent, whereas the increase for the Great Plains area as-a-whole was only seven percent.

A final interstate comparison involves the area irrigated in 1978 as a percentage of the total cropland used for crops (Table 9). The percentage varies widely among the Great Plains states--ranging from 78 in Wyoming and 50 in New Mexico to only two in South Dakota and 0.5 in North Dakota.

A major conclusion emerging from the study of the data in Tables 9 and 10, therefore, is that the irrigated acreage in South Dakota is much less than that in any other Great Plains state except for North Dakota. On the

other hand, South Dakota ranked fifth out of the 10 Great Plains states in the absolute increase in its irrigated area between 1969 and 1978. Further, its relative rate of increase in irrigated area during the 1970's was greater than that for any other Great Plains state, and was second only to that for Georgia in the nation as-a-whole. While the likelihood of South Dakota advancing much in its rank among the nation's top 20 irrigated states appears to be small, there is no question but that the development of private irrigation within the State in the 1970's was very striking.

The final issue on irrigated area examined in this section involves a county-by-county portrayal of the irrigated area in South Dakota. The 11 counties in South Dakota having over 10,000 irrigated acres each in 1978 account for 54 percent of the State's total irrigated area (USDA, 1982,121). Three of these counties--accounting for about 72,000 acres, or just over 20 percent of the State's total irrigated area--are in the extreme west central portion of the State (Figure 9). The other eight counties are scattered throughout the State, with two adjacent to the east bank of the Missouri River and five in various locations in the eastern part of the State. The nine counties with less than 500 irrigated acres each are also widely scattered throughout the State.

Groundwater versus surface water

Attention is given in this section to the nature of water sources for irrigation in South Dakota. As mentioned above, the earliest sources developed for irrigation in the State were streams. The dominant means of tapping surface water in South Dakota's streams is via pumping from active streamflows. Four rivers, however, also have large-reservoir storage-facilities: the Missouri, Belle Fourche, Cheyenne, and Grand. (For information on the storage

capacities of these reservoirs, see Table 3.) Further, in those relatively few instances where topography permits, surface water is diverted by gravity from streams for irrigation use.

Groundwater for irrigation is obtained from deep bedrock aquifers (300 to several thousand feet below ground-level) or relatively shallow aquifers in glacial drift or alluvial deposits. Deep bedrock aquifers can be found throughout the State, but their economic importance is much greater west than east of the Missouri.[16/] Shallow aquifers are relatively widespread in glacial drift deposits east of the Missouri and in alluvial deposits along the lower reaches of rivers in the East, such as the Vermillion (USGS, 1975, 181 and 188-192).

Of the 93,900 acres of privately-developed irrigated land in South Dakota in 1970, 58 percent was irrigated from surface sources and 42 percent was from groundwater surfaces (Table 11). Regional variations were substantial, with surface sources accounting in 1970 for 86 percent of West River irrigation and only 25 percent of East River irrigation. Of the State's privately-developed surface water irrigation in 1970, somewhat over one-half was in the West River Region and only a little more than one-fourth was in the Missouri Mainstem Region.

By the end of the 1970's, however, a five-fold plus expansion in groundwater irrigation in the State led to the relative importance of groundwater increasing from 43 to 57 percent of the State's total privately developed-irrigation (Table 11). Of the State's total irrigated area, including the "non-privately" developed irrigated area, the relative importance of groundwater sources increased from 18 percent in 1970 to 42 percent in 1979. One factor underlying the expanded use of groundwater was the added knowledge associated with aquifer mapping that became available in the 1960's.

The major shift between 1970 and 1979 in privately-developed irrigation was the increased relative importance of the Missouri Mainstem Region (by 10

percentage points) at the expense of irrigation in the West (its relative importance in the State dropped by over 14 percentage points) (Table 11). Further, an over five-fold expansion in surface water irrigation in the Missouri between 1970 and 1979 led the Missouri to account for about one-half of the area irrigated from privately-developed surface sources in the State in 1979.

Between 1970 and 1979, the area irrigated from groundwater sources in the Missouri Mainstem Region increased by over six times. Because groundwater sources expanded almost as fast elsewhere in the State, however, the relative importance of the Missouri Mainstem Region in the State's privately-developed groundwater irrigation changed rather little between 1970 and 1979.

The compound annual growth rates in privately-developed irrigated area between 1970 and 1979, by water source, are shown in Table 12. The rate of expansion of surface water irrigation in the State was 13 percent per year, with the growth rate in the Missouri Mainstem Region (22 percent) much greater than that in either the West (9 percent) or the East (7 percent). The growth rate in groundwater irrigation in the State was 22 percent per year, with only minor variations in growth among regions.[17/]

The time-paths of expansion in privately-developed groundwater and surface water irrigation between 1969 and 1979 are shown in Figures 10 and 11, respectively. The East River Region has maintained its dominance in groundwater irrigation over this 10-year period, and the West River Region has consistently involved the least groundwater irrigation.[18/]

The situation for surface water sources is less clear-cut. In the early 1970's, the West River Region was the State's dominant area for surface water irrigation, and the East River Region was least important. During the period of rapid expansion of irrigation in the mid-1970's, however, the area irrigated from surface sources in the Missouri Mainstem Region increased greatly, and in 1977 the Missouri Mainstem Region surpassed the West River Region as the State's leading region for privately-developed surface water irrigation.

Although the area of privately-developed groundwater irrigation in South Dakota increased rapidly during the 1970's, the ~~relative importance of groundwater in the State's total~~ irrigation is still low compared to that in most other Great Plains states. For example, in 1980 about 53 percent of South Dakota's ~~total~~ irrigation was from groundwater sources (Table 13). The corresponding percentage in Montana was lower (13 percent), but for every other Great Plains state the percentage is considerably higher. It ranges from 61 in Wyoming to 97 in Kansas, and averages 85 for the Great Plains states as-a-group and 78 throughout the U.S.

Irrigation permit area

In 1955, the South Dakota Legislature passed the major legislation that currently governs water rights in the State. All water is declared to be "the property of the people", rights to water use now are in accordance with the "appropriation" system, no groundwater mining is permitted, and water is to be applied to its fullest beneficial use. The right for a potential irrigator to use water has to be secured via procedures formally prescribed in the statute.

The procedure followed by a farmer to secure a "permit" to develop a possible water source for irrigation involves two types of approvals. The first involves a determination by the Soil Conservation Commission of soil and water compatability. A sample of the water proposed for irrigation is tested, and the results are evaluated in relation to the nature of soil that is to be irrigated. If the findings concerning soil and water compatibility are positive, the permit application is forwarded to the Board of Water Management in the DWNR for a second approval. The Board's main concerns are the availability of water proposed for irrigation and the likely impact on existing water-users of the requested additional use of the groundwater. Once the Board grants its approval, an irrigation permit is issued.

An irrigator's right to retain his "permit" depends on his actions to develop and use his water right. He must complete construction of necessary waterworks within five years of ~~his having received~~ receiving his permit. The water must be "applied to beneficial use"--i.e., used for irrigation--within four years following the completion of construction work. Assuming that these conditions are met, the irrigator then receives a license permitting him to exercise his right to use of water for irrigation. If he fails to use the water for a period exceeding three consecutive years, however, his right to use the water is forfeited (Garton, 1976).

Information on the area of land in South Dakota having irrigation permits is shown in Table 14 and Figure 12. On January 1, 1970, about 65 percent of the State's groundwater irrigation permit area was in the East River Region, 24 percent was in the Missouri Mainstem Region, and about 11 percent was in the West River Region. Of the State's surface water permit area in 1970, about 46 percent was in the Missouri Mainstem Region, 41 percent was in the West, and 14 percent was in the East.

Between January 1, 1970 and January 1, 1982, the total irrigation permit area in South Dakota increased from less than one-half million acres to over 1.1 million acres. Nearly one-half of the state-wide increase was in the East River Region, with the remainder of the increase split about equally between the Missouri Mainstem and West River regions.

About 55 percent of the state-wide increase in permit area involved groundwater sources. Of the growth in groundwater irrigation permit area, about 80 percent was concentrated in the East River area alone. About 90 percent of the growth in surface water irrigation permit area was shared equally between the West River and Missouri Mainstem regions.

The data in Figure 13 reflect a somewhat sporadic time path of growth in irrigation permit area. For the State as-a-whole, the irrigation permit area

increased only slightly between 1969 and 1974. Between 1974 and 1977, however, the State's permit area increased by 2.7 times. Since then, the permit area has continued to increase, but at a much slower rate.

The time-paths of growth in irrigation permit areas differ greatly among regions in the State. In the West, except for 1977 to 1979, the permit area has increased rather steadily over time. In the East, the permit area changed little between 1970 and 1974. It accelerated rapidly between 1974 and 1977, then decreased some until 1979, and has increased modestly since then. The Missouri Mainstem Region has experienced two periods of substantial decreases in its irrigation permit area (from 1970 to 1974 and since 1979) and a six-year intervening period in which the permit area expanded rapidly (by over five times).

Changes over time in irrigation permit areas reflect the net result of new permits granted and old permits forfeited. An event partially responsible for the large-scale forfeiture of permits in the early 1970's in the Missouri Mainstem Region was the cancelling of permits covering over 30,000 acres of proposed development for the Grey Goose Project north of Pierre which was not included in the project as constructed (Larson, 1979).

Between 1969 and 1979, the area actually irrigated as a ratio to the irrigation permit area in South Dakota showed a definite upward trend (Figure 14). For the State as-a-whole, the percentage of permit area actually irrigated increased from less than ~~25~~ 20 in the late 1960's to over 35 in the late 1970's. This upward trend reflects changes in both the regulations surrounding the granting of permits and the perspectives of farmers concerning their applying for irrigation permits.

An institutional change involves the payment for water permit applications now being based on the acreage intended to be developed[19/] rather than on the earlier flat rate per permit. Farmers are also believed to be showing more reasoned and less speculative assessments of future irrigation potentials.

This includes a reduced role of the psychology that "I must obtain the right to an unclaimed water source now before someone else does". Further, the expanded role of groundwater in the state-wide mix of irrigation has probably been accompanied by greater caution in irrigation permit applications. This is due to the fact that potential groundwater irrigators have to bear the expense of test-hole borings from which water samples for testing can be drawn, whereas surface water irrigators merely need to dip water from active streamflows.

DISTRIBUTION OF IRRIGATION WATER

Types of systems for applying water

In South Dakota, irrigation water is distributed across fields either under pressure or via gravity. The OWR reports data on center pivot, big gun, hand move, towline, sidewheel roll, and portable boom pressurized sprinkler systems and on flood, gated pipe, and siphon gravity systems.

Center pivot machines consist of lateral line pipes which rotate around center pivot points and on which are mounted sprinklers or spray nozzles. While center pivot arms vary in length, the most common ones--designed for quarter-section fields--are 1289 feet long. Unless special corner units are used, these quarter-section center pivots irrigate about 130 acres each.[20/]

Big gun irrigation involves large radius high pressure gun sprinklers that can either be continuously self-moving or stationery.

Hand move sprinklers involve irrigation pipe and nozzle units that are moved successively by hand across the fields being irrigated.

Towline irrigation involves sections of lateral line pipes with mounted sprinklers that are towed by tractor across fields.

Sidewheel roll irrigation involves lateral line pipes--with mounted sprinklers--which serve as axles for wheels. The lateral line pipes roll across the fields as irrigation water is applied.

Portable boom irrigation involves 50 to 100 feet sections of lateral line pipes with mounted sprinklers that rotate on turntables and are towed by tractor across fields.

Flood irrigation involves the passing of water through gates, pipes, or breaches in the walls of irrigation ditches, and the spreading out of the water as it moves across fields by gravity.

Gated pipe systems involve the placement of pipes with gated openings across the upstream end of irrigated fields. When the gates along the pipe are opened, water is released from the pipes. The water usually flows in furrows or rills by gravity across the fields.

Siphon irrigation is similar to gated pipe irrigation, except that water passes over the walls of irrigation ditches via siphon tubes rather than through the gated openings in pipes at the upstream end of irrigated fields.

Information on the types of systems used for applying privately-developed irrigation water in South Dakota is shown in Table 15 and Figure 15. The relative importance of the three regions in the State as sites for the respective types of water distribution is shown in sequence across the top panel of "inter-regional comparisons" in Figure 15. The relative importance of the various types of water distribution within each region of the State--and for the State as-a-whole-- is shown in the bottom "intra-regional" panel of Figure 15.

Both in 1970 and 1979, the vast majority (about 90 percent) of the State's flood systems were found in the West River Region. Over one-half of the State's center pivot systems are in the East River Region. The East River Region has replaced the West River Region as the State's major area for big gun sprinklers. Gated pipe systems, on the other hand, are distributed rather equally across the three main regions of the State.

In 1970, between 17 and 21 percent of the State's irrigation systems involved each of flood, hand move, gated pipe, and towline systems. Regional differences were substantial. In the West River Region, about one-half of the privately-developed irrigation water was distributed via flooding. In the Missouri Mainstem Region, nearly one-third of the irrigation systems involved gated pipe distribution, and about one-fifth involved each of towline and hand

move systems. In the East, the pattern of irrigation systems was more diverse. Slightly more than one-fifth of the systems involved each of hand moved and towline sprinklers, and between 12 and 16 percent of the systems involved each of gated pipe, portable booms, and center pivot water distribution.

By 1979, a remarkable change had occurred. The change involved the "rise" of the center pivot machine. The introduction in South Dakota during the 1970's of over 2,000 center pivot machines resulted in center pivot systems coming to represent nearly 60 percent of the State's irrigation systems in 1979, compared to 7 percent in 1970. The next most common systems of water distribution state-wide in 1979--by flooding and gated pipes--each involved only 10 or 11 percent of the State's systems.

Within the Missouri Mainstem and East River regions in 1979, over 70 percent of the irrigation systems involved center pivot systems. Only in the West River Region did the center pivot machine fail to take over. In that region, slightly more than one-third of the systems on privately-developed irrigated land involved flooding and slightly less than one-fourth of the systems involved each of center pivot and gated pipe systems.

In the Great Plains states as-a-group, 31 percent of the total area irrigated in 1982 was handled by sprinklers (Table 16). The only states in which more than one-half of total irrigation is via sprinklers are South Dakota and North Dakota. In these states, sprinklers account for 87 and 78 percent of total irrigation, respectively. In Oklahoma, Nebraska, and Kansas, between one-third and one-half of their respective irrigated areas are handled by sprinklers. At the other end of the continuum are New Mexico, Wyoming, and Montana, in which sprinklers account for only eight to 11 percent of total irrigation.

Center pivot machines dominate South Dakota and North Dakota irrigation to an extent that no other irrigation method dominates in any other Great Plains state. In 1982, for example, about 70 percent of the irrigated area in each of these states was irrigated by center pivot systems. Center pivot systems in the other states covered from only two percent (Montana) to 35 percent (Nebraska and Kansas) of the total irrigated areas. Two features of the 1970's undoubtedly help to explain the dominance of center pivot irrigation in the Dakota's. This was a time when both (1) the relative rate of expansion of irrigation in the Dakota's exceeded that in the other Great Plains states and (2) the center pivot technology became well-developed and was readily available on the market.

The second most common type of irrigation in the Great Plains region involves flooding. In Montana, Wyoming, New Mexico, and Colorado, the percentages of total irrigated area involving flood systems in 1982 ranged from 59 to 36. The development of irrigation in these states--much of it with public funding--took place largely in the pre-center pivot era.

Sources of energy to divert water

In 1970, about 83 percent of South Dakota's privately-developed irrigated land involved three energy sources: electricity, propane, and diesel (Table 17 and Figure 16). At the State-level, electricity accounted for 34 percent of the total irrigated area, and propane and diesel for 27 and 22 percent, respectively.

Regional variations in energy sources in 1970 were considerable. In the West River Region, electricity and diesel were equally important, with each accounting for about 30 percent of the irrigated area. In the Missouri Mainstem Region, on the other hand, propane dominated the market--accounting

for a larger irrigated area than all other energy sources combined. In the East River Region, electricity accounted for 45 percent of the total irrigated area, followed by propane (27 percent) and diesel (17 percent).

Virtually all of the privately-developed irrigated area added during the 1970's in South Dakota involved either electricity or diesel power sources. The expansion for electricity was nearly 3.5 times as great as that for diesel.[21/] In 1979, electricity served over two-thirds of the State's total irrigated area. This represented an eight-fold increase since 1970. The growth-multiple for electricity in the Missouri Mainstem Region was above-average (17 times) and in the West it was below average (four times). Diesel sources expanded by over four times at the State-level, with an above-average expansion in the Missouri Mainstem Region (a 6.7 growth-multiple) and a below average expansion in the West River Region (a 2.8 growth-multiple).

The pattern of relative importance among energy sources inter-regionally within the State shifted considerably from 1970 to 1979. In 1970, about one-half of the total area in the State irrigated by electric power was in the East River Region, one-half of each of diesel power and gasoline in the State was West River, one-half of the State's propane was in the Missouri River Region, and 95 percent of the State's gravity diversion was in the West River Region. In 1979, the East River Region continued to account for about one-half of the State's electrically powered irrigation systems, but the Missouri Mainstem Region replaced the West River Region as the number two area for electricity. In 1979, diesel sources were spread over almost equal areas in the State's three main regions.

Data from the most recent Irrigation Survey (1982) show further in-roads of electric power in South Dakota's irrigation (Table 18). In 1982, 80 percent of South Dakota's irrigation systems are reported to have been electrically-

powered. Electricity is the dominant power source for irrigation in North Dakota, Montana, Wyoming, and Colorado as well. In several Great Plains states--Kansas, Oklahoma, Texas, and New Mexico--however, natural gas is the most common energy source. In Nebraska, unlike in the other Great Plains States, the sources of energy used in irrigation are diversified, with no one source accounting for more than one-third of a state's irrigation power units.

To determine possible reasons for different mixes of energy sources in different states, data on the costs of pumping irrigation water with various types of energy were examined (Tables 19 and 20). Since the most recent comparative cost data are for 1974, the mixes of energy sources in the different states in 1974 were also examined (Sloggett, 1974, 15). Except for South Dakota, whose energy sources in 1974 were diversified in a way similar to that for Nebraska, however, the relative importance of different energy sources in the various states in 1974 differed little from that in 1982.

In general, the relationship is inverse between the popularity of different kinds of irrigation power units and the cost per-acre foot of pumping with the various energy sources. One notable exception, however, is a lower cost with natural gas than with electricity for each state in which comparative data are available. In those states having more irrigation units powered with electricity than natural gas, there undoubtedly are constraints on the widespread availability of natural gas. Further possible explanations for electricity being more popular than natural gas include possible perceptions that natural gas is especially vulnerable to future price increases, natural gas supplies are less reliable and less convenient to use than is electricity, and natural gas units involve greater investment and maintenance costs than electric-powered units.

The data in Tables 19 and 20 show South Dakota's groundwater pumping

costs to be intermediate relative to those in other Great Plains states, but much above-average for surface water sources. One partial explanation is that the average lift of pumped groundwater in South Dakota is intermediate (but below-average) as compared to other Great Plains states, and that the average lift for surface water used in South Dakota irrigation is much higher than that for any other Great Plains state (Table 21).

Level of irrigation water application

Year-to-year variations between 1969 and 1979 in the level of irrigation water applications for privately-developed irrigation in South Dakota and within each of the three regions in the State are considerable (Figure 17). The peak applications in 1976 are from 1.5 to 2.2 times as great as those in the year of least application, 1979.

The mean depth of irrigation application for South Dakota between 1969 and 1979 was 13.5 inches (Table 22). The mean levels of application in the West River and Missouri Mainstem regions (14.2 and 15 inches) do not differ significantly from one another, but are significantly higher than those in the East River Region (11.2 inches). One reason for less irrigation in the East is the higher rainfall experienced there.

Within the individual drainage basins, there are considerable differences in the mean depths of water application over time and in the applications from year to year (Table 23). The component drainage basins in the State are classified as above-average, intermediate, or below-average in their mean water application and as having a high, intermediate, or low year-to-year variation in water applications. Illustrative classifications are as follows:

- Lower Cheyenne, above average mean and high variation;
- Missouri, above-average mean and low variation;

- White, Vermillion, and James; intermediate mean and intermediate variation; and
- Big Sioux, below-average mean and low variation.

For the State as-a-whole, the mean surface water application (14.9 inches) is significantly higher than that for the mean groundwater application (11.9 inches) (Table 22 and Figure 18). The relationship between surface water and groundwater levels of irrigation application differs greatly among regions, however. In the Missouri Mainstem Region, surface water applications are significantly higher than groundwater applications, whereas in the East River Region the opposite relationship is found. In the West River Region, on the other hand, there is no significant difference between groundwater and surface water applications.

The reasons underlying these findings are not fully understood. Some possible explanations, however, include the following. Surface water irrigators who physically see apparently abundant water supplies flowing by their fields may be less inclined to shut off their irrigation systems than groundwater irrigators who experience pumping draw-down and know that shutting off their systems can help enable a re-establishment of underground water levels. Surface water irrigators who usually have little control over their water supplies may also tend to over-irrigate when water supplies are available as informal insurance against possible later water shortages. Further, surface water irrigators who do not pay volumetrically for irrigation water--as groundwater irrigators in effect do--do not have economic incentives to limit their water applications.

On the other hand, in situations when surface water supplies drop and curbs are put on the use of water for irrigation (as sometimes experienced in the James River, for example), surface water irrigators may be obliged to

restrict irrigation to levels that are less than those applied by groundwater irrigators. Many other factors other than these also influence the levels of irrigation water that farmers apply. Determining the magnitude and relative importance of different factors influencing irrigation water applications is one subject being analyzed in a new research project currently being initiated in the Economics Department.

July and August are the months of peak irrigation water application in South Dakota (Figure 19). Seasonal differences in water applications are greater in the Missouri Mainstem and East River regions than in the West River Region. In 1978, for example, 67 percent of the yearly applications in the Missouri Mainstem and East River regions was applied in July and August, whereas the corresponding figure for the West River Region was only 53 percent.

Seasonal variations in irrigation applications appear to be becoming less marked over time. This is particularly true in the Missouri Mainstem and East River regions, where the July-August water applications relative to the total annual applications between 1970 and 1978 dropped 20 and 15 percentage points, respectively. This tendency reflects an increasing consciousness of irrigators to initiate irrigation earlier in the year before their soil dries out so as to avoid difficulties of trying to "catch up" later in the season with water applications.

Sloggett's (1982) estimated state-wide irrigation water application rates during 1980 show South Dakota's 15 inches to be below-average in the Great Plains region (Table 24). The highest rates--more than double that in South Dakota--are in New Mexico and Montana which have mainly surface irrigation and fixed per acre charges for water. Only North Dakota and Colorado had lower rates of irrigation water application than in South Dakota in 1980.

AREAS OF MAJOR IRRIGATED CROPS

The principal crop grown under irrigation in South Dakota is corn. Depending on the source of data and the year to which the data apply, between 48 and 57 percent of the State's total irrigated area is estimated to be under corn production (Table 25). The second most common irrigated crop is alfalfa. Estimates of the percentage of the State's total irrigated area in alfalfa range from 19 to 34. The remaining 18 to 24 percent of the State's irrigated area is rather diversified. The most important other crops in the Missouri Mainstem and East River Regions, however, are soybeans and "dry-field" ("edible") beans. In the West River Region, the most important other irrigated crop is "hay and pasture".

In 1970, nearly one-half of the State's irrigated corn was produced in the East River Region and about 35 percent was in the West River Region (Figure 24a). In 1978, the inter-regional distribution of irrigated crops was rather similar. However, the Missouri Mainstem Region gained about four percentage points--at the expense of the West River Region--in its relative importance as an area of irrigated corn production.

In 1970, the West River Region accounted for 65 percent of the State's total irrigated alfalfa area. About 21 percent of the State's irrigated alfalfa was East River, and 14 percent was in the Missouri Mainstem Region. Although the area of irrigated alfalfa in the West River Region more than doubled during the 1970's, the growth of irrigated alfalfa in the other regions was even greater. As a result, the relative importance of the West River Region, in the State's irrigated alfalfa production dropped 17 percentage points between 1970 and 1978. The relative gain in irrigated alfalfa area was shared about equally between the other two regions of the State.

In 1970, one-half of the State's privately-developed irrigated area was planted to corn and one-fourth was in each of alfalfa and other crops (Figure 24b). By 1978, the importance of irrigated corn relative to irrigated alfalfa increased by about five percentage points.

During the 1970's, the mix of irrigated crops on privately-developed land in the drainage basins west of the Missouri changed rather much. The principal change was the replacement of alfalfa by corn as the most important irrigated crop. In the East River drainage basins, on the other hand, the relative importance of irrigated alfalfa increased during the 1970's (by about 10 percentage points).

Corn is now the most important irrigated crop in each of the three regions. In 1978, for example, it covered about five-eighths of the irrigated area in the Missouri River and East River drainage basins, and about 30 percent of the irrigated area west of the Missouri. The mix of irrigated crops within each of the three regions at the end of the 1970's, however, was somewhat more diversified than at the beginning of the 1970's.

Between 1969 and 1979, the area of irrigated corn in South Dakota grew at a compound annual growth rate of 20.4 percent (Table 26). The rate of growth in irrigated corn area was somewhat less in the West River Region than elsewhere in the State.

The rate of growth in the area of irrigated alfalfa in the State between 1969 and 1979 was smaller than that for irrigated corn (15.9 versus 20.4 percent per year). This outcome arises because of relatively limited growth in irrigated alfalfa in the West River Region. In the Missouri Mainstem and East River regions, on the other hand, the rate of growth between 1969 and 1979 in the area of irrigated alfalfa slightly exceeded that for irrigated corn.

Estimates of the mix of irrigated crops in the various Great Plains states are shown in Table 27. A main finding is a definite above-average relative importance of corn as an irrigated crop in the Dakota's. In fact, only in Nebraska is corn relatively more common in the State's irrigated agriculture (two-thirds of Nebraska's total irrigated area versus about one-half in the Dakota's). Corn accounts for 31 percent of the total irrigated areas in fourth and fifth ranking Colorado and Kansas, and for as little as two to four percent of the irrigated areas in Wyoming and Montana.

For irrigated "pasture and hay crops", on the other hand, South Dakota ranks at the bottom among the Great Plains states. Only two percent of its irrigated area is in hay and pasture. At the other extreme is Wyoming for which hay and pasture account for 83 percent of the State's total irrigated area.

The final information presented involves the depth of irrigation water applied to corn and alfalfa which rely upon privately-developed irrigation sources (Table 28). For the State as-a-whole, the mean depth of water application over 1969 to 1979 for alfalfa was 15.3 inches. This is significantly more than the 14.4 inches which was applied to corn.

The within-region analysis of irrigation water applications, however, shows different findings. For the Missouri Mainstem and West River regions, the mean water applications for corn exceed those for alfalfa. In the East River Region, less water is applied to corn than alfalfa. Within none of the three regions, however, are the differences in water applied to corn versus alfalfa statistically significant. Thus, except from the most macro State-policy point of view, the data in this study suggest that farmers in South Dakota do not typically irrigate alfalfa more heavily than they do corn.

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ENDNOTES

1/ Irrigated production was realized from only two other federally-supported irrigation projects prior to the year when irrigated production was first forthcoming from the Belle Fourche Project (WPRS, 1980a, 69 and 70).

2/ The year-to-year response rates to the questionnaires by irrigators has ranged from 74 to 86 percent, which for a mailed questionnaire is "high". The OWR data reported in this paper are "blown up" to the 100 percent level, assuming that the respondents to the OWR questionnaire are representative of the total population of irrigators in the State to which the questionnaire was mailed. Empirical data to support the validity of this assumption, are unavailable. No alternative approach for dealing with this issue seemed more appropriate, however.

3/ As explained below (in the section, "irrigation permit area"), state-issued "permits" are required before water sources can be developed for irrigation. Once an irrigator has completed construction of his irrigation facilities and applied the irrigation water to beneficial use, he is eligible to receive a "license" entitling him to the right to use the water for irrigation.

4/ For background on the nature of water rights in South Dakota, see Garton (1976).

5/ A "dry-draw" is defined as "any ravine or watercourse not having an average daily flow of at least 0.4 cubic feet per second of water during the period May 1st to September 30th inclusive" (Garton, 1976, 14).

6/ Data are reported by the OWR separately for the lower and upper parts of the Cheyenne River Basin, implying the existence of 15 different sets of data. Further, between 1973 and 1977, data for the Missouri Coteau (now part of the Missouri River Basin) and the Big Sioux Coteau (now part of the Big Sioux and James river basins) were reported separately.

7/ The OWR report for 1978 was not available at the time when this paper was drafted.

8/ The Keya Paha River, however, drains a small area in south-central South Dakota and enters the Niobrara River, a tributary of the Missouri River, in Nebraska. The Little Missouri River also drains a small area in the northwestern part of South Dakota and enters the Missouri in North Dakota.

9/ For an inventory of the resources in each of South Dakota's river drainage basins, see DNRD (South Dakota Water Plan, Vol. II-B, Sec.'s 1-16). For additional descriptive information about the river drainage basins, see USGS (1964 and 1975).

10/ For more detailed information on the soils of South Dakota, see Malo and Westin (1978), USDA (1982), and Westin and Malo (1978).

11/ The Niobrara Tributaries Basin is a minor exception. Cropland comprises about 35 percent of its total area.

12/ In general, the geographic pattern of variation in temperatures in South Dakota corresponds with that for precipitation, with higher temperatures in higher rainfall areas. Because evapotranspiration varies directly with temperature, the range in moisture which is effective for plant use across the state is less than the range in precipitation across the state.

13/ For the definition of "privately-developed" irrigation in this paper, see the earlier section, "sources of data used in the study". The term "non-privately developed" area is used to describe the other irrigated areas in the State.

14/ In the semilogarithmic or ratio charts used in this paper, time is shown on the arithmetic horizontal scale and area is shown on the logarathmic vertical scale. With conventional arithmetic scales on both axes, equal spaces represent equal absolute amounts. With semilog charts, equal spaces represent equal rates of change for the variable on the vertical axis. Thus, a comparison of the slopes for two semilog functions reveals directly the difference in the rate of growth for the two functions.

15/ The compound annual growth rates were computed using the mean values for the data available in 1968-1970 versus in 1969-1971.

16/ The Ogallala Formation and Arikaree Group extend into South Dakota from the south along the central one-half of the State's border west of the Missouri. These deep bedrock aquifers underlie about 8,000 square miles in the White and Niobrara Tributaries river basins.

17/ Except for the Missouri River, as yet untapped supplies of surface water for irrigation in South Dakota are relatively limited. Because the most favorable sites along the Missouri--from the standpoints of their elevation relative to the level of water in the river and to a lesser extent their distance from the river--have already been developed, one can probably expect that the development of surface water sources for irrigation in the State will continue to be slower than that for groundwater surfaces.

18/ Most of the expansion of groundwater that has taken place in the West River Region has been from the Ogallala and Arikaree formations.

19/ Technically, the water permit fee is based on the acre-feet of water required for the intended area to be irrigated. In practice, the fee is closely related to the area intended to be developed for irrigation.

20/ For an insightful account of the historical development of center pivot irrigation in the U.S., see Splinter (1976).

21/ One explanation for the shift toward greater reliance on electricity in irrigation is relatively less escalation during the 1970's in the price of electricity than in the prices of other energy sources. Sloggett (1982, 6) shows, for example, the following percentage increases between 1973 and 1980 in energy prices: electricity 139, LPG 210, gasoline 254, diesel 335, and natural gas 400.

LIST OF TABLES

Table 1. Irrigated Area, South Dakota, Decade-by-Decade, 1889-1978

Year	Acreage	Change from prior decade	
		Acres	Percent
1889	15,717	n/a	n/a
1899	43,676	+ 27,959	+177.9
1909	55,000	+ 11,324	+ 25.9
1919	90,000	+ 35,000	+ 63.6
1929	67,107	- 22,893	- 25.4
1939	60,198[a/]	- 6,909	- 10.3
1949	84,356	+ 24,158	+ 40.1
1959	115,629	+ 31,273	+ 37.1
1969	148,000	+ 32,371	+ 28.0
1978	341,000	+193,000	+130.4

Sources: USGS (1964,224) for data through 1959, and USDA (1981, 419) for 1969 and 1978.

[a/] The low point in the 1919-1949 trough was 1944 when only 52,895 acres were irrigated.

Table 2. Demographic Data, by River Drainage Basin, South Dakota

Region and river drainage basin	Total population residing in the drainage basin, 1970		Rural population residing in the drainage basin, 1970[a]		Rural population as a percent of total population	Percent change in population from 1950 to 1970	
	Number	Percent of state total	Number	Percent of state total		Total	Rural
West River							
Cheyenne	77,491	11.6	23,000	9.2	29.7	+45.4	+35.3
Belle Fourche	34,437	5.2	11,403	4.5	33.1	+12.1	+12.9
White	25,551	3.8	18,400	7.3	72.0	- 0.9	- 5.6
Niobrara Tributaries	9,765	1.5	6,570	2.6	67.3	+ 2.9	- 3.5
Grand	7,973	1.2	4,482	1.8	56.2	-22.3	-22.6
Moreau	7,035	1.1	3,600	1.4	51.2	-11.7	-58.6
Bad	7,019	1.0	2,500	1.0	35.6	- 0.1	-23.1
Little Missouri	370	0.1	370	0.1	100.0	n/a	n/a
Sub-total	(169,641)	(25.5)	(70,325)	(27.9)	(41.5)	n/a	n/a
Missouri Mainstem	87,049	13.1	35,207	14.0	40.5	- 4.7	-28.6
East River							
Big Sioux	170,776	25.7	44,700	17.8	26.2	+27.0	- 4.0
James	137,725	20.7	52,596	20.9	38.2	- 6.4	-22.3
Vermillion	37,960	5.7	16,549	6.6	43.6	- 6.5	-27.0
Big Sioux Coteau	26,297	3.9	14,016	5.6	53.3	-27.6	-35.6
Minnesota Tributaries	19,791	3.0	9,500	3.8	48.0	-17.8	-30.1
Missouri Coteau	10,518	1.6	5,600	2.2	53.2	-22.6	-28.2
Red Tributaries	5,214	0.8	3,000	1.2	57.5	-23.3	-33.3
Sub-total	(408,281)	(61.4)	(145,961)	(58.1)	(35.8)	n/a	n/a
South Dakota	664,971	100.0	251,493	100.0	37.8	n/a	n/a

Source: DNRD (South Dakota Water Plan, Vol. II-B, Sec.'s 1-16)

[a] These are "estimated" rural populations.

Table 3. Water and Land Resources, by River Drainage Basin, South Dakota

Region and river drainage basin	Drainage area in South Dakota[a] Square miles	Drainage area in South Dakota[a] Percent of state total	Surface water availability[b] Acre-feet ('000)	Surface water availability[b] Percent of state total	Aggregate water-use in 1975[c] Acre-feet ('000)	Aggregate water-use in 1975[c] Percent of state total
West River						
Cheyenne	9,663	12.5	775	3.0	184	5.9
White	8,247	10.6	377	1.5	65	2.1
Moreau	5,037	6.5	138	0.5	61	2.0
Grand	4,714	6.1	241	0.9	82	2.6
Belle Fourche	3,292	4.2	461	1.8	141	4.5
Bad	3,151	4.1	108	0.4	33	1.1
Niobrara Tributaries	2,000	2.6	48	0.2	48	1.5
Little Missouri	605	0.8	98	0.4	8	0.3
Sub-total	(36,709)	(47.4)	(2,246)	(8.7)	(622)	(20.0)
Missouri Mainstem	16,610[d]	21.4	22,565	87.2	1,575	50.6
East River						
James	13,997[e]	18.1	270	1.0	226	7.3
Big Sioux	5,740[e]	7.4	603	2.3	512	16.5
Vermillion	2,232	2.9	80	0.3	84	2.7
Minnesota Tributaries	1,572	2.0	66	0.25	70	2.2
Red Tributaries	600	0.8	57	0.2	22	0.7
Sub-total	(24,141)	(31.2)	(1,076)	(4.1)	(914)	(29.4)
South Dakota	77,460	100.0	25,887	100.0	3,111	100.0

Source: DNRD (South Dakota Water Plan, Vol II-B, Sec.'s 1-16) for the first major section in the table. DNRD (South Dakota Water Plan, Vol. II-3, Sec. 3, 32) for the second and third major sections in the table.

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Table 3. Water and Land Resources, by River Drainage Basin, South Dakota, Continued

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a/ Some of the rivers provide drainage to areas in other states as well as in South Dakota. For such rivers, the total areas (square miles) drained are as follows: Cheyenne 25,500; Little Missouri 9,500; Minnesota - no information; Niobrara Tributaries - no information; Big Sioux 9,570; Missouri - no information; James 21,000; and Belle Fourche 7,122.

b/ Surface water availability includes annual average streamflows for each river, including large-reservoir storage on four of the rivers. The storage capacities (thousands of acre-feet) in 1975 were as follows: the South Dakota portion of the Missouri Mainstem 22,565; Belle Fourche 195; Cheyenne 163; and Grand 74.

c/ The "aggregate water-use" refers to irrigation, industrial and municipal, stockwater, and rural domestic uses, as well as pond and lake evaporation and recreational uses. These data reflect both groundwater and surface water sources.

d/ Since the "Missouri Mainstem Region" is now defined to include not only the four mainstem sub-basins along the Missouri River, but also the former Missouri Coteau, the 2,580 square miles comprising the Missouri Coteau are added to the drainage areas for the four Missouri Mainstem sub-basins.

e/ The 2,920 square miles comprising the four Big Sioux Coteau is arbitrarily divided equally by me between the Big Sioux and James River drainage basins.

Table 4. Water-Use, by Consuming Sector and River Drainage Basin, South Dakota, 1975

Region and river drainage basin	Irrigation		Industrial & municipal		Stockwater		Rural domestic		Total (acre-feet)
	Acre-feet	Percent of basin total	Acre-feet	Percent of basin total	Acre-feet	Percent of basin total	Acre-feet	Percent of basin total	
West River									
Cheyenne	76,200	69.3	28,600	26.0	3,900	3.5	1,300	1.2	110,000
Belle Fourche	70,100	88.5	6,600	8.3	1,800	2.3	700	0.9	79,200
Grand	16,800	85.7	600	3.1	1,900	9.7	300	1.5	19,600
White	27,600	80.0	1,200	3.5	4,600	13.3	1,100	3.2	34,500
Moreau	10,900	81.3	300	2.2	1,900	14.2	300	2.3	13,400
Bad	7,900	77.5	600	5.9	1,500	14.7	200	1.9	10,200
Niobrara Tributaries	10,300	81.7	500	4.0	1,500	11.9	300	2.4	12,600
Little Missouri	3,800	90.4	100	2.4	200	4.8	100	2.4	4,200
Sub-total	(223,600)	78.8	(38,500)	13.6	(17,300)	6.1	(4,300)	1.5	(283,700)
Missouri Mainstem	118,300	78.3	10,600	7.0	19,900	13.2	2,300	1.5	151,100
East River									
Big Sioux	29,800	28.2	59,900[a/][b/]	56.7	12,800	12.1	3,200	3.0	105,700
James	46,900	46.7	31,300[b/]	31.1	19,400	19.3	2,900	2.9	100,500
Vermillion	19,700	66.1	4,300	14.4	4,700	15.8	1,100	3.7	29,800
Minnesota Tributaries	257	2.4	7,840[c/]	73.8	2,055	19.4	468	4.4	10,620
Red Tributaries	9	1.0	118	13.2	645	72.0	124	13.8	896
Sub-total	(96,666)	39.1	(103,458)	41.8	(39,600)	16.0	(7,792)	3.1	(247,516)
South Dakota	438,566	64.3	152,558	22.3	76,800	11.3	14,392	2.1	682,316

Source: DNRD (South Dakota Water Plan, Vol. II - 3, Sec. 3, p. 25)

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Table 4. Water-Use, by Consuming Sector and River Drainage Basin, South Dakota, 1975, Continued

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a/ This figure appears to be "very large". It is true, however, that almost 30 percent of the state's population resides in the Big Sioux River Basin and several meat packing plants, gravel washing operations, and water-cooled electric power generation plants are in the Big Sioux region.

b/ Approximately 20 percent of the State's population resides in the James River region.

c/ The Big Stone Power Plant requires about 7,000 acre-feet of water annually.

Table 5. Overall Land Use, by River Drainage Basin, South Dakota[a/]

Region and river drainage basin	Cropland	Pasture and rangeland
	(percent of the total area in each drainage basin)	
West River		
Moreau	14.9	71.7
Little Missouri	5.8	65.9
Bad	21.9	65.3
Belle Fourche	12.0	64.6
White	19.3	62.5
Grand	19.3	62.4
Cheyenne	8.9	59.5
Niobrara Tributaries	34.8	59.4
Missouri Mainstem	42.3	46.9
East River		
Vermillion	82.4	10.0
Big Sioux	73.6	14.7
Minnesota Tributaries	68.5	22.4
James	63.5	25.5
Red Tributaries	56.8	31.0

Source: DNRD (South Dakota Water Plan, Vol. II - B, Sec.'s 1-16)

[a/] Categories of land use not covered in the table include public lands, forests and woodlands, and a variety of rather minor uses.

Table 6. Cropland Acreages, by River Drainage Basin[a/], South Dakota

Region and river drainage basin	Average for these years	Wheat	Alfalfa	Corn and Sorghum	Oats and Barley	Soybeans	Flax	Hay	Other[b/]
				(percent of basin total)					
West River									
Bad	1966 - 1972	40.7	25.1	10.0	13.4	n/a	n/a	n/a	10.8
Belle Fourche	1966 - 1971	16.8	50.5	9.4	14.1	n/a	n/a	n/a	9.2
Cheyenne	1966 - 1971	19.2	50.4	4.8	12.0	n/a	n/a	7.5	6.1
Grand	1966 - 1972	39.7	25.7	5.8	18.8	n/a	n/a	n/a	10.0
Moreau	1966 - 1972	32.6	27.5	6.0	16.6	n/a	n/a	n/a	17.3
Niobrara Tributaries	1969 - 1974	11.3	n/a	17.0	14.0	n/a	n/a	57.0	0.7
White	1966 - 1971	25.2	20.3	14.5	12.7	n/a	n/a	23.1	4.2
Missouri Mainstem	1966 - 1971	22.5	17.1	32.7	23.1	1.4	n/a	n/a	3.2
East River									
Big Sioux	1963 - 1970	4.1	11.9	29.1	25.4	2.3	16.1	5.5	5.6
James	1970 - 1975	16.4	14.9	28.5	20.7	0.6	n/a	n/a	18.9
Minnesota Tributaries	1966 - 1972	8.3	13.5	24.8	27.0	n/a	17.0	n/a	9.4
Red Tributaries	1963 - 1970	14.5	12.4	21.9	23.8	4.8	17.4	2.1	3.1
Vermillion	1966 - 1971	n/a	9.9	51.7	25.3	9.6	n/a	n/a	3.5

Source: DNRD (South Dakota Water Plan, Vol. II - B, Sec.'s 1-16)

a/ Data on the Missouri and Big Sioux Coteau areas are not reported in the table. Information on the different crops produced on the Little Missouri's 22,600 acres of cropland is not shown in the Water Plan document for that drainage basin.

b/ For some drainage basins, the "other" category covers crops listed separately in this table. "Fallow" and "idle" acres are not included in the "other" category.

Table 7. Privately-Developed Irrigated Area, by River Drainage Basin in South Dakota, 1970 and 1979

Region and river drainage basin	1970		1979		Increase from 1970 to 1979		
	Acres	Percent	Acres	Percent	Acres	Percent of the state total	Ratio of 1979 to 1970
West River							
White	8,137	8.7	21,341	5.7	13,204	4.7	2.62
Belle Fourche	12,088	12.9	18,125	4.8	6,037	2.1	1.50
Upper Cheyenne	4,455	4.7	13,533	3.6	9,078	3.2	3.04
Niobrara Tributaries	1,357	1.4	8,983	2.4	7,626	2.7	6.62
Grand	3,665	3.9	8,481	2.2	4,816	1.7	2.31
Lower Cheyenne	2,083	2.2	6,023	1.6	3,940	1.4	2.89
Bad	1,203	1.3	4,268	1.1	3,065	1.1	3.55
Moreau	1,560	1.7	2,928	0.8	1,368	0.5	1.88
Little Missouri	311	0.3	1,990	0.5	1,679	0.6	6.40
Sub-total	(34,859)	(37.1)	(85,672)	(22.7)	(50,813)	(18.0)	(2.46)
Missouri Mainstem	23,305	24.8	130,773	34.7	107,468	37.9	5.61
East River							
James	22,057	23.5	75,666	20.1	53,609	18.9	3.43
Big Sioux	8,497	9.0	49,867	13.2	41,370	14.6	5.87
Vermillion	5,115	5.5	27,402	7.3	22,287	7.9	5.36
Minnesota Tributaries	67	0.1	5,758	1.5	5,691	2.0	85.94
Red Tributaries	n/a	n/a	2,054	0.5	2,054	0.7	n/a
Sub-total	(35,736)	(38.1)	(160,747)	(42.6)	(125,011)	(44.1)	(4.50)
Total	93,900	100.0	377,192	100.0	283,292	100.0	4.02

Table 8. "Non-Privately Developed" Irrigated Areas, South Dakota[a/]

Nature of irrigation		Irrigated acreage	
Federal irrigation projects (1981)			
Belle Fourche		54,952	
Angostura		11,448	
Federal sub-total			66,400
Dry draw, spreader irrigation (1975)[b/]			
West River			
Upper Cheyenne River Basin	13,200		
Lower Cheyenne River Basin	8,600		
Belle Fourche River Basin	6,200		
Grand River Basin	6,000		
Moreau River Basin	5,900		
White River Basin	4,600		
Bad River Basin	4,300		
Little Missouri River Basin	1,700		
West-River sub-total		50,500	
Missouri River		1,800	
Dry draw, spreader sub-total			52,300
Vested water rights originating before 1907 (apply mainly to Rapid Creek, Redwater River, Spearfish Creek, and Beaver Creek)			9,000
Irrigation by Indian Tribes (primarily in Rosebud and Lower Brule areas)			6,000
Grand total			133,700

Sources: BOR (1982, 189 and 198) for federal projects; DNRD (State Water Plan, Vol. II-E, Sec. 2, 1976) for dry draw spreader irrigation, and personal communication with Al Bender, SD Water Resources Institute, Brookings for the areas irrigated under vested water rights and by Indians.

a/ The "non-privately" developed irrigated area is interpreted to represent that part of the State's total irrigated area for which there are no state-issued irrigation permits.

b/ "Dry, draw spreader irrigation" involves the backing up of water behind dams in small creeks by individual farmers and ranchers. This approach to irrigation is permitted as long as the backing up of water does not damage upstream farmers and ranchers.

Table 9. Irrigation Development; Great Plains States; 1944, 1969, and 1978[a/]

State[a/]	Acres irrigated ('000) 1944	1969	1978	National ranking according to 1978 area irrigated	Increase from 1944 to 1969: Thousand acres	% of the regional total	Ratio of 1969 to 1944	Increase from 1969 to 1978: Thousand acres	% of the regional total	Ratio of 1978 to 1969	Irrigated area in 1978 as a % of the total cropland used for crops
Texas	1,320	6,888	7,018	2	5,568	51.3	5.22	130	2.4	1.02	28.5
Nebraska	632	2,857	5,698	3	2,225	20.5	4.52	2,841	51.3	1.99	28.0
Colorado	2,669	2,895	3,458	5	226	2.1	1.08	563	10.2	1.19	38.5
Kansas	96	1,522	2,686	6	1,426	13.1	15.85	1,164	21.0	1.76	10.0
Montana	1,555	1,841	2,086	7	286	2.6	1.18	245	4.4	1.13	14.3
Wyoming	1,354	1,523	1,685	10T	169	1.6	1.12	162	2.9	1.11	78.2
New Mexico	535	823	904	15	288	2.7	1.54	81	1.5	1.10	49.7
Oklahoma	2	524	602	18	522	4.8	262.00	78	1.4	1.15	6.3
South Dakota	53	148	341	20T	95	0.9	2.79	193[b/]	3.5	2.30	2.0
North Dakota	23	63	141	26	40	0.4	2.74	78	1.4	2.24	0.5
Great Plains Region	8,239	19,084	24,619[b/]	n/a	10,845	100.0	2.32	5,535	100.0	1.29	16.0

Source: USDA (1981, 417 - 419)

[a/] The acres irrigated in 1978 in the two states neighboring South Dakota that are not shown in the table were as follows: Minnesota - 272,000 and Iowa - 101,000.

[b/] In absolute terms, South Dakota ranked twelfth out of the U.S.'s 20 top states in its 1969 to 1978 growth in irrigated area.

Table 10. Irrigated and Non-Irrigated Farms,[a/] Great Plains States, 1969 and 1978

State	Non-irrigated farms				Irrigated farms			
	No. in 1969	No. in 1978	Change from 1969 to 1978 Number	Percent	No. in 1969	No. in 1978	Change from 1969 to 1978 Number	Percent
Texas	96,047	112,457	+ 16,410	+17.1	24,751	21,655	- 3,096	-12.5
Nebraska	44,332	37,649	- 6,683	-15.1	19,053	23,812	+ 4,759	+25.0
Colorado	8,604	9,173	+ 569	+ 6.6	12,738	13,395	+ 657	+ 5.2
Kansas	62,329	59,656	- 2,673	- 4.3	6,065	7,745	+ 1,680	+27.7
Montana	12,652	12,655	+ 3	0	7,951	8,301	+ 350	+ 4.4
Wyoming	2,715	2,553	- 162	- 6.0	4,464	4,471	+ 7	+ 0.2
New Mexico	3,806	4,549	+ 743	+19.5	3,904	4,630	+ 726	+18.6
Oklahoma	48,180	55,147	+ 6,967	+14.5	3,495	3,492	- 3	- 0.1
South Dakota	39,492	35,124	- 4,368	-11.1	978	1,766	+ 788	+80.6
North Dakota	41,092	38,124	- 2,968	- 7.2	436	766	+ 330	+75.7
Total	359,249	367,087	+ 7,838	+ 2.2	83,835	90,033	+ 6,198	+ 7.4

Source: USDC (1982, 15)

[a/] Attention is given only to farms with sales of $2,500 or more.

Table 11. Privately-Developed Area Irrigated, Groundwater and Surface Water Sources, by Region in South Dakota, 1970 and 1979

Year and region	Groundwater			Surface water[a/]			Total	
	Acres	Percent of regional total	Percent of state total	Acres	Percent of regional total	Percent of state total	Acres	Percent of state total
1970								
West River	4,847	13.9	12.1	30,012	86.1	55.6	34,859	37.1
Missouri Mainstem	8,092	34.9	20.3	15,113	65.1	28.0	23,205	24.7
East River	26,957	75.2	67.6	8,879	24.8	16.4	35,836	38.2
South Dakota	39,896	42.5	100.0	54,004	57.5	100.0	93,900	100.0
1979								
West River	21,590	25.2	10.1	64,082	74.8	39.3	85,672	22.7
Missouri Mainstem	50,262	38.4	23.5	80,511	61.6	49.3	130,773	34.7
East River	142,068	88.4	66.4	18,679	11.6	11.4	160,747	42.6
South Dakota	213,920	56.7	100.0	163,272	43.3	100.0	377,192	100.0

[a/] The "non-privately" developed irrigated area (recall Table 8) involves surface water sources. If that area were added to the privately-developed area irrigated by surface sources, surface water would account for 82 and 58 percent of the State's total irrigated area in 1970 and 1979, respectively.

Table 12. Annual Growth Rates in Privately-Developed Irrigated Area, Groundwater and Surface Water Sources, by Region in South Dakota, 1969-1979[a/]

Region	Groundwater	Surface water	Total
		(percentage)	
West River	20.4	8.8	10.8
Missouri Mainstem	22.6	22.1	22.2
East River	22.2	7.0	19.6
South Dakota	22.1	13.3	17.6

[a/] The compound annual growth rates are computed with respect to three-year averages centered on 1970 and 1978.

Table 13. Area Irrigated by Groundwater as a Percent of the Total Area Irrigated with Pumped Water, Great Plains States, 1980[a/]

State	Percent Groundwater
Kansas	97.4
Nebraska	92.4
North Dakota	92.0
Oklahoma	86.1
New Mexico	84.8
Texas	82.2
Colorado	75.6
Wyoming	60.8
South Dakota	53.2
Montana	13.0
Great Plains States	85.4[a/]

Source: Adapted from Sloggett (1982, 13 and 14)

[a/] For the U.S. as a whole, 77.8 percent of the total area irrigated is from groundwater sources.

Frederick (1984/66) shows Δ's overdraw in GW percent for USA. He says 39% GW for USA in 1975

Table 14. Irrigation Permit Area, Groundwater and Surface Water Sources, by Region in South Dakota, 1970 and 1982

Region and water source	Acres of permit area		Change from 1970 to 1982		
	January 1, 1970	January 1, 1982[a]	Acres	Percent of the state total	Ratio of 1982 to 1970
West River					
Groundwater	16,570	60,313	43,743	7.0	3.6
Surface water	137,071	263,940	126,869	20.2	1.9
Sub-total	153,641	324,253	170,612	27.2	2.1
Missouri Mainstem					
Groundwater	37,706	62,791	25,085	4.0	1.7
Surface water	153,874	286,749	132,875	21.2	1.9
Sub-total	191,580	349,540	157,960	25.2	1.8
East River					
Groundwater	102,980	374,260	271,280	43.2	3.6
Surface water	45,671	73,434	27,763	4.4	1.6
Sub-total	148,651	447,694	299,043	47.6	3.0
South Dakota					
Groundwater	157,256	497,364	340,108	54.2	3.2
Surface water	336,616	624,123	287,507	45.8	1.9
Total	493,872	1,121,487	627,615	100.0	2.3

[a] The data for January 1, 1982 are based on a South Dakota County map entitled, "Irrigation Water Right Permits Granted and 'Vested Right' Records Established July 1, 1955 - January 1, 1982," issued by the Division of Water Rights, DWNR. The judgment of staff in the Division of Water Rights was used to apportion the permit areas in counties at the periphery of the Missouri Mainstem Region between the Missouri Mainstem Region and either the West River or East River regions.

Table 15. Types of Systems for Applying Privately-Developed Irrigation Water, by Region in South Dakota, 1970 and 1979

Type of system	West River				Missouri Mainstem				East River				South Dakota			
	1970 (No.)	1979 (No.)	Change from 1970 to 1979 No.	Ratio[a]	1970 (No.)	1979 (No.)	Change from 1970 to 1979 No.	Ratio[a]	1970 (No.)	1979 (No.)	Change from 1970 to 1979 No.	Ratio[a]	1970 (No.)	1979 (No.)	Change from 1970 to 1979 No.	Ratio[a]
Center Pivot	7	226	+219	32.29	18	762	+744	42.33	50	1,071	1,021	21.42	75	2,059	+1,984	27.45
Flood	188	334	+146	1.78	11	17	+ 6	1.55	11	10	21	1.91	210	372	+ 162	1.77
Gated Pipe	44	152	+108	3.45	72	116	+ 44	1.61	65	74	9	1.14	181	342	+ 161	1.89
Big Gun	8	45	+ 37	5.63	1	49	+ 48	49.00	5	127	122	25.40	14	221	+ 207	15.79
Hand Move	47	68	+ 21	1.45	44	38	- 6	0.86	98	57	-41	0.58	189	163	- 26	0.86
Towline	24	44	+ 20	1.83	53	57	+ 4	1.08	97	54	-43	0.56	174	155	- 19	0.89
Siphon	50	52	+ 2	1.04	7	3	- 4	0.43	16	3	-13	0.19	73	58	- 15	0.79
Sidewheel Roll	0	11	+ 11	n/a	0	21	+ 21	n/a	0	11	+11	n/a	0	43	+ 43	n/a
Portable Boom	5	4	- 1	0.80	15	10	- 5	0.67	54	22	-32	0.41	74	36	- 38	0.49
Other	0	15	+ 15	n/a	11	5	- 6	0.45	20	15	- 5	0.75	31	35	+ 4	1.13
Total	373	951	+578	2.55	232	1,078	+846	4.65	416	1,455	+1,039	3.50	1,021	3,484	+2,463	3.41

[a] This is the ratio of 1979 to 1970.

Table 16. Types of Systems for Applying Irrigation Water, Great Plains States, 1982

State	Areas irrigated by selected methods as percentages of the total irrigated area				Sprinkler area as a percent of the total irrigated area
	Center pivot	Sprinklers other than center pivots	Flood	Gated pipe	
South Dakota	68.7	18.2	7.7	4.4	86.9
North Dakota	70.9	7.3	18.9	2.9	78.2
Oklahoma	19.8	29.5	n/a	20.9	49.3
Nebraska	35.1	8.5	n/a	31.6	43.6
Kansas[a/]	34.5	2.5	n/a	n/a	37.0
Texas[b/]	12.7	15.8	8.5	3.4	28.5
Colorado	20.7	2.0	35.5	3.6	22.7
New Mexico	10.4	0.4	42.9	21.4	10.8
Wyoming	5.0	5.0	46.5	15.8	10.0
Montana	1.9	6.5	59.2	n/a	8.4
Great Plains Region	n/a	n/a	n/a	n/a	30.7

Source: Irrigation Survey (1982)

a/ The dominant irrigation method in Kansas--accounting for 54.9 percent of the total irrigated area--is "gated pipe and underground."

b/ The dominant irrigation method in Texas--accounting for 54.0 percent of the total irrigated area--is "underground with valves."

Ill 75%. CP
Ind 70%.
Iowa 71
Mo 68
MN 64

Table 17. Types of Energy for Diverting Privately-Developed Irrigation Water, by Region in South Dakota, 1970 and 1979

Type of energy	West River				Missouri Mainstem				East River				South Dakota			
	1970 (acre)	1979 (acre)	Change from 1970 to 1979 Acres	Ratio[a]	1970 (acre)	1979 (acre)	Change from 1970 to 1979 Acres	Ratio[a]	1970 (acre)	1979 (acre)	Change from 1970 to 1979 Acres	Ratio[a]	1970 (acre)	1979 (acre)	Change from 1970 to 1979 Acres	Ratio[a]
Electricity	10,523	37,731	+27,208	3.59	5,517	92,953	+87,436	16.85	15,959	125,077	+109,118	7.84	31,999	255,761	+223,762	7.99
Diesel	10,209	28,649	+18,440	2.81	4,461	30,089	+25,628	6.74	6,149	27,663	+ 21,514	4.50	20,819	86,401	+ 65,582	4.15
Propane	2,632	4,082	+ 1,450	1.55	12,509	6,129	- 6,380	0.49	9,834	5,929	- 3,905	0.60	24,975	16,140	- 8,835	0.65
Gravity	7,091	10,676	+ 3,585	1.51	0	388	+ 388	n/a	411	1,253	+ 842	3.05	7,502	12,317	+ 4,815	1.64
Gasoline	3,474	3,156	- 318	0.91	383	390	+ 7	1.02	3,071	692	- 2,379	0.23	6,928	4,238	- 2,690	0.61
Natural Gas	0	335	+ 335	n/a	109	617	+ 508	5.66	399	133	- 266	0.33	508	1,085	+ 577	2.14
Other	930	1,043	+ 113	1.12	226	207	- 19	0.92	13	0	- 13	0	1,169	1,250	+ 81	1.07
Total	34,859	85,672	+50,813	2.46	23,205	130,773	+107,568	5.64	35,836	160,747	+124,911	4.49	93,900	377,192	+283,292	4.02

[a] This is the ratio of 1979 to 1970.

Table 18. Type of Irrigation Power Units, Great Plains States, 1982

	Natural Gas	Electricity	Diesel	LPG	Gasoline
		(percent of power units)			
States in which electricity is dominant					
North Dakota	0	88	11	1	0
Montana	0	86	1	1	2
South Dakota	0	80	14	4	2
Wyoming	8	80	10	1	1
Colorado	9	74	5	11	1
States in which natural gas is most common					
Kansas	59	19	15	7	0
Oklahoma	56	16	9	17	2
Texas	55	35	6	2	0
New Mexico	55	35	10	3	2
A state with diversified energy sources					
Nebraska	21	33	30	15	1

Source: Irrigation Survey (1982)

Table 19. Cost of On-Farm Pumping of Irrigation Water from Groundwater Sources, by Type of Energy, Great Plains States, 1974

	Natural Gas	Electricity	Diesel	LPG	Gasoline
		(dollars per acre foot)			
States in which electricity is dominant					
North Dakota	n/a	13.22	21.19	26.86	34.39
Montana	6.19	10.26	18.48	24.77	31.71
South Dakota	n/a	12.26	18.67	22.89	29.67
Wyoming	7.13	16.26	21.90	25.69	36.53
Colorado	3.99	9.06	12.24	15.41	19.56
States in which natural gas is most common					
Kansas	5.41	11.20	17.06	18.75	27.11
Oklahoma	7.68	17.51	22.93	28.68	36.88
Texas	5.56	12.66	16.11	21.48	25.48
New Mexico	9.44	19.54	28.96	35.23	47.30
A state with diversified energy sources					
Nebraska	3.99	8.20	11.48	14.25	20.69

Source: Sloggett (1977, 33)

Table 20. Cost of On-Farm Pumping of Irrigation Water from Surface Water Sources, by Type of Energy, Great Plains States, 1974

	Natural Gas	Electricity	Diesel	LPG	Gasoline
		(dollars per acre foot)			
States in which electricity is dominant					
North Dakota	n/a	2.17	3.31	4.19	5.37
Montana	n/a	3.48	6.26	8.39	10.74
South Dakota	n/a	14.18	21.60	26.48	34.33
Wyoming	n/a	2.13	2.74	3.22	4.58
Colorado	n/a	1.51	n/a	n/a	3.11
State in which natural gas is most common					
Kansas	n/a	1.69	2.58	2.83	n/a
Oklahoma	n/a	n/a	11.87	14.85	n/a
Texas	2.05	4.89	5.95	7.93	9.41
New Mexico	0.49	1.02	n/a	n/a	n/a
A state with diversified energy sources					
Nebraska	n/a	1.57	n/a	2.73	3.97

Source: Sloggett (1977, 32)

Table 21. Estimated Average Lift of Pumped Irrigation Water,[a/] Groundwater and Surface Water, Great Plains States, 1980

State	Groundwater	Surface Water
	(feet)	
New Mexico	260	5
Texas	210	40
Oklahoma	200	16
Kansas	190	15
Wyoming	150	25
Colorado	125	10
South Dakota	120	130
Montana	100	50
Nebraska	100	20
North Dakota	75	35
Unweighted mean	153	35

Source: Sloggett (1982, 11 and 12)

Table 22. Depth of Irrigation Water Applied for all Crops, Privately-Developed Groundwater and Surface Water Sources, by Region in South Dakota, 1969-1979

Region	Mean depth of application (inches)[a/]		
	Groundwater	Surface water	Total
West River	13.6	14.4	14.2
Missouri Mainstem	11.6	17.0	15.0
East River	11.5	9.7	11.2
South Dakota	11.9	14.9	13.5

[a/] The statistical significance of differences for the following two sets of mean water applications--determined using "t" tests--is denoted via: *** = 0.01 level, ** = 0.05 level, * = 0.1 level, and ns = not significant.

1. Within-region differences in groundwater versus surface water applications

- West River	ns
- Missouri River	***
- East River	**
- South Dakota	***

2. Between-region differences in water applications

East River versus West River	***
East River versus Missouri River	***
West River versus Missouri River	ns

Table 23. Depth of Irrigation Water Applied for All Crops, Privately-Developed Irrigation Sources, by Drainage Basin in South Dakota, 1970-1979

River Basins[a]	Classification category[b]	Mean depth per season	Standard deviation of yearly depths
		(acre - inches)	
Lower Cheyenne (WR)	I	Above-average (16.5)	High (7.3)
Upper Cheyenne (WR)	II	Above-average (18.4)	Low (2.6)
Missouri	II	Above-average (15.5)	Low (2.7)
Bad (WR)	III	Intermediate (12.1)	High (5.8)
White (WR)	IV	Intermediate (14.1)	Intermediate (3.1)
Grand (WR)	IV	Intermediate (12.5)	Intermediate (3.5)
Vermilllion (ER)	IV	Intermediate (13.4)	Intermediate (3.0)
James (ER)	IV	Intermediate (12.0)	Intermediate (3.2)
Belle Fourche (WR)	V	Intermediate (14.2)	Low (2.3)
Niobrara Tributaries (WR)	V	Intermediate (13.0)	Low (2.7)
Little Missouri (WR)	VI	Below-average (7.5)	High (4.3)
Red Tributaries (WR)	VII	Below-average (7.0)	Intermediate (3.2)
Minnesota Tributaries (ER)	VII	Below-average (7.2)	Intermediate (3.0)
Big Sioux (ER)	VIII	Below-average (10.1)	Low (2.5)
Moreau (WR	VIII	Below-average (7.7)	Low (0.9)

[a] WR = West River Region and ER = East River Region.

[b] The joint consideration of the mean and standard deviation data for the various river drainage basins gives rise to the eight different categories indicated in this column.

Table 24. Estimated Irrigation Water Application Rates, Great Plains States, 1980

State	Water application rate
	(inches)
New Mexico	33
Montana	32
Oklahoma	22
Wyoming	22
Nebraska	21
Kansas	20
Texas	18
South Dakota	15
Colorado	13
North Dakota	12
Unweighted mean	21

Source: Adapted from Sloggett (1982, 11 and 12)

Table 25. Estimated Areas of Major Irrigated Crops, South Dakota

	Agric. Census (1978)		Office of Water Rights (1979)		Irrig. Survey (1982)	
	Acres	Percent	Acres	Percent	Acres	Percent
Corn	175,323	54.6	215,584	57.2	221,000	48.4
Alfalfa	79,222	24.6	72,508	19.2	154,000	33.7
Beans[a/]	14,217	4.4	38,383	10.2	24,400	5.3
Other	52,577	16.4	50,717	13.4	57,400	12.6
Total	321,339	100.0	377,192	100.0	456,800	100.0

Sources: USDC (1980, 18-20); DWNR (1979); Irrigation Survey (1982)

[a/] The Agric. Census shows "soybeans" and "dry field" beans separately. The other two sources show only "beans". This category presumably reflects both "soybeans" and "dry field" or "edible" beans.

Table 26. Annual Growth Rates in Irrigated Alfalfa and Corn, Privately-Developed Irrigation, by Region, 1969-1979[a/]

Region	Alfalfa	Corn
	(percentage)	
West River	10.4	14.5
Missouri Mainstem	21.1	20.2
East River	20.6	18.1
South Dakota	15.9	20.4[b/]

[a/] The compound annual growth rates are computed with respect to three-year averages centered on 1970 and 1978.

[b/] Because the data which are available for 1969-1971 differ among the four geographic areas covered in the table, the state-wide annual growth rate is not necessarily expected to be intermediate among the growth rates for the various regions.

Table 27. Areas of Major Irrigated Crops, Great Plains States, 1982

State	Corn	Alfalfa	Pasture and hay crops	Soybeans	Other[a/]
			(percent of irrigated area)		
Nebraska	65.8	n/a	9.1	11.0	14.1
South Dakota	48.4	33.7	2.4	5.3	10.2
North Dakota	46.9	n/a	33.4	0	19.7
Colorado	31.3	n/a	41.2	0.1	27.4
Kansas	30.9	n/a	14.3	6.3	48.5
New Mexico	10.9	n/a	37.7	n/a	51.4
Texas	8.9	n/a	5.7	3.8	81.6
Oklahoma	8.6	n/a	24.8	2.8	63.8
Wyoming	4.4	n/a	82.9	n/a	12.7
Montana	2.4	20.8	63.9	n/a	12.9

Source: Irrigation Survey (1982)

[a/] For those states in which the "other" category accounts for a greater acreage than that for any of the four crops indicated in the table, the dominant "other" category crops are as follows (percentages of total irrigated areas for each such crop are shown in parentheses):

Kansas - sorghum (20.8) and wheat (17.3)
Texas - cotton (31.7) and wheat (17.7)
Oklahoma - grain sorghum (27.5) and wheat (20.0) and
New Mexico - wheat (13.9), sorghum (12.0) and cotton (11.9)

Table 28. Depth of Irrigation Water Applied, Corn versus Alfalfa, Privately-Developed Irrigation Sources, by Region in South Dakota, 1969-1979

Region	Mean depth of application (inches)[a/] Corn	Alfalfa
West River	16.7	15.7 ns
Missouri Mainstem	16.3	15.9 ns
East River	11.5	12.2 ns
South Dakota	14.4	15.3 *

[a/] The levels of significance for the "t" test of differences between the corn and alfalfa means are denoted as follows: *** = 0.01, ** = 0.05, * = 0.10, and ns = not significant.

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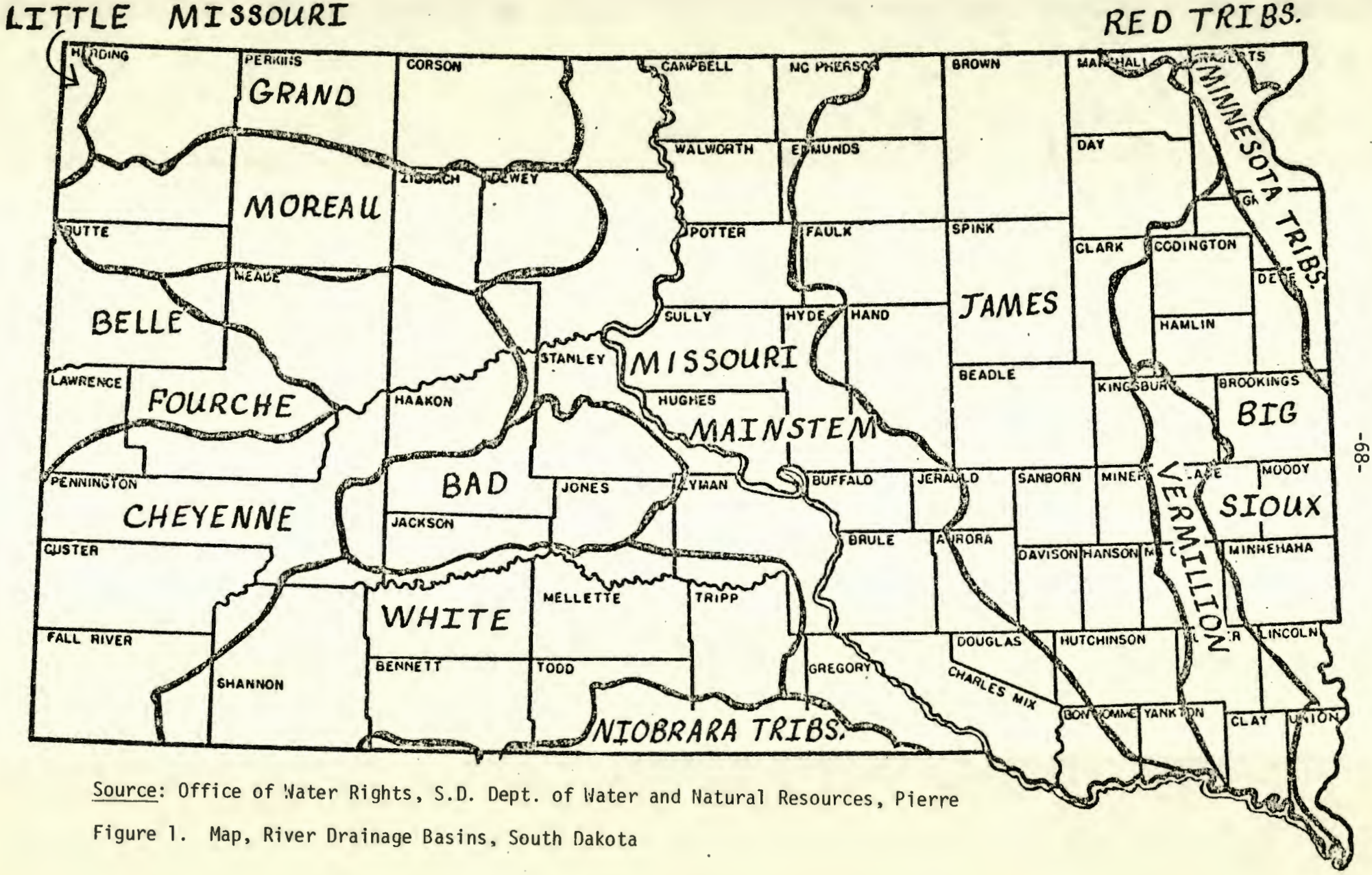
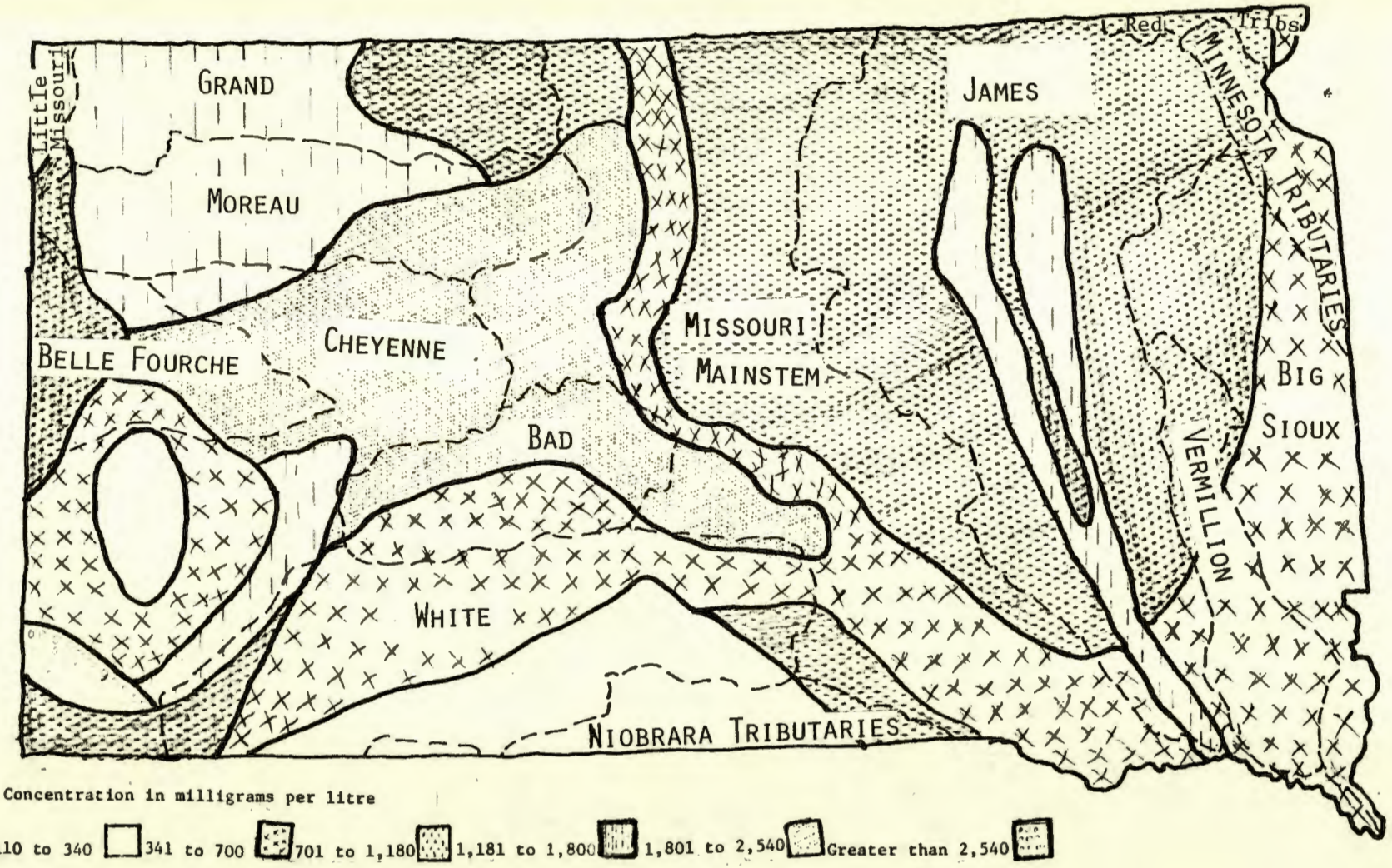


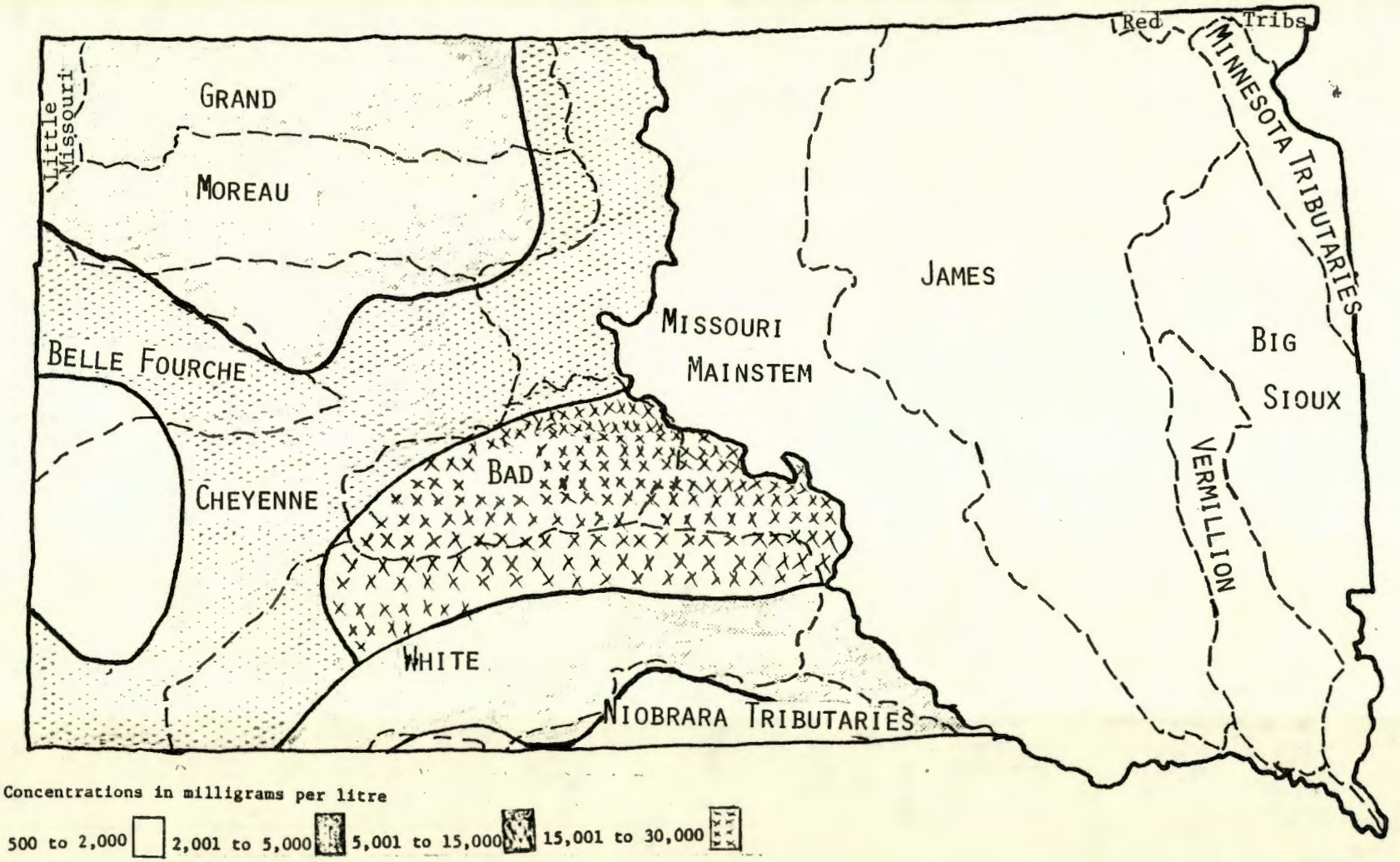
Source: Office of Water Rights, S.D. Dept. of Water and Natural Resources, Pierre

Figure 1. Map, River Drainage Basins, South Dakota



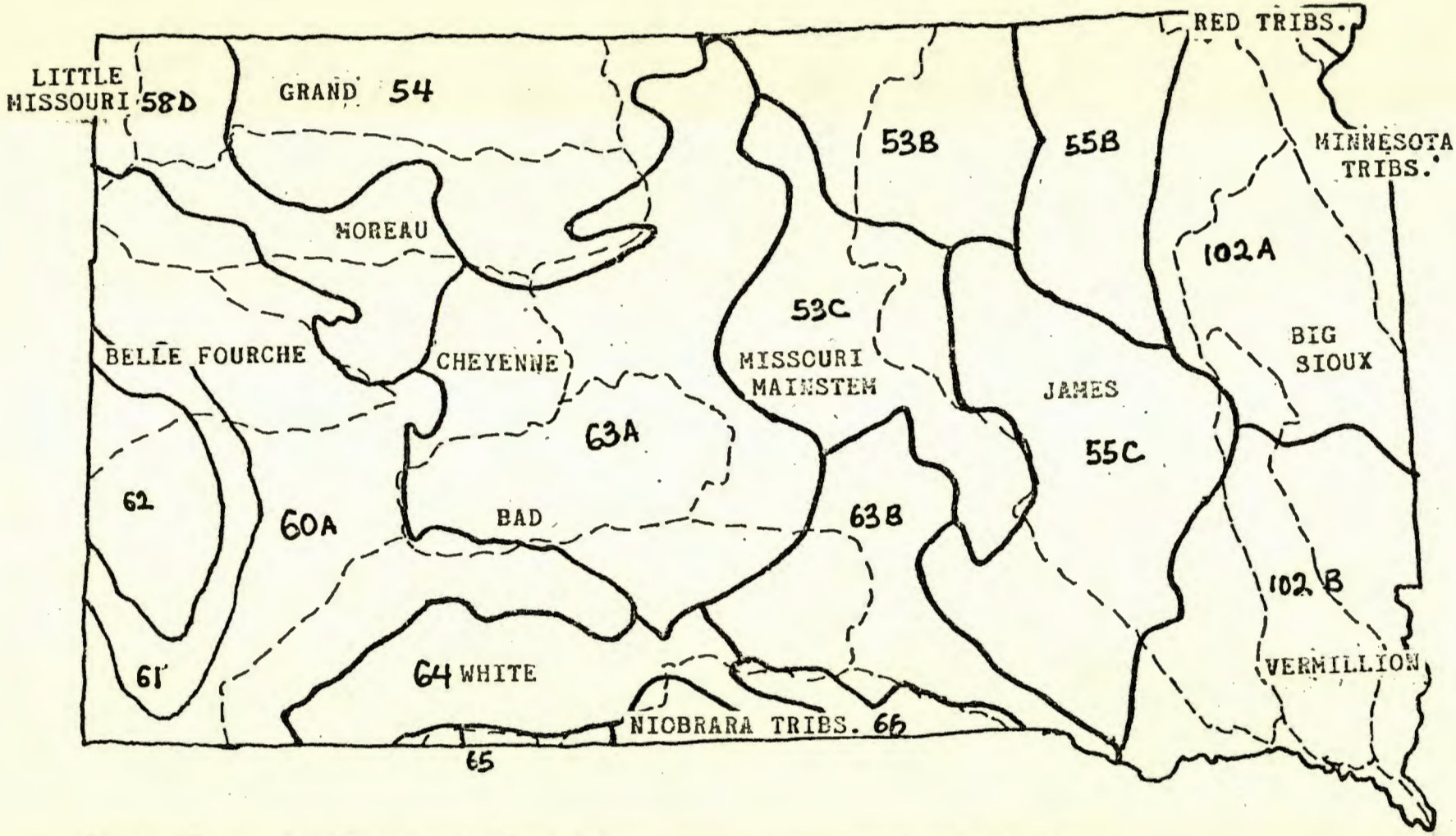
Source: USGS (1975)

Figure 2. Water Quality: Dissolved Solids Concentration in Major Streams, River Drainage Basins, South Dakota



Source: USGS (1975)

Figure 3. Water Quality: Suspended Sediment Concentration in Major Streams, River Drainage Basins, South Dakota



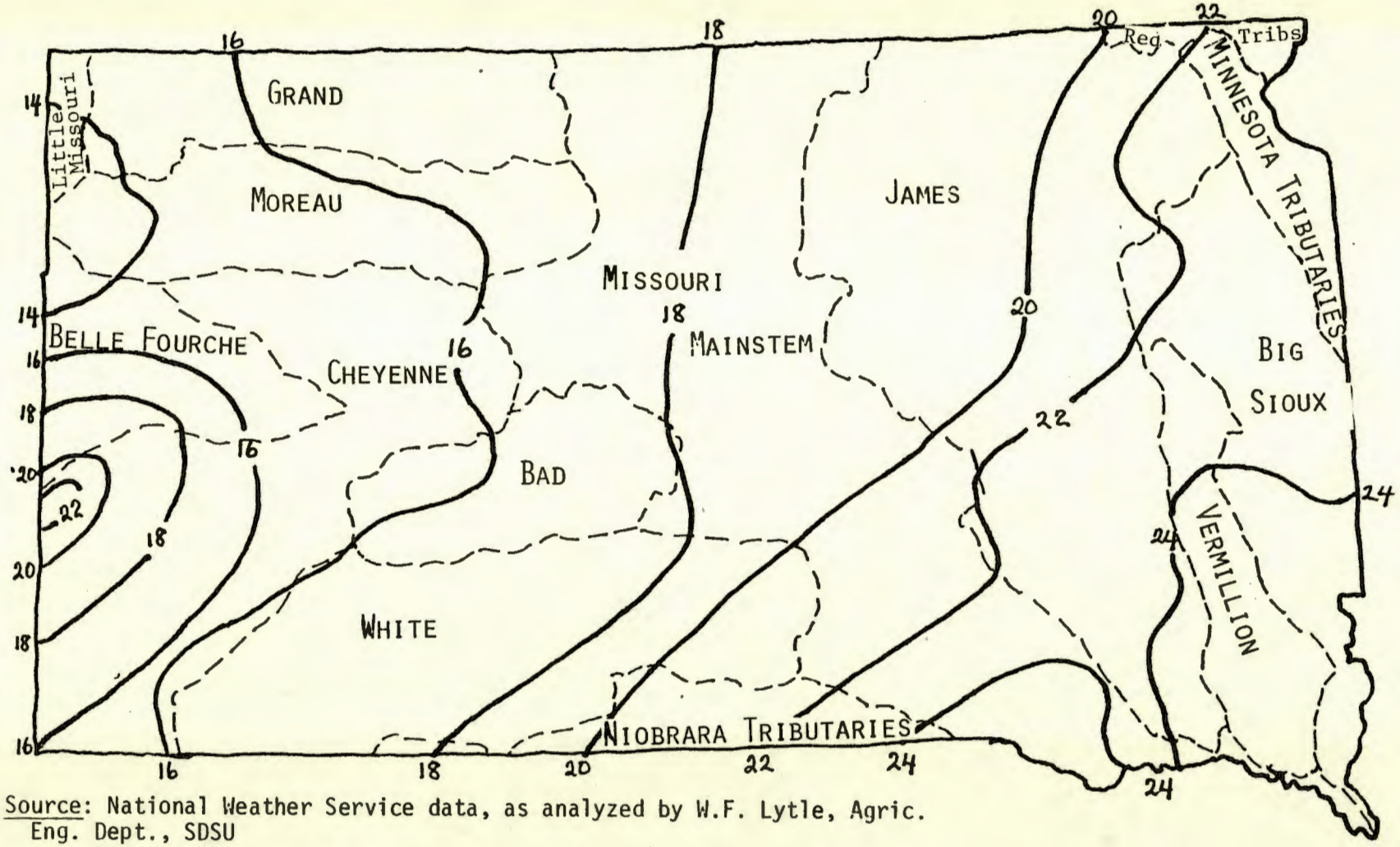
Source: Prepared by Gary Lemme, Plant Science Dept., SDSU; based on USDA (1982)

[a]The "major land resource areas" associated with each code are described on the next page.

Figure 4. Major Land Resource Areas, River Drainage Basins, South Dakota[a]

Figure 4. Major Land Resource Areas, River Drainage Basins, South Dakota, Continued

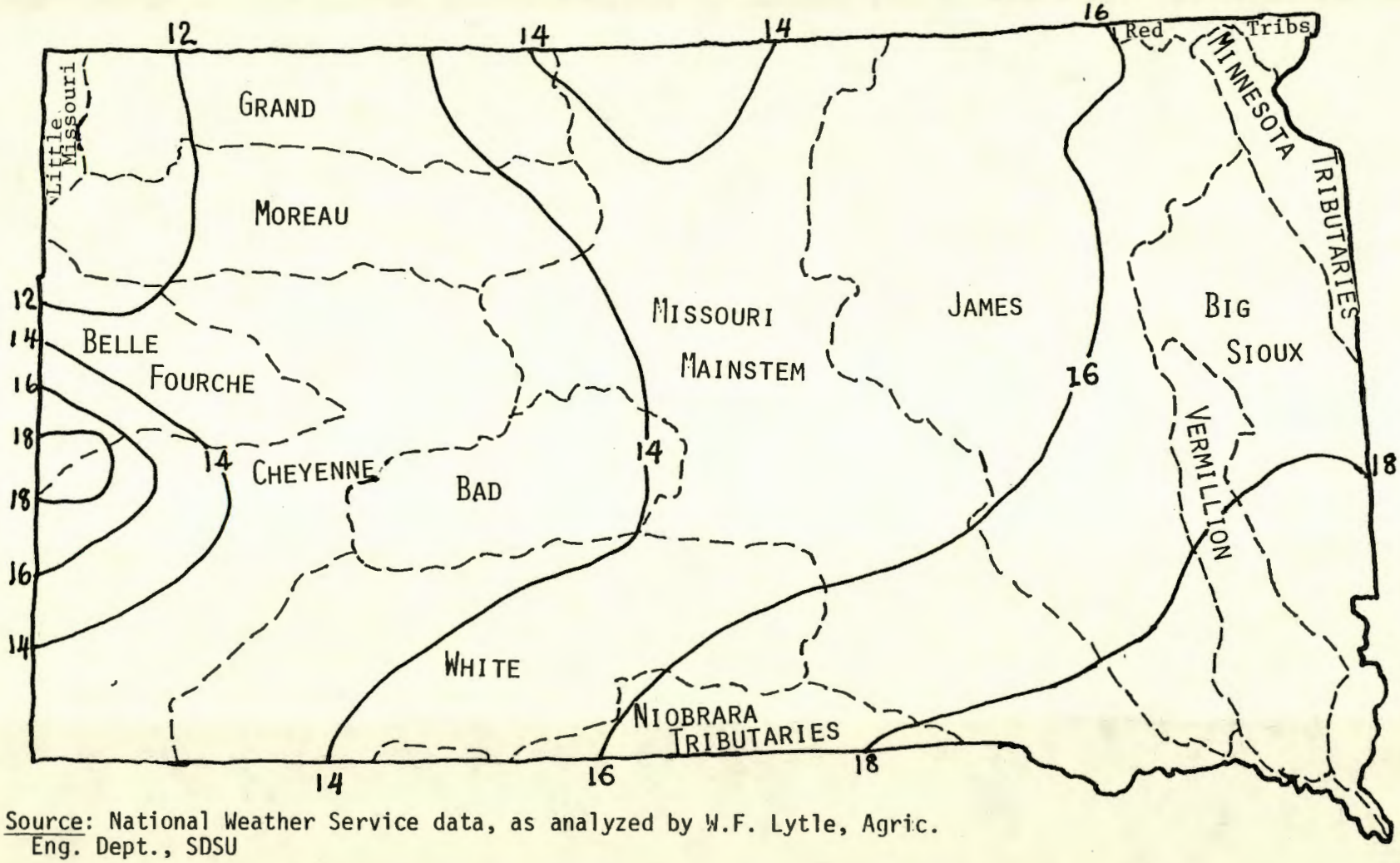
Code Number	Description of the "major land resource area"
53B	Central Dark Brown Glaciated Plains Nearly level to rolling till plains with many closed depressions; deep, well drained loamy, glacial till soils with a frigid temperature regime.
53C	Southern Dark Brown Glaciated Plains Nearly level to gently rolling till plains with many closed depressions; deep, well drained, loamy glacial till soils with a mesic temperature regime.
54	Rolling Soft Shale Plain Moderately dissected rolling residual plain; moderately deep and deep, well drained, loamy and clayey soils developed in soft calcareous shale, sandstone and siltstone residuum with a frigid temperature regime.
55B	Central Black Glaciated Plains Nearly level glaciolacustrine plain; deep, well drained, clayey soils developed in glacial lake sediments with a frigid temperature regime.
55C	Southern Black Glaciated Plains Nearly level to undulating till plains; deep, well drained, loamy glacial till soils with a mesic temperature regime.
58D	Northern Rolling High Plains, Eastern Part Gently rolling to steep dissected residual plain; moderately deep and shallow, well drained, loamy to clayey soils developed in shale and sandstone residuum with a frigid temperature regime.
60A	Pierre Shale Plains and Badlands Gently sloping residual plain; moderately deep, well drained, clayey soils developed in shale and siltstone residuum with a mesic temperature regime.
61	Black Hills Foot Slopes Hilly to steep hogback and foothills; deep to shallow, well drained, clayey and loamy soils developed in shale and limestone residuum with a mesic temperature regime.
62	Black Hills Steep mountainous area with narrow valleys; shallow to moderately deep, well drained, loamy and clayey soils developed in limestone, slate, schist, and granite with frigid and cryic temperature regimes.
63A	Northern Rolling Pierre Shale Plains Rolling residual plain; moderately deep and deep, well drained clayey soils, developed in shale residuum with a mesic temperature regime.
63B	Southern Rolling Pierre Shale Plains Nearly level to rolling residual plain; moderately deep and deep, well drained, clayey soils developed shale residuum with a mesic temperature regime.
64	Mixed Sandy and Silty Tableland Nearly level to gently sloping tableland; moderately deep and deep, well drained, sandy and silty soils developed in loess, siltstone and sandstone residuum and eolian sand with a mesic temperature regime.
65	Nebraska Sandhills Rolling to steep irregular sand dunes; deep, excessively drained, sandy soils developed in eolian sand with a mesic temperature regime.
66	Dakota-Nebraska Eroded Tableland Moderately sloping residual plain; moderately deep and deep, well drained, loamy soils developed in siltstone and sandstone residuum with a mesic temperature regime.
102A	Rolling Till Prairie Rolling till plain with many closed depressions; deep, well drained, loamy and silty soils developed in glacial till with a frigid temperature regime.
102B	Loess Uplands and Till Plains Gently rolling to nearly level uplands; deep, well drained, silty and loamy soils developed in loess and glacial till with a mesic temperature regime.



Source: National Weather Service data, as analyzed by W.F. Lytle, Agric. Eng. Dept., SDSU

Units: inches, reflecting the annual average for 1941-1970

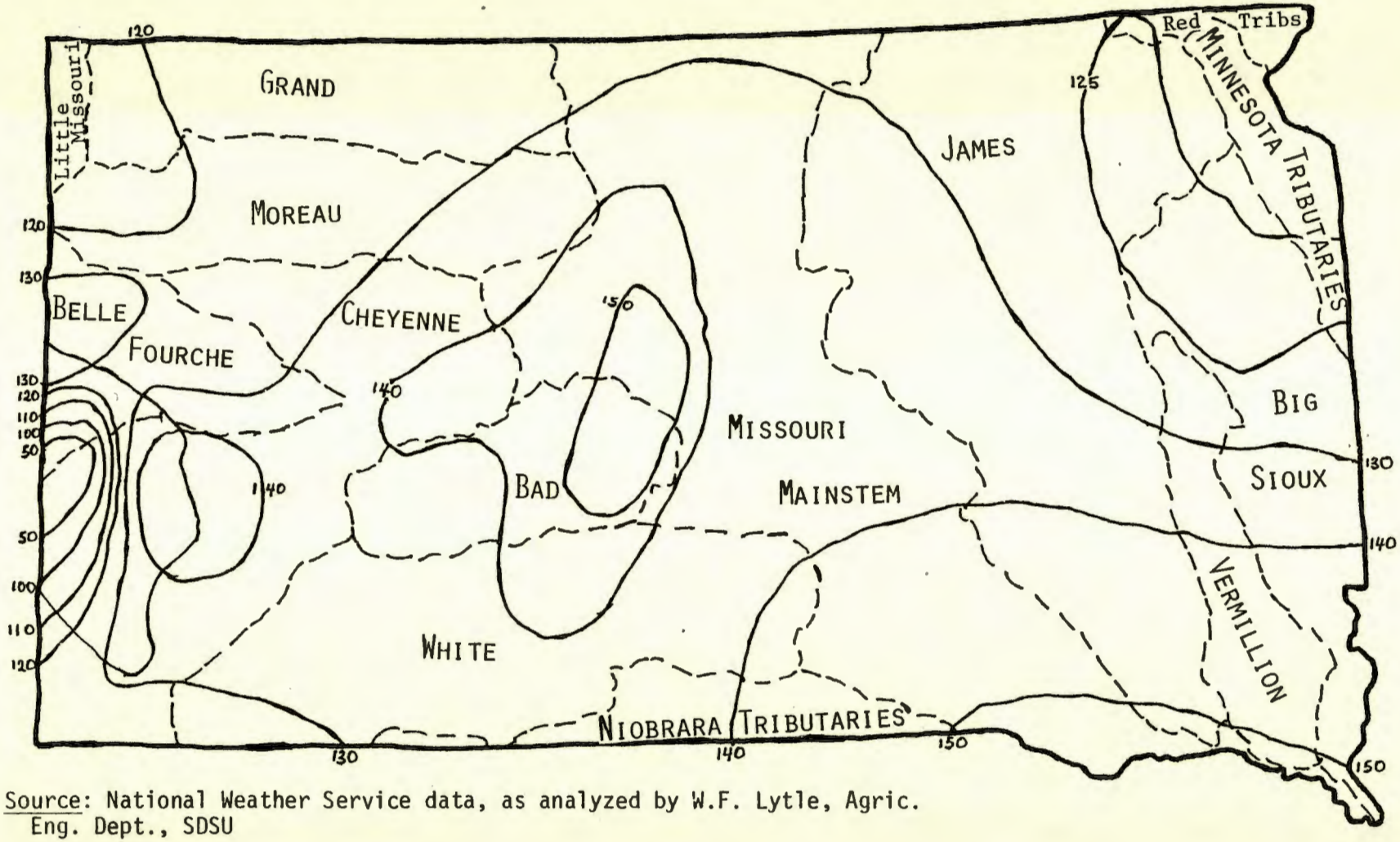
Figure 5. Average Annual Precipitation, River Drainage Basins, South Dakota



Source: National Weather Service data, as analyzed by W.F. Lytle, Agric. Eng. Dept., SDSU

Units: inches, reflecting the annual average for April through September for 1941-1970

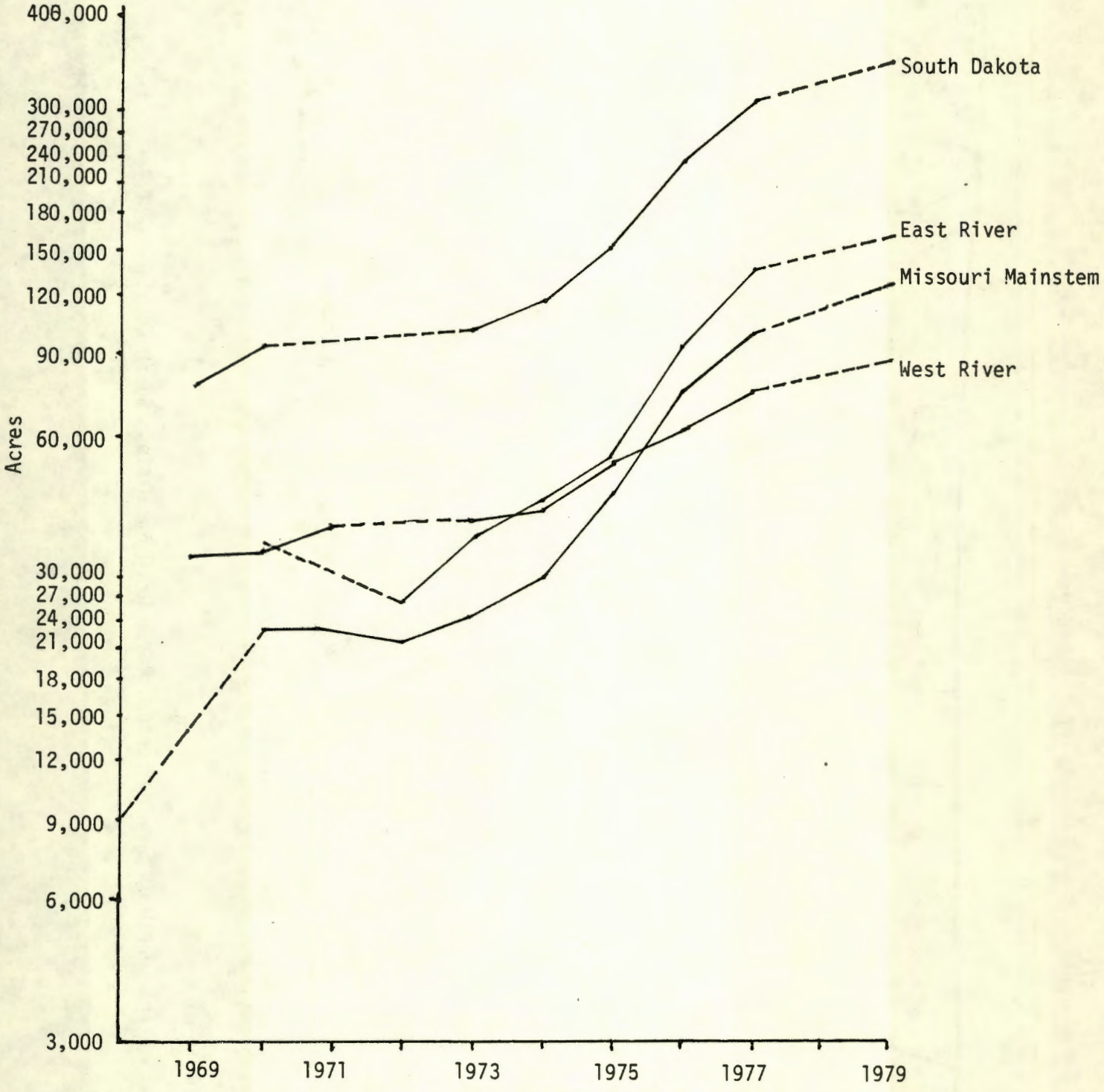
Figure 6. Average Normal Growing Season Precipitation, River Drainage Basins, South Dakota



Source: National Weather Service data, as analyzed by W.F. Lytle, Agric. Eng. Dept., SDSU

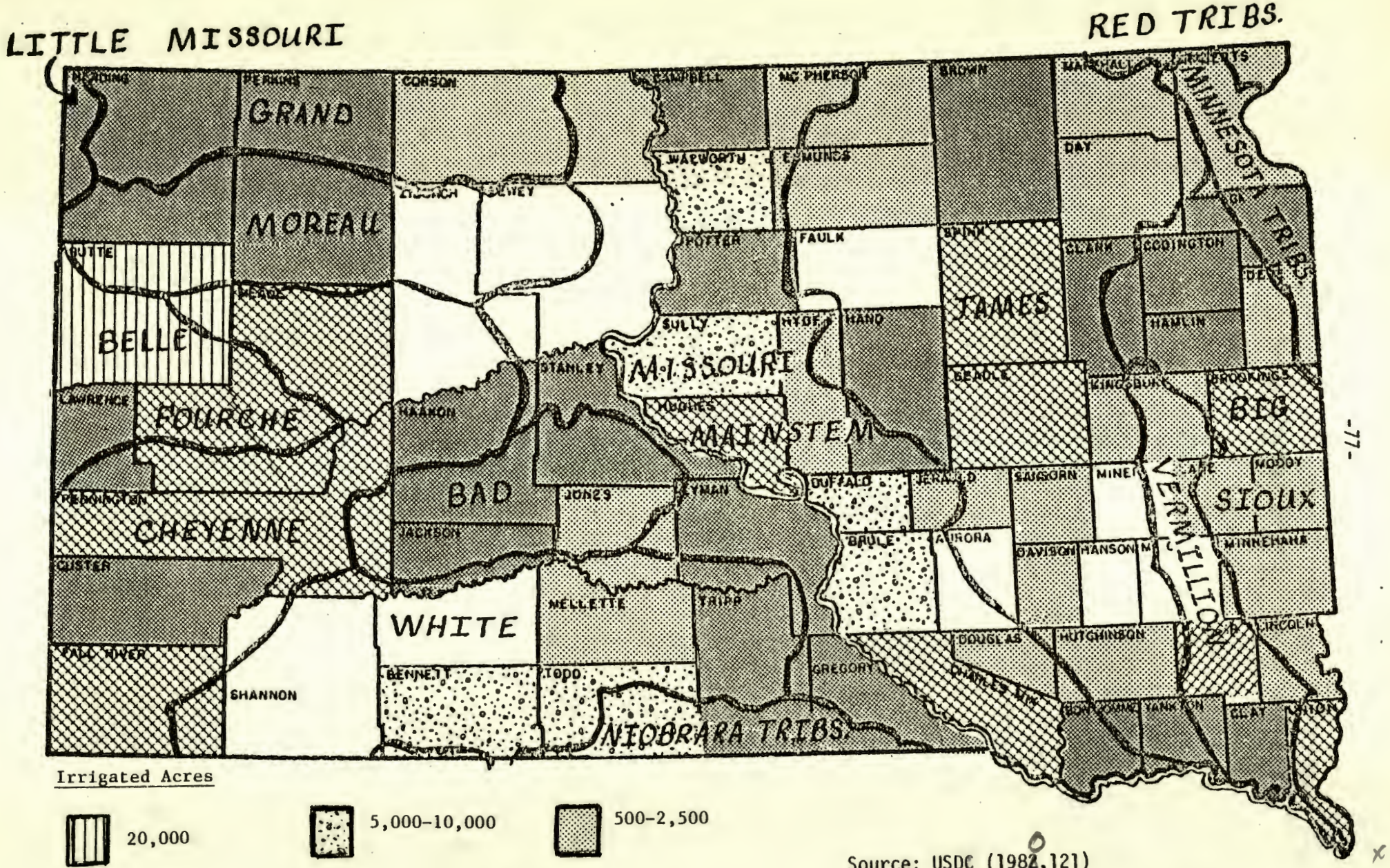
Units: numbers of days

Figure 7. Average Length of Growing Season, River Drainage Basins, South Dakota



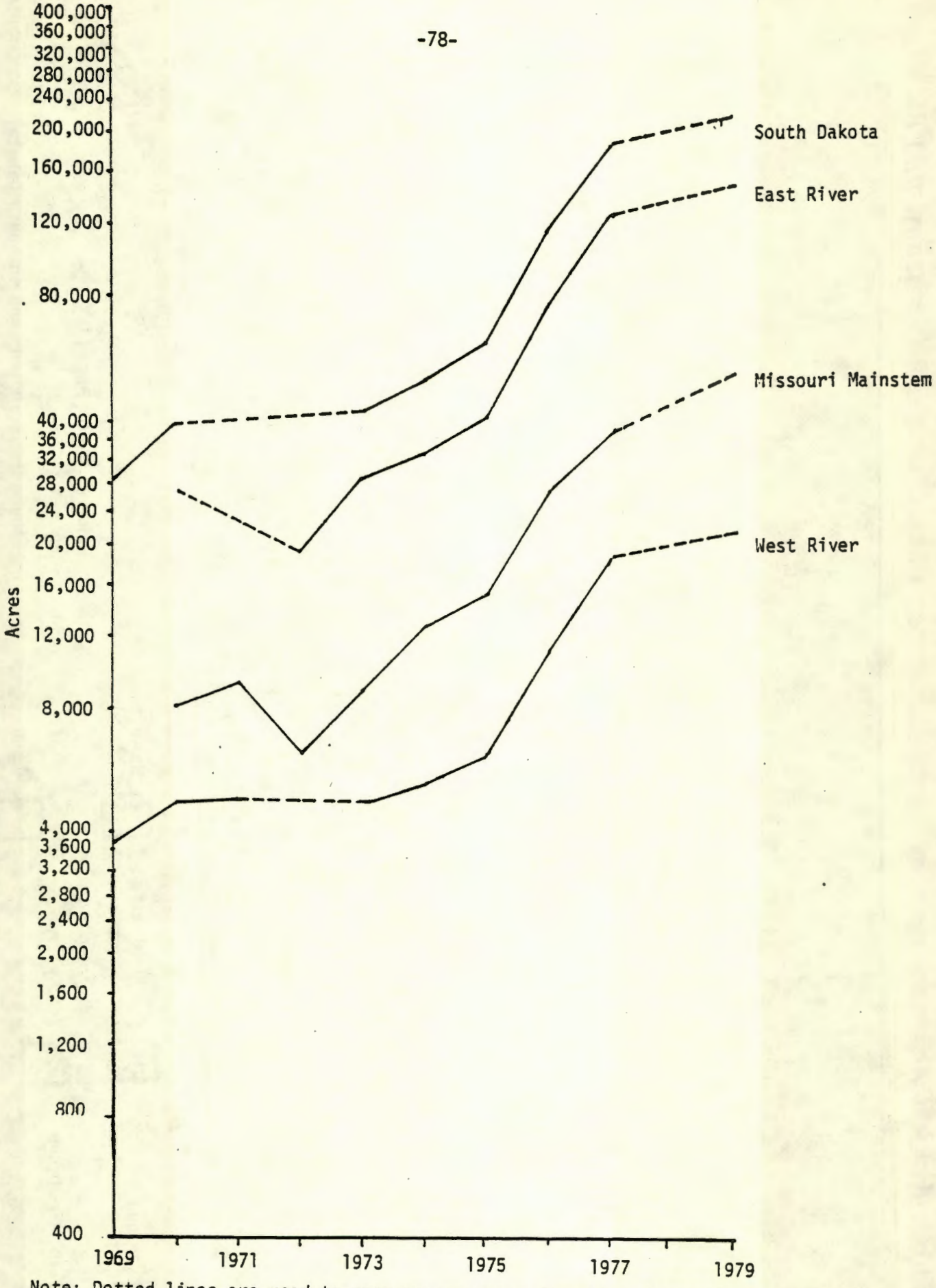
Note: Dotted lines are used to span across years for which data are unavailable..

Figure 8. Total Privately-Developed Irrigated Area, by Region in South Dakota, 1968-1979



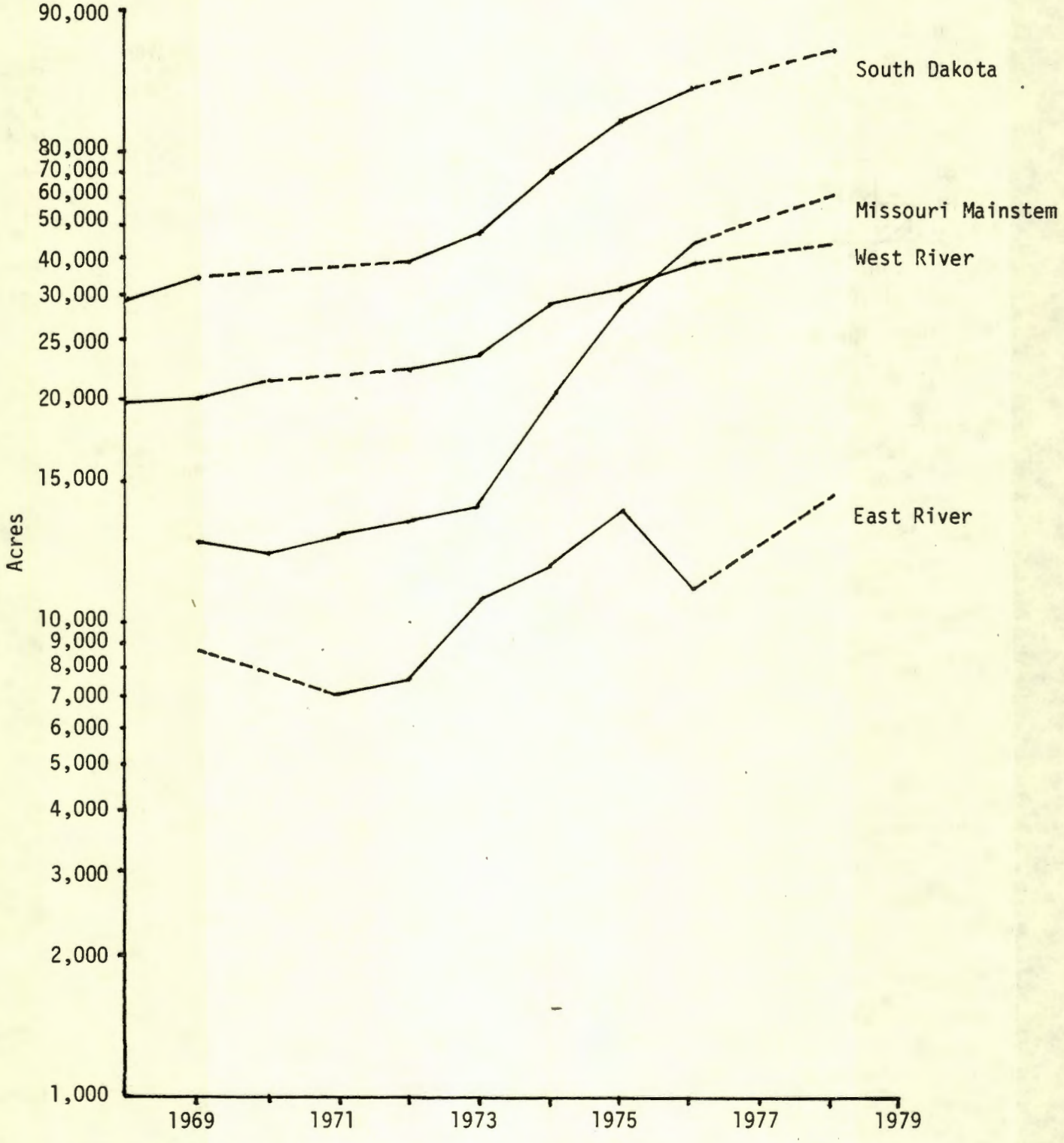
Source: USDC (1982,121)

Figure 9. Irrigated Land in South Dakota, by County, 1978



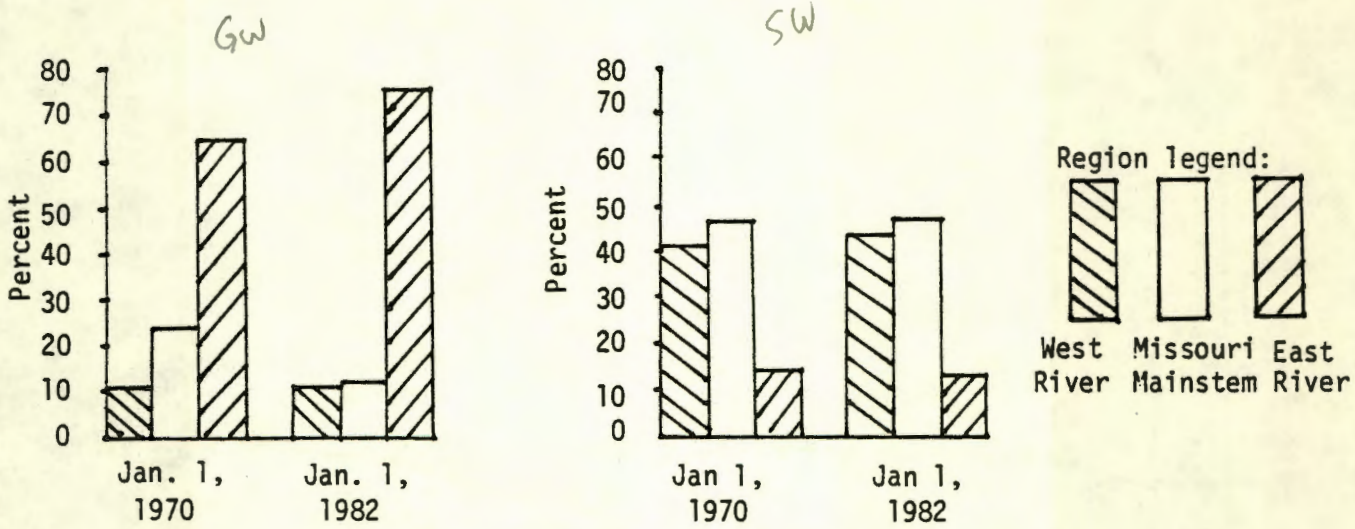
Note: Dotted lines are used to span across years for which data are unavailable.

Figure 10. Privately-Developed Area Irrigated from Groundwater Sources, by Region in South Dakota, 1969-1979



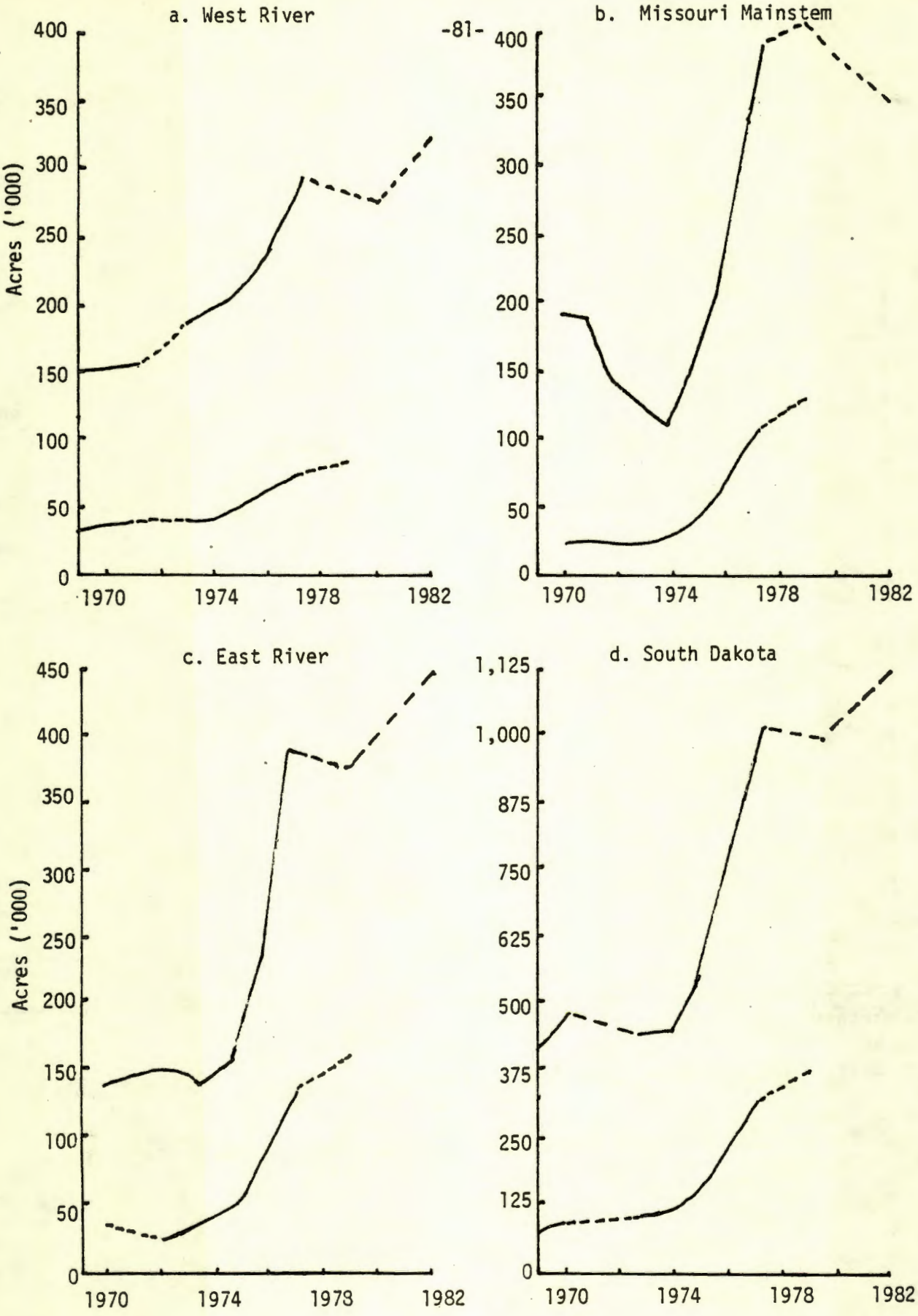
Note: Dotted lines are used to span across years for which data are unavailable.

Figure 11. Privately-Developed Area Irrigated from Surface Water Sources, by Region in South Dakota, 1969-1979



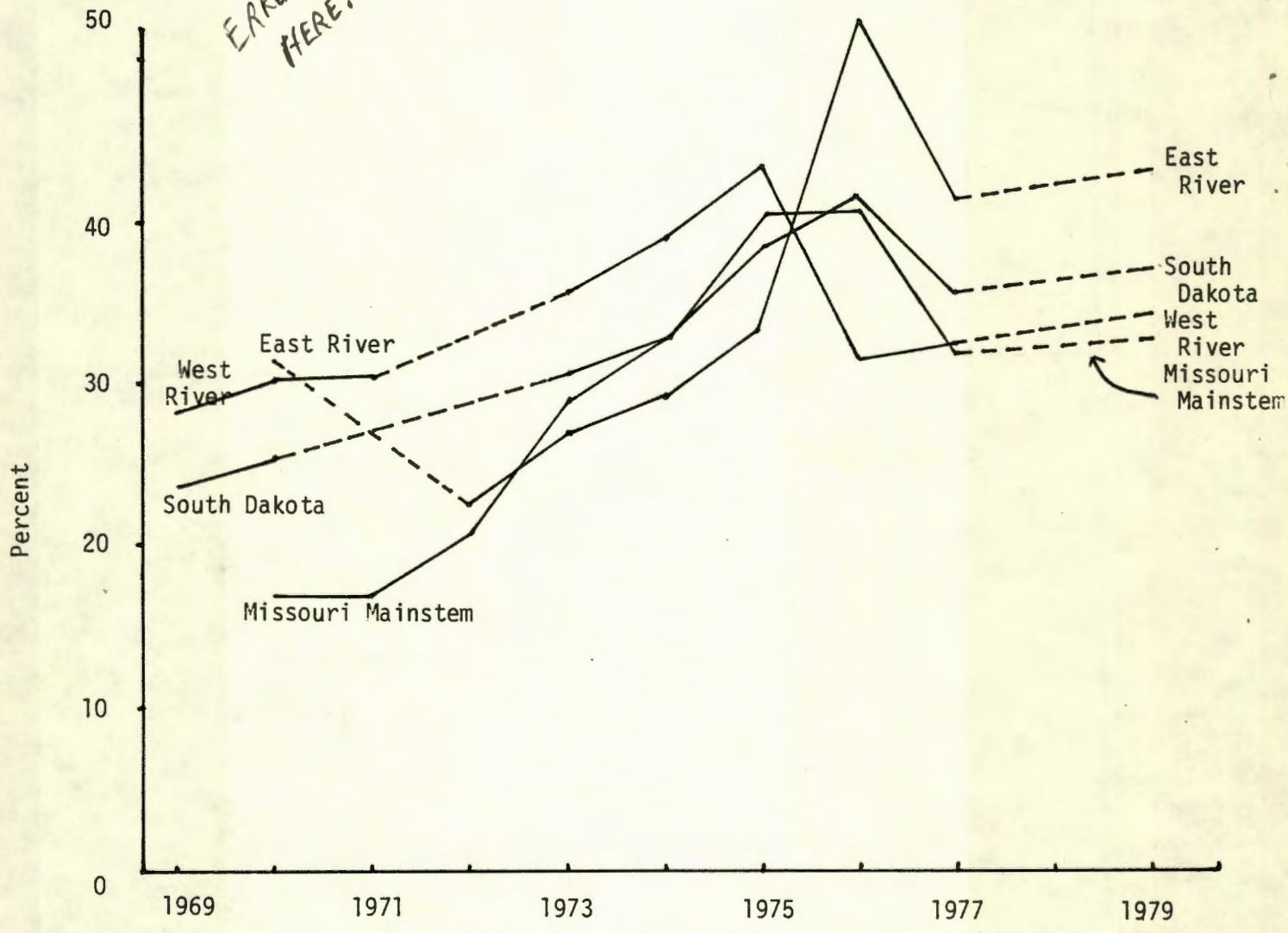
Source: The January 1, 1982 data are from the same source as that indicated for Table 14.

Figure 12. Irrigation Permit Area, Groundwater and Surface Water in Each Region as Percentages of the South Dakota State Total, by Region, 1970 and 1982



Source: The January 1, 1982 irrigation permit areas are from the same source as that indicated for Table 14.

Figure 13. Irrigation Permit and Actual Irrigated Areas, by Region in South Dakota, 1969-1982



Note: Dotted lines are used to span across years for which data are unavailable.

Figure 14. Actually Irrigated Areas as Percentages of Irrigation Permit Areas, by Region in South Dakota, 1969-1979

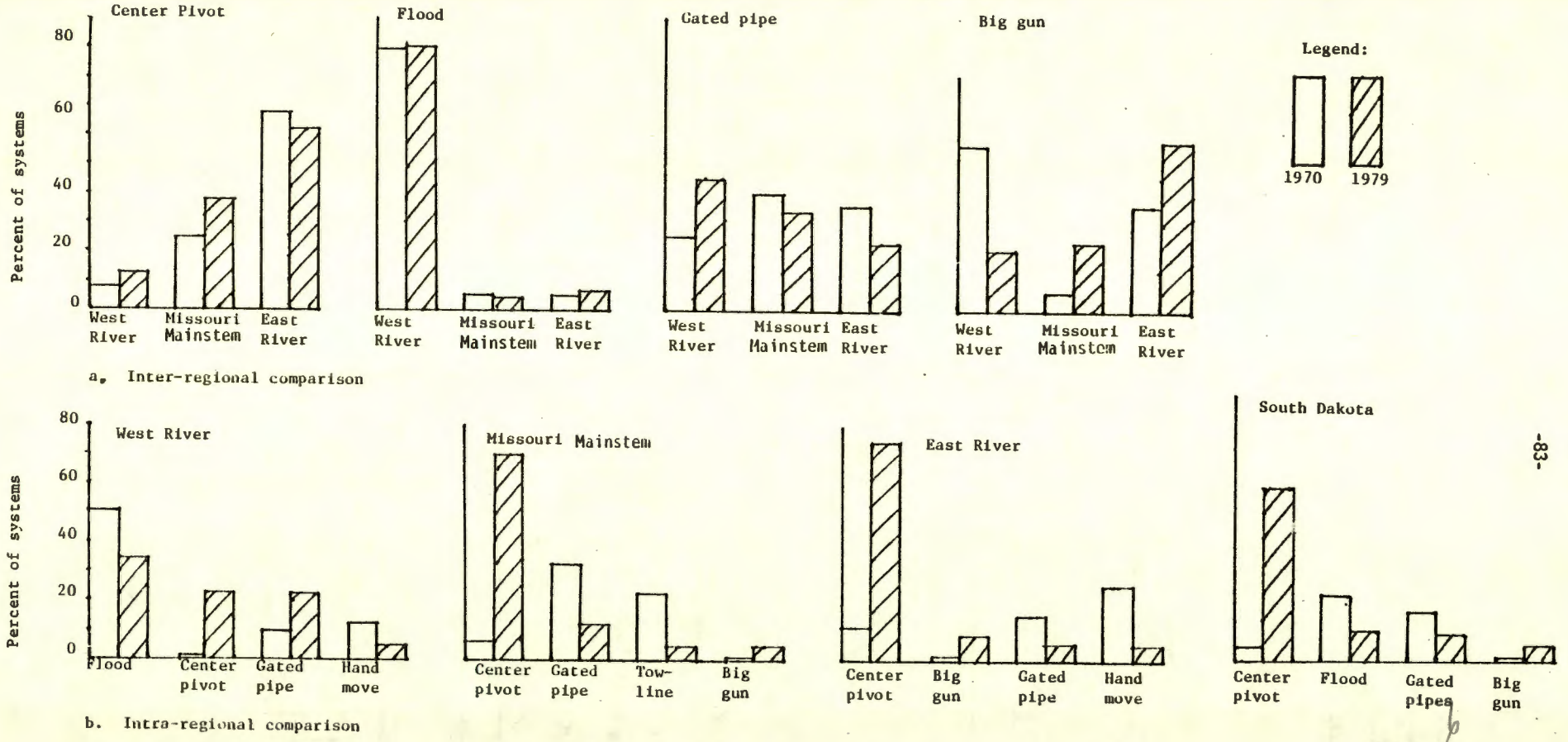


Figure 15. Relative Importance of Selected Types of Systems for Distributing Privately-Developed Irrigation Water, by Region in South Dakota, 1970 and 1979

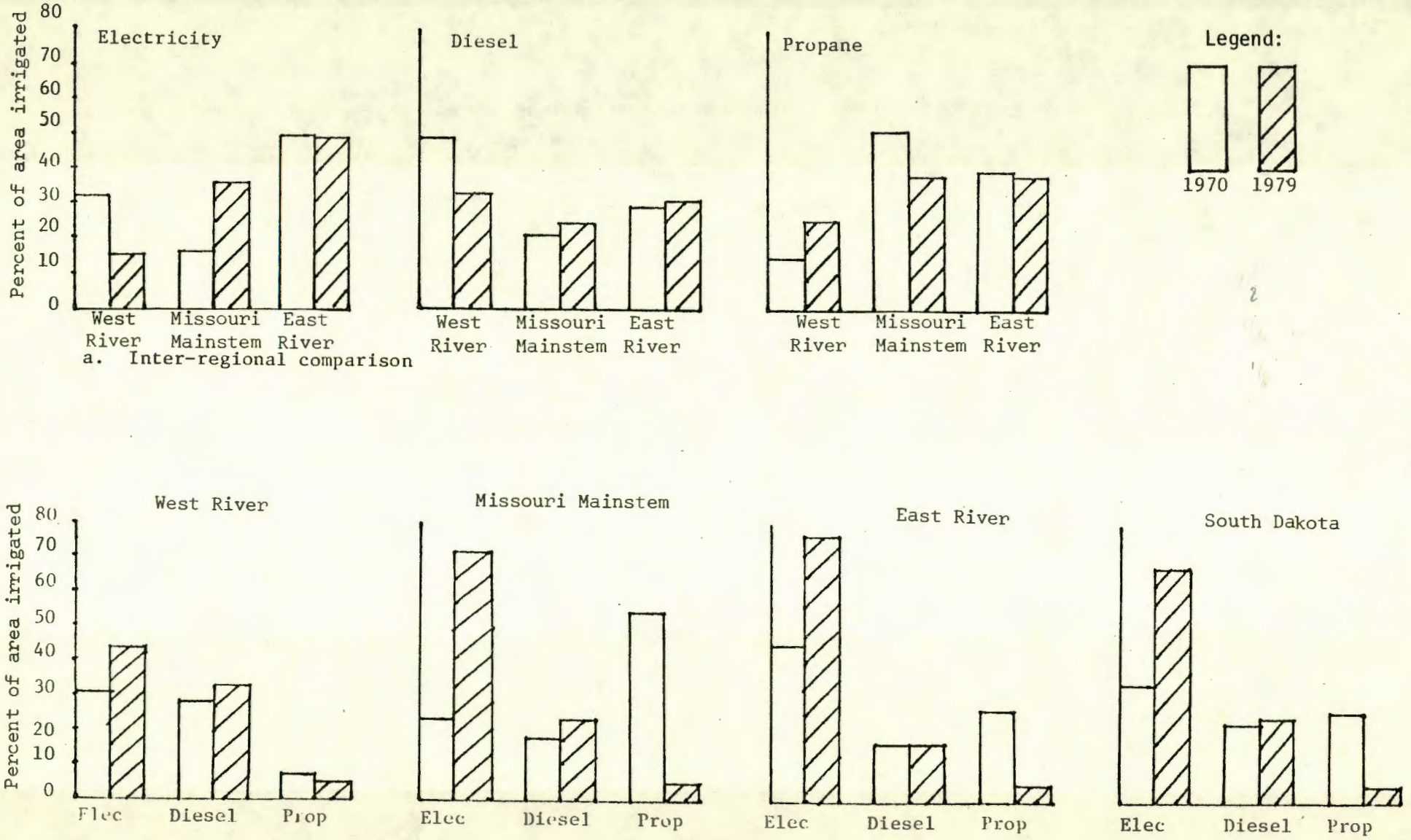


Figure 16. Relative Importance of Selected Types of Energy for Diverting Privately-Developed Irrigation Water, by Region in South Dakota, 1970 and 1979

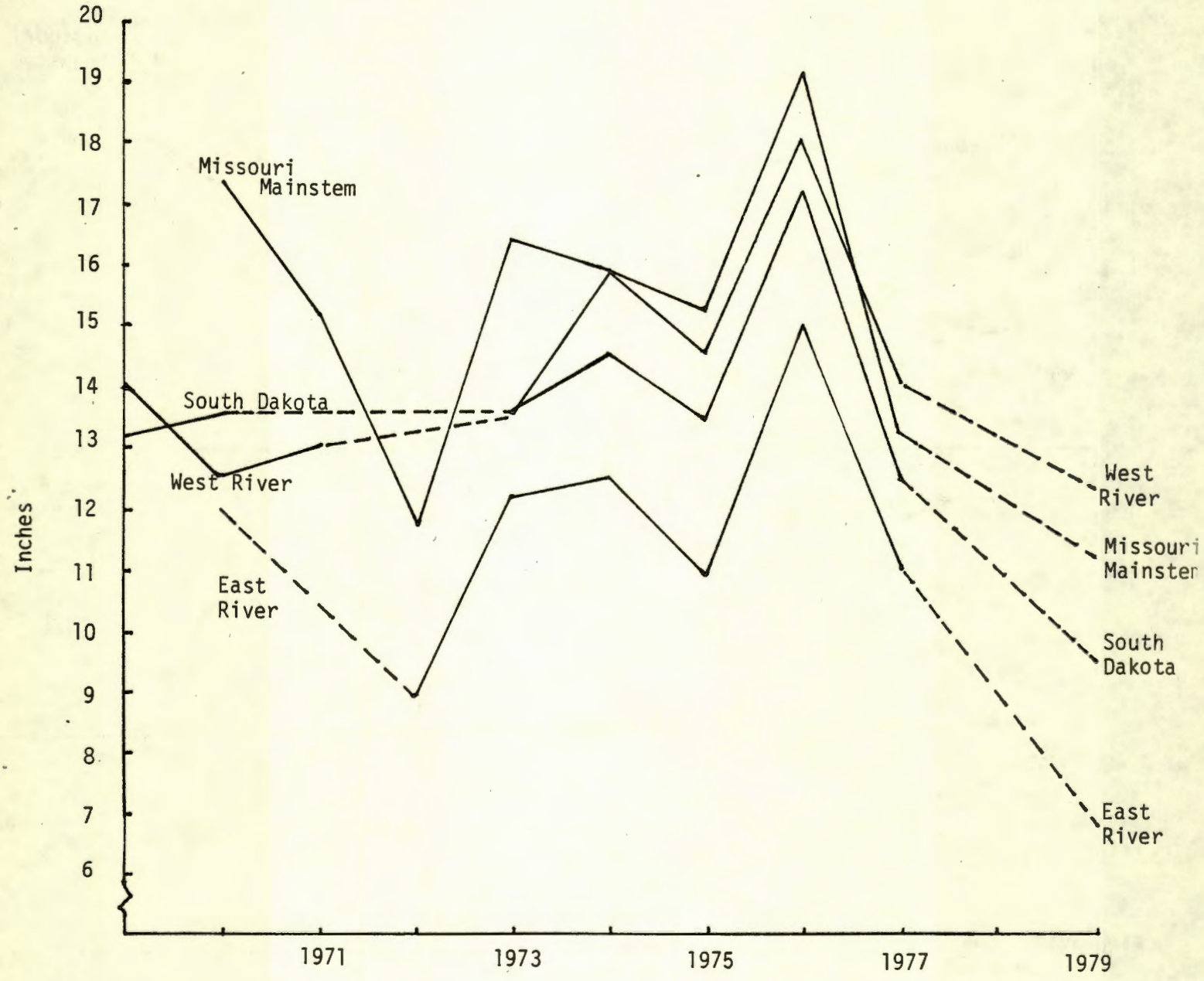
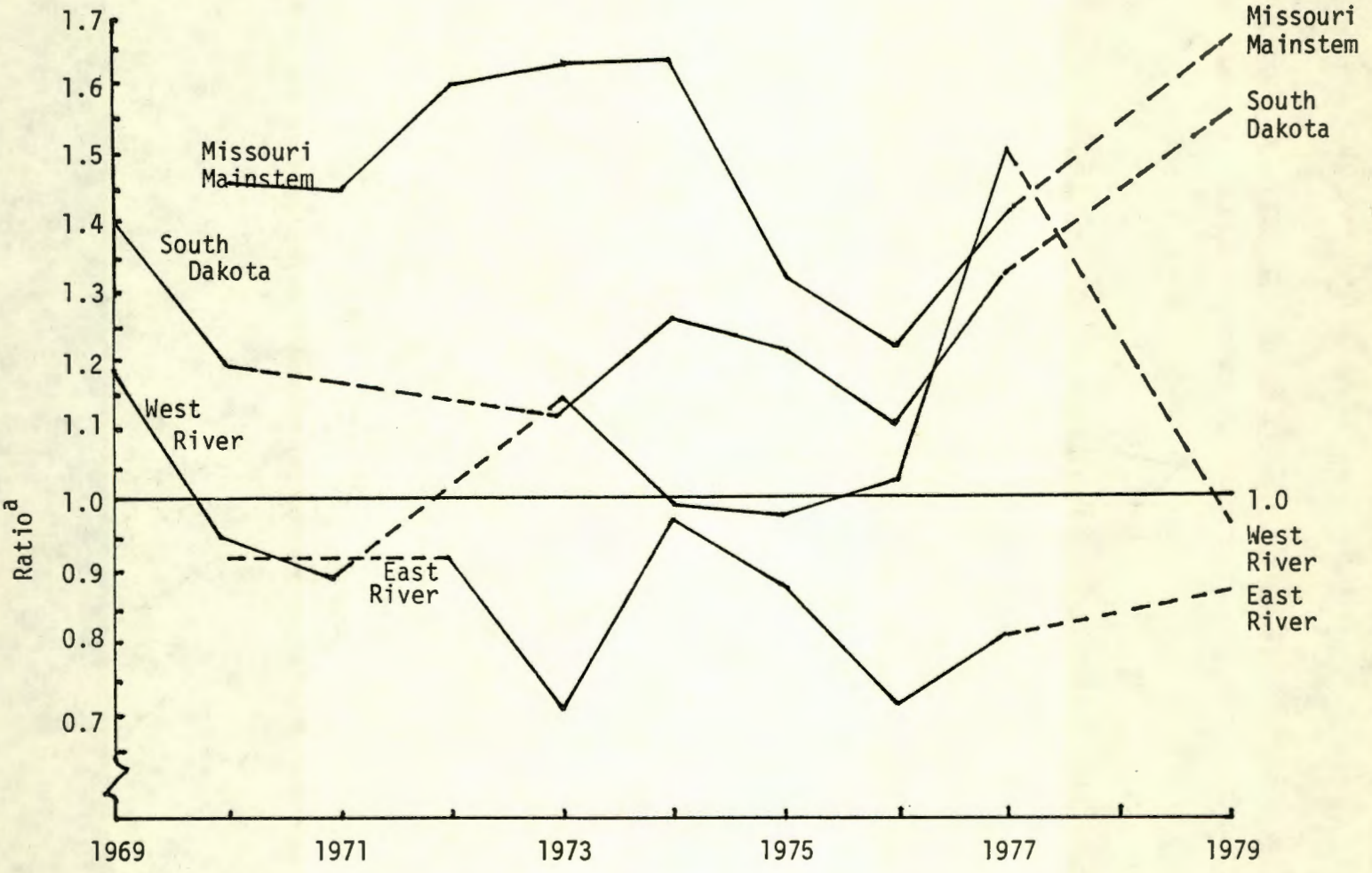
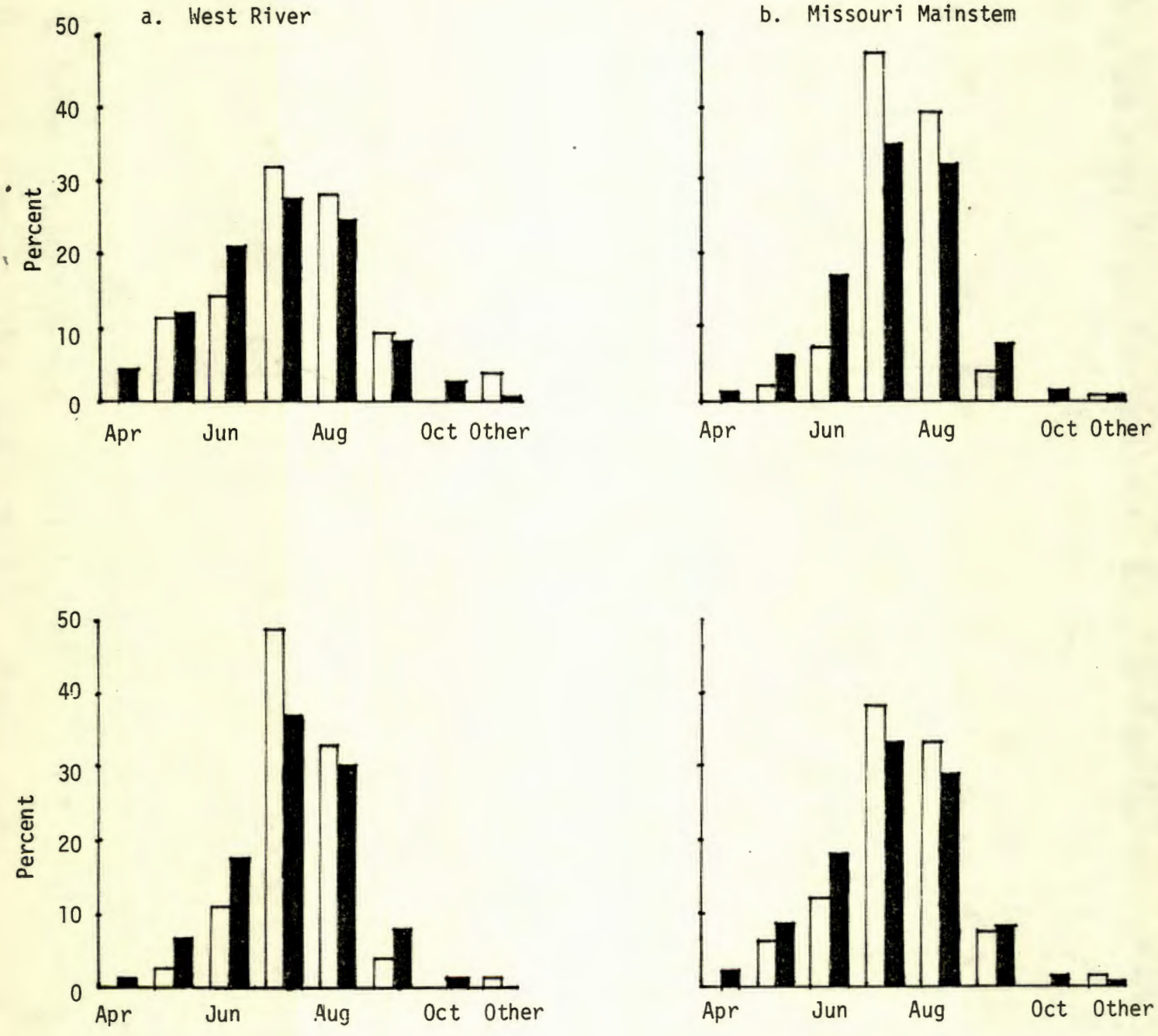


Figure 17. Average Depth of Irrigation Water Applied per Season, Privately-Developed Irrigation Sources, by Region in South Dakota, 1969-1971



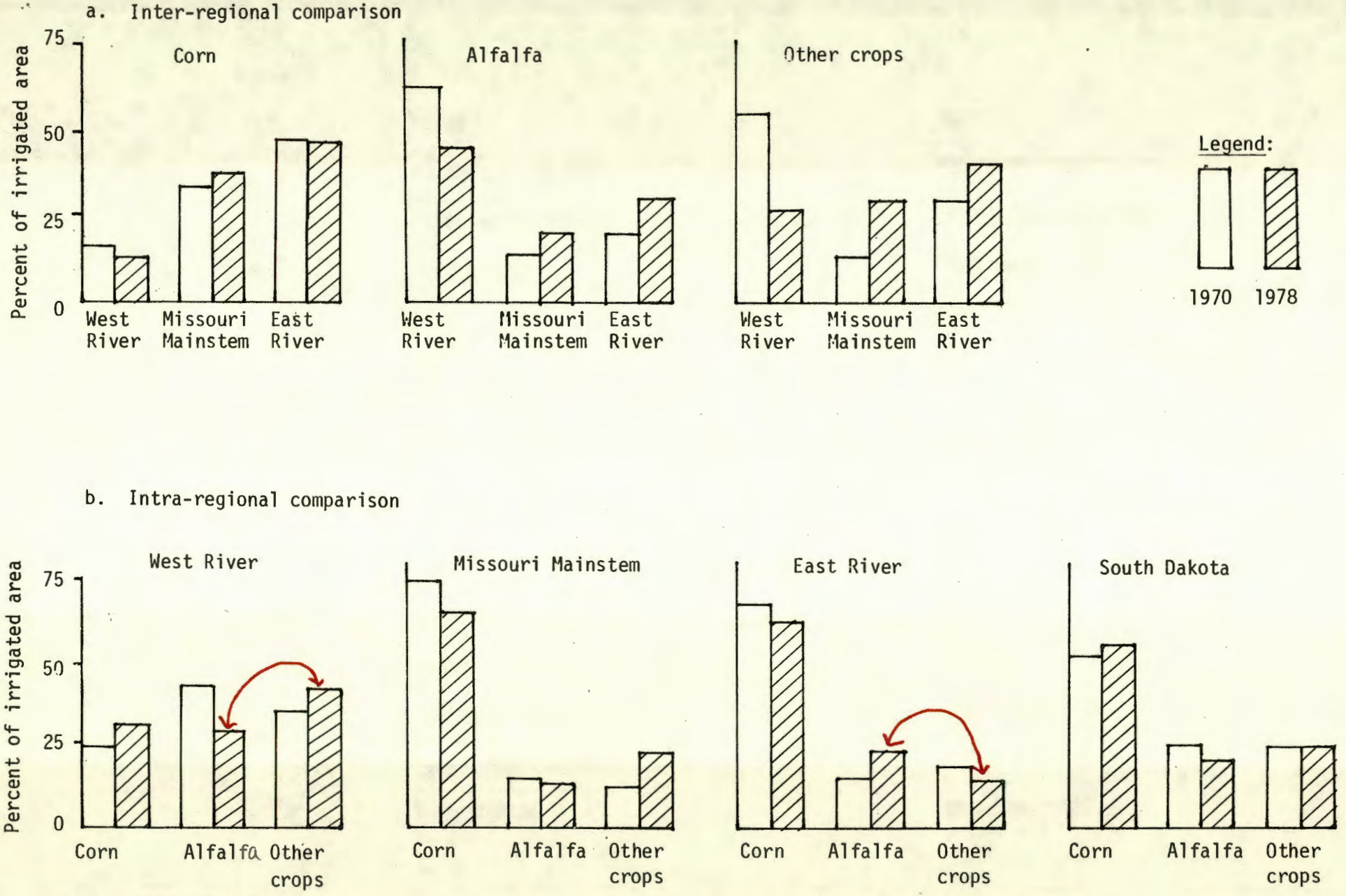
a The ratios are the acre inches of irrigation water applied from surface water sources relative to the acre inches from groundwater sources.

Figure 18. Depths of Irrigation Water Applied, Privately-Developed Surface Water versus Groundwater Sources, by Region in South Dakota, 1970-1979



a The "1970" and "1978" data reported in the figure reflect three-year averages of the available data centered on the years concerned.

Figure 19. The Seasonal Distribution of Irrigation Water Applications, Privately-Developed Irrigation Sources, by Region in South Dakota, 1970-1978[a]



a The "1970" and "1978" data reported in the figure reflect three-year averages of the available data centered on the years concerned.

Figure 20. Areas of Irrigated Corn and Alfalfa, Privately-Developed Irrigation Sources, by Region in South Dakota, 1970 and 1978.