ANALYSIS OF GROUND-WATER AND STREAMFLOW DATA
WESTERN DAKOTAS REGION OF SOUTH DAKOTA

TASK 3.D AND 4.C: GROUND-WATER RECHARGE

FINAL REPORT

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INTRODUCTION

This report is part of a series of studies being conducted by the U.S. Army Corps of Engineers to evaluate water resources in western South Dakota. The output contained in this report is restricted to portions of South Dakota west of the Missouri River. The following Sub-TASKS are the output for this report.

TASK 3 - Conduct a ground-water resource inventory in the Black Hills area including bedrock and alluvial deposits.

D. Make estimates of probable maximum-minimum natural recharge rates to aquifers, where feasible.

TASK 4 - Update, expand, and detail the "Reconnaissance Elements of Western South Dakota Region of South Dakota, Part 2" (Rahn, 1981).

C. Make estimates of probable maximum-minimum natural recharge rates to aquifers, where feasible.

The first part of these TASKS (3.A.B.C. and 4.A.B.) was submitted previously and identified 15 major regional aquifer units and 11 non-aquifer units (Allen, Iles, and Petres, 1984). The general surface distribution of these units in western South Dakota are shown on figure 1.

RECHARGE TO AQUIFERS IN BLACK HILLS AREA

Alluvium

No data are available for calculation of recharge rates to alluvium in the Black Hills. However, comparison to similar types of deposits in eastern South Dakota does provide general values for comparison.

In eastern South Dakota extensive areas of surficial glacial outwash deposits are present (Hedges and others, 1981, pl. 7). These deposits are composed primarily of coarse sand and gravel and where saturated provide water table aquifers. Natural recharge to these aquifers range from 2 to 5.6 inches per year (Hedges and others, 1983). In general, the higher recharge rates are found in the east and southeast part of eastern South Dakota where annual precipitation is as much as 25 inches per year. The lower recharge rates are found in the western and northwestern part of eastern South Dakota where the precipitation is as low as 17 inches per year. Thus, there appears to be a general direct relationship between precipitation and recharge for these types of deposits.

Alluvium in the Black Hills is generally comprised of coarse sand and gravel (Rahn, 1981). Where saturated, these deposits are aquifers under water table conditions. Precipitation in the Black

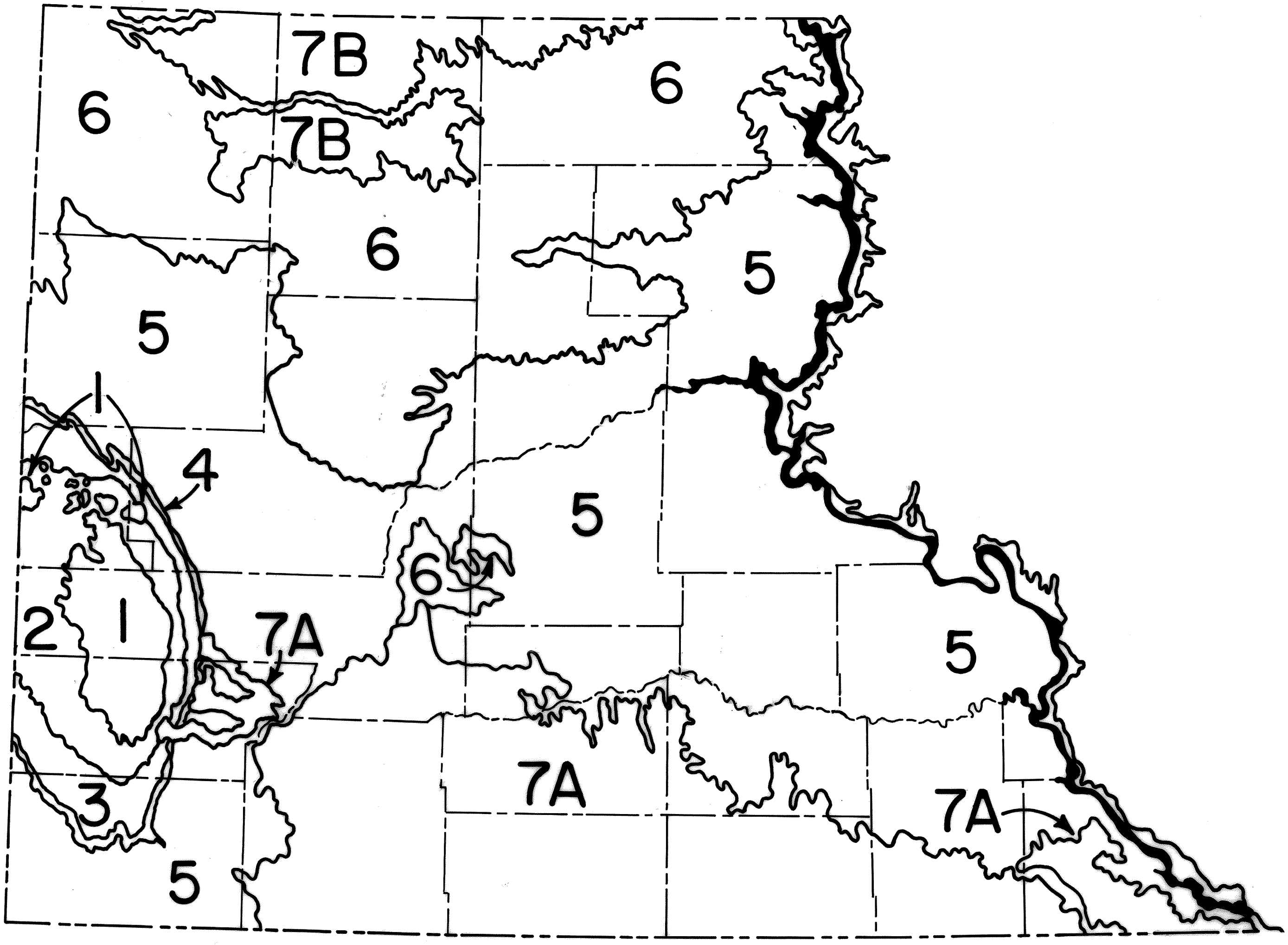

FIGURE 1. GEOLOGIC MAP OF WESTERN SOUTH DAKOTA
(See explanation on next page.)

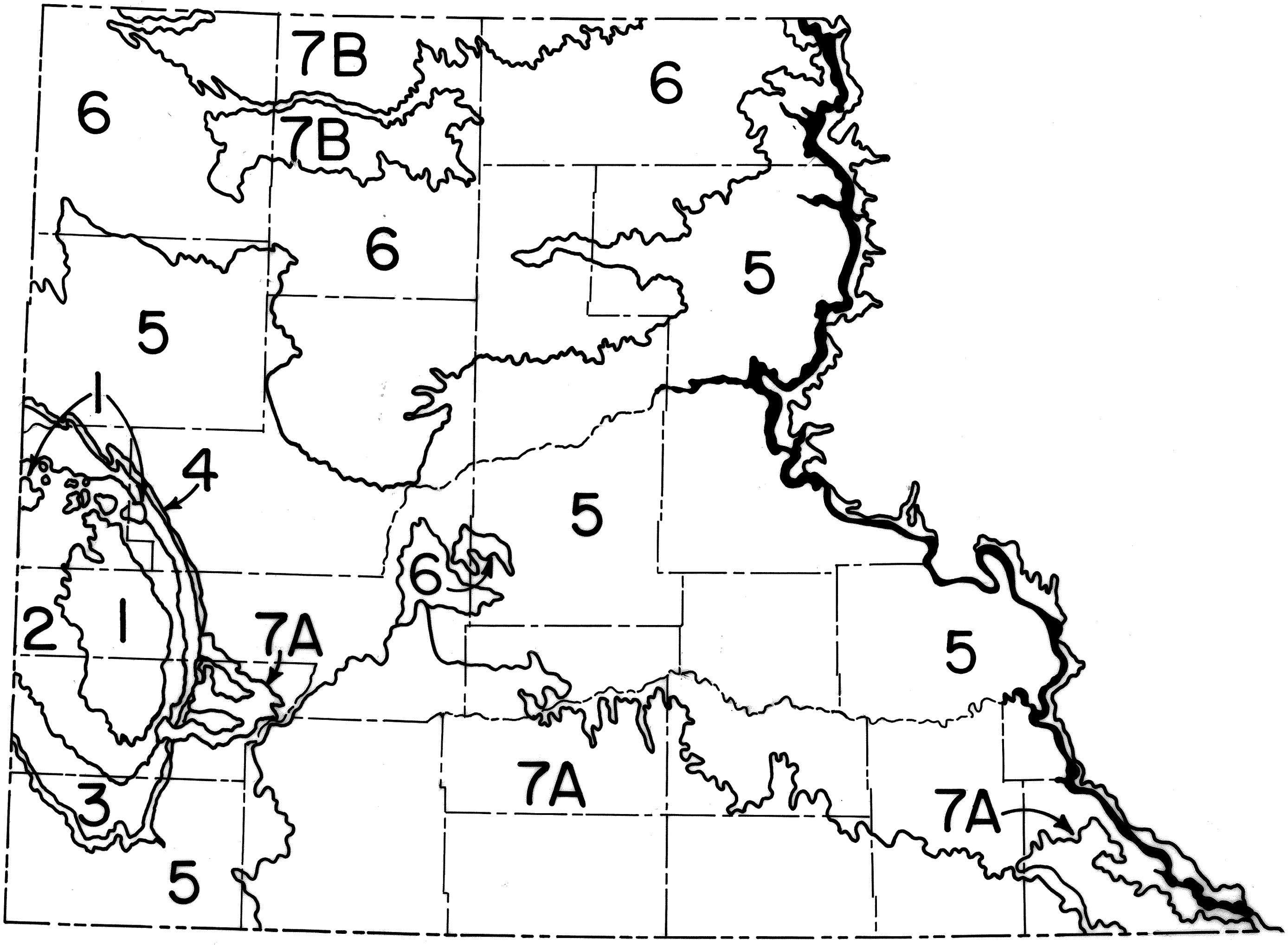

FIGURE 1. GEOLOGIC MAP OF WESTERN SOUTH DAKOTA
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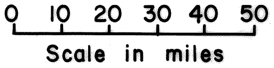


FIGURE 1 -- Explanation

	Aquifer	Non-Aquifer
Area 1	Precambrian igneous Precambrian metamorphic Tertiary igneous	
Area 2	Deadwood Formation Red River Formation Madison Group Minnelusa Group Minnekahta Limestone	Opeche Shale
Area 3	Sundance Formation	Spearfish Formation Morrison Formation Unkpapa Sandstone*
Area 4	Inyan Kara Group Dakota-Newcastle Formation	Skull Creek Shale Mowry Shale Belle Fourche Shale Greenhorn Limestone Carlile Shale Niobrara Formation*
Area 5		Pierre Shale
Area 6	Fox Hills Formation Hell Creek Formation	
Area 7A	Arikaree Group Ogallala Group	
Area 7B	Fort Union Group	
Area 8	Alluvium (not shown on this map)	

* The Niobrara Formation and Unkpapa Sandstone are capable of supplying modest amounts of water in western South Dakota. These stratigraphic units were not assigned major aquifer status because of the lack of available data to assess their potential use as aquifers in western South Dakota.

Hills ranges from about 18 to 25 inches (fig. 2). Because all the alluvium in the Black Hills is located along streams, periodic flooding would also enhance recharge to these deposits.

Geologic conditions and annual precipitation ranges are similar for alluvium in the Black Hills and the surficial glacial outwash depsoits in eastern South Dakota. Thus, without additional corroborative data, it can only be estimated that recharge rates to the alluvium in the Black Hills is comparable to the range of recharge (2 to 5.6 inches annually) rates to the surficial glacial outwash deposits.

The areal extent of the major alluvium deposits in the Black Hills are shown in TASK 1B. Table 1 of this report shows the estimated amount of possible recharge to the major alluvial deposits using the range of figures mentioned above. Total recharge to the alluvium in the Black Hills thus may range from about 50,000 to 150,000 acre feet per year. Minor alluvial deposits were not considered, so these estimates are probably minimal values for the entire Black Hills.

Bedrock

Bedrock aquifers in the Black Hills, represented as Areas 1, 2, 3, and 4 (fig. 1), receive all of their recharge directly from precipitation within the Black Hills area. While there may be vertical flow components between these units at any given location, the net change in storage due to vertical movement is considered to be zero. Because the entire Black Hills area is considered to be a recharge area, ground-water flow is away from the Hills in all directions. Thus ground- water inflow is not a component of recharge.

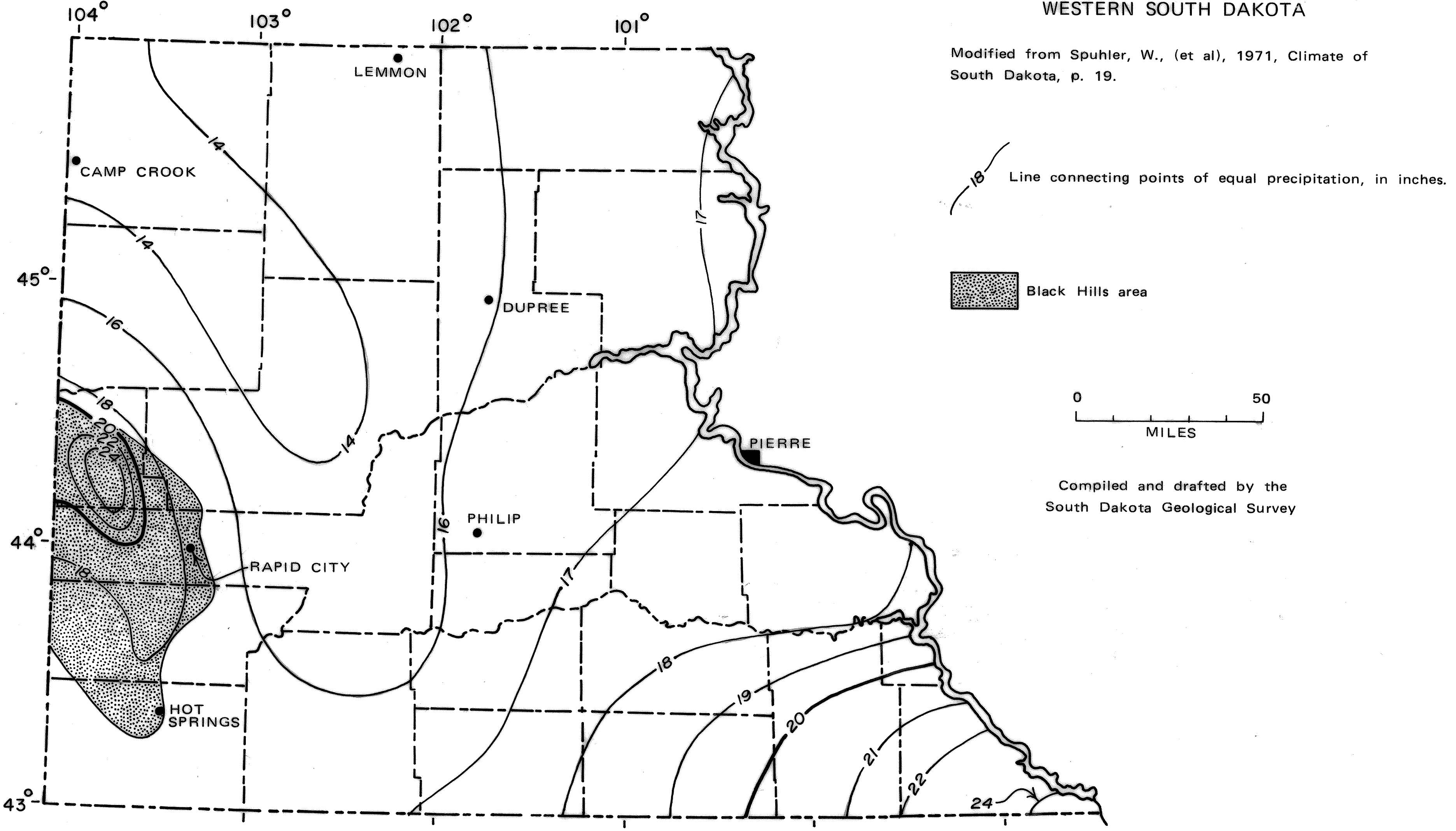
The bedrock aquifer units of areas 6, 7A and 7B (fig. 1) receive their recharge through downward percolation of precipitation. In addition, regional piezometric maps (Kolm and Case, 1983) indicates that there is ground-water inflow from Nebraska into the Arikaree-Ogallala aquifers of area 7A (fig. 1).

An extensive study of the water resources in the Black Hills and surrounding area was conducted for the U.S. Bureau of Land Management by Woodward-Clyde Consultants as part of an Environmental Impact Statement for the proposed ETSI pipeline (Woodward-Clyde Consultants, Inc., 1981). Concerning recharge in the Black Hills, they concluded:

> " The actual quantity of water that recharges the Madison aquifer and overlying Minnelusa aquifer in the Black Hills region is not known. Data are available, though, which permit the placement of upper and lower bounds on the recharge rate."

Figure 2.
Annual Average Precipitation
WESTERN SOUTH DAKOTA

Modified from Spuhler, W., (et al), 1971, Climate of South Dakota, p. 19.



Compiled and drafted by the South Dakota Geological Survey

TABLE 1

List of Drainage Basins in the Black Hills and Probable Recharge Volumes for Alluvial Aquifers

Basin	Acres	Minimum Recharge (acre feet per year)	Maximum Recharge (acre feet per year)
Alkali Creek	---	---	---
Battle Creek	32,000	5,330	14,931
Bear Butte Creek	---	---	---
Beaver Creek	---	---	---
Bennett Canyon	---	---	---
Box Elder Creek	---	---	---
Cascade Creek	---	---	---
Chilson Canyon	---	---	---
Cottonwood Creek	3,200	533	1,500
Crow Creek	---	---	---
Driftwood Creek	---	---	---
Elk Creek	117,760	19,620	54,950
Fall River	---	---	---
False Bottom Creek	---	---	---
French Creek	23,680	3,945	11,050
Hay Creek	---	---	---
Inyan Kara Creek	---	---	---
Lame Johnny Creek	10,880	1,810	5,075
Maloney Creek	---	---	---

(TABLE 1 -- continued on next page)

TABLE 1 -- continued.

Basin	Acres	Minimum Recharge (acre feet per year)	Maximum Recharge (acre feet per year)
Nine Mile Creek	12,800	2,130	5,970
Oyster Mountain	6,400	1,070	2,985
Pass Creek	---	---	---
Rapid Creek	87,040	14,500	40,610
Red Canyon-Pleasant Valley-Four Mile Creek	---	---	---
Redwater River	---	---	---
Sand Creek	---	---	---
Spearfish Creek	---	---	---
Spring Creek	19,840	3,300	9,255
Stinking Water Creek	---	---	---
Stockade-Beaver Creek	---	---	---
Whitewood Creek	640	106	300
Willow Creek	---	---	---
TOTALS	314,240	52,344	145,276

They went on to conclude that:

> " On the basis of work by Rahn and Gries and calculated potential recharge, recharge to the Madison aquifer in the Black Hills is calculated to be in the range of about 140,000 to 400,000 acre-feet per year."

From table 3-1 (Woodward-Clyde Consultants, Inc., 1981) the total Madison-Minnelusa outcrop area was calculated to be 914,560 acres. Thus total recharge ranges from a minimum of 1.8 inches to a maximum of 5.3 inches.

Rahn and Gries (1973) calculated recharge and evapotranspiration on two drainage basins; one in the northern hills (precipitation = 22 inches per year) and one in the southern hills (precipitation = 17 inches per year). Their calculations showed 0.61 inches recharge to ground water and evapotranspiration of 16.4 inches per year in the southern hills. In the northern hills the recharge to ground water was calculated at 6.8 inches per year and the evapotranspiration rate at 15.2 inches per year. While the values of Rahn and Gries cannot be directly compared to those from Woodward-Clyde Consultants, they do indicate similar conclusions about the annual recharge rate to ground water for the Madison-Minnelusa aquifer complex.

The Juro-Cretaceous (Miller, 1972) sandstones are the only other aquifers in the Black Hills for which recharge data are available. These aquifer units are identified as the Unkpapa sandstone, Lakota and Fall River Formations (Inyan Kara Group), and the Newcastle sandstone (Dakota Formation equivalent). Miller (1972) estimated total recharge to all these units at 42 cfs (about 30,000 acre feet per year). No estimates were made of recharge to individual units. Therefore, no attempt has been made to calculate a rate per aquifer value for average annual recharge. Regardless of the rate of recharge, evidence presented by Schoon (1971) and Miller (1972) suggests that at present discharge exceeds recharge to the Juro-Cretaceous sandstones. Furthermore, as stated by Rahn (1981), there seems to be considerable debate as to the method of recharge and whether significant recharge occurs at all.

No estimates of recharge are available for the Deadwood Formation, Red River Formation, Minnekahta Limestone, and the Sundance Formation.

Igneous and Metamorphic Rocks

Due to the extreme paucity of data no valid quantitative estimate of natural recharge rates can be made for igneous and metamorphic rocks. This conclusion was also reached by Rahn (1981, p. 2-3) who stated:

> " The amount of ground water recharge to these rocks is not known. It undoubtedly is very low, because

> little precipitation sinks below the root zone in the crystalline rocks. It is unlikely that Unit #1 could produce much more water than is presently being extracted without "mining" the water (producing a widespread permanent decline in the water table)."

Examination of water use figures from TASK 6 (Burch, 1984) shows a total appropriation of 5,934 acre feet of ground water and an estimated use (from non-appropriative categories) of 597 acre feet, for a total estimated maximum use of 6,531 acre feet of water from the igneous and metamorphic rocks. Over the approximately 268,800 acres comprising these rocks in the Black Hills this would amount to 0.02 feet or 0.24 inches of water. It should be pointed out that appropriation probably exceeds actual use so the estimated use of 6,531 acre-feet per year is probably high. To date the actual use from all categories has not caused regional lowering of the water table. However, if it is assumed that 6,531 acre feet is the actual use then the minimum recharge rate would be 0.24 inches per year.

RECHARGE TO THE AQUIFERS OF SOUTHWEST SOUTH DAKOTA

The High Plains Aquifer (Kolm and Case, 1983) is the major aquifer in southwest South Dakota. They described it as a single water table aquifer consisting of the upper sandstone units of the Arikaree Formation and the overlying Ogallala and Sand Hills Formations. In this report, the High Plains Aquifer is treated as two separate units, one consisting of the Arikaree Group, and the other consisting of the Ogallala and Sand Hills Formation referred to hereafter as the Ogallala Group. The areal distribution of these two units is shown on plates 2 through 6 (Allen, Iles, and Petres, 1984).

Estimates from Observation Well Data

Ogallala Group

The methodology used for calculating recharge from observation well data is the same as previously used for eastern South Dakota (Hedges, Allen, and Holly, 1983, and app. A, this report). For those calculations and the current ones, a specific yield value of 0.15 was used. Of the 63 observation wells completed in the Ogallala, records of 6 wells were discarded as being anomalous. The remaining 57 were analyzed and a value of 3.4 inches average annual recharge was calculated for the Ogallala Group.

The value of 3.4 inches calculated using water level fluctuations in observation wells yields a higher value than most estimates calculated by other investigators (referenced later in this report). This could be attributed to the possibility that the Ogallala has a specific yield less than 0.15. In fact, Kolm and Case (1983), estimate specific yields ranging from 0.04 to 0.14

in sand and sandy loams which are the soil types primarily associated with the Ogallala. If an average of 0.09 is used as the specific yield value, then the corresponding recharge rate would equal 2.04 inches. This later value is in closer agreement with the estimates of other investigators and is in close agreement with the 1.88 inches estimated from base flow recession curve analysis discussed later in this report.

Alternatively, the annual recharge as calculated from observation well response may actually be in excess of 3 inches annually. The difference between this figure and the 1.88 inches as estimated from stream flow could represent evapotranspiration losses and evaporation losses from seeps and springs whose discharge never reaches a gaging station to be recorded as streamflow.

Another factor that should be brought to the reader's attention is that the Ogallala overlies the Arikaree throughout much of its extent. In this instance, the Arikaree receives its recharge as downward percolation from the Ogallala and that water reaching the Arikaree is part of the Ogallala recharge water. Thus, the Ogallala recharge water is shared by both aquifers where they are both present.

In the digital model study of the High Plains Aquifer, Kolm and Case (1983) stated that the eastern part, with annual precipitation as much as 22 inches, received about 1.8 inches annual recharge whereas the drier western portion, with annual precipitation as low as 16 inches, received about 1.3 inches annual recharge. In the present study there was no effort to make this distinction. However, the values calculated for average annual recharge using both the observation well method and later the base flow recession curve analysis, has the precipitation factor built in because both methods are directly related to precipitation.

Arikaree Group

The Arikaree Group had a reported total of 39 observation wells. Of these, 3 were discarded because of anomalous readings. Calculations on the remaining 36 wells yielded an average annual recharge rate of 3.1 inches per year when using a specific yield value of 0.15. However, because the sediments comprising the Arikaree are generally finer grained than those of the Ogallala, the value of 0.15 used to calculate the specific yield is probably too high. Thus, the calculated recharge rate is probably significantly lower than 3.1 inches per year.

As already mentioned, the "upper sandstone units" of the Arikaree are considered to be the aquifer portion of the formation (Kolm and Case). However, the main water producing horizon may be buried as much as 300 to 400 feet under less permeable material that act as confining or semi-confining layers (personal communication, Jim Goodman, Department of Water and Natural Resources, Division of Water Rights). In this case, observation wells may respond as a confined aquifer rather than an unconfined aquifer and this method (analysis of water level fluctuations from observation wells) of calculating recharge would not be valid.

Because of the uncertainties of using water level fluctuations, the average annual recharge to the Arikaree in southwest South Dakota is very likely substantially less than the 3.1 inches per year calculated using this method.

Estimates from Base-Flow Recession Analysis

The method of calculating recharge from base flow recession analysis for the White and Little White Rivers was adapted from Fetter (1980) and Meyboom (1961) and follows the methodology previously used in TASK 7, Ground Water Recharge (Hedges, Allen, and Holly, 1983) for eastern South Dakota (see also app. B, this report).

Ogallala Group

Calculation of recharge for the Ogallala Group was accomplished by analyzing base flow recession curves developed from data collected at U.S. Geological Survey stream gage No. 4495 located on the Little White River approximately 6 miles north of Rosebud, South Dakota. The period of time for which the analysis was made was from October, 1976, to January, 1979.

The basin above the stream gage covers about 554 square miles and recharge calculated using this area yielded a value of 1.67 inches. However, about 62 square miles of this area is underlain with Arikaree sediments which probably contribute little to base flow when compared to the Ogallala. If recharge is recalculated using only the area covered by the Ogallala, then a value of 1.88 inches per year is the calculated recharge rate.

Arikaree Group

Calculation of recharge for the Arikaree Group was accomplished by analyzing base flow recession curves constructed from data collected at U.S. Geological Survey stream gage No. 4470 located on the White River approximately 5 miles south of Kadoka. The average annual recharge calculated from data at this location is about 0.10 inch if applied to the entire basin above the gage site.

However, examination of the geologic map (Ellis and Adolphson, 1971) shows the Arikaree is absent north and west of the River, as well as in significant areas south of the White River. The

White River Group sediments are present where the Arikaree is absent. If it is assumed that the contribution to base flow from the relatively impermeable White River sediments is zero, then all the base flow in the White River must be from the Arikaree. Recalculating the recharge using the surface area of only the Arikaree yields 0.25 inches of average annual recharge.

However, the value of 0.25 inches may be too high because the White River above the gaging station has a well developed alluvial floodplain. Undoubtedly, the alluvium contributes significant amounts of water to the base flow of the White River. If the volume of water calculated as base flow were attributed entirely to discharge from the alluvium, it would require approximately 3.4 inches recharge annually. Thus, it is possible that virtually all the base flow to the White River in this reach is derived from the alluvium and that the contribution from the Arikaree approaches zero.

Because of the unknown contribution to base flow from the alluvium and the uncertainties introduced with the observation well analysis, the actual recharge from the Arikaree is unknown. However, assuming that methodology of calculating recharge from base flow recession analysis is valid, it does indicate that recharge to the Arikaree is relatively low. It would further indicate that most of the recharge that does occur to the Arikaree is offset by pumping, lost to evaporation as springs or seepage where it discharges at the contact of the Arikaree Group and White River Group, or is lost to evapotranspiration.

Estimates from Water Use Data

Ogallala

Total water use from the Ogallala can be estimated from the data presented in TASK 6. Table 2 lists the estimated average annual use from the Ogallala by water use category and shows a total average annual use of 30,203 acre feet. Because the Ogallala aquifer covers an area of about 1,170,000 acres, the annual use rate is about 0.03 feet or approximately 0.36 inches. To date the rate of water use from the Ogallala has not caused any detectable long-term decline in the water table.

Arikaree

Estimated average annual water use from the Arikaree is about 7,000 acre-feet. The Arikaree covers about 2,500,000 acres, therefore, the annual use rate is about 0.003 feet or approximately 0.036 inches. To date the rate of water use from the Arikaree has not caused any detectable long term decline in the water table.

TABLE 2

Estimated Total Average Annual Ground-Water Use From Ogallala Aquifer

Use Category	**Acre feet/year**
Irrigation	19,241 *
Livestock	1,298
Municipal	7,992 **
Rural Domestic	451
Rural-Water System	1,200 **
Suburban Housing	21 **
Acre feet per year	30,203

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* Calculated by: (no. of permitted acres per county) x .5, = (average yearly acres irrigated) x average yearly rate of application per county) = average annual ground-water use.

** Appropriation x 0.5 = average annual use. (Experience has shown that in most instances appropriation significantly exceeds actual use. Therefore, a value of one-half the appropriation is assumed).

Estimates from Other Studies

Over the years several other investigators have made estimates of recharge to the Ogallala. Because these studies were generally regional studies that did not specifically differentiate the various geologic units, the results cannot be directly compared to the present study but they are useful for comparison purposes. Langbein and others (1949) estimated recharge at 2.5 to 3.0 inches per year; Bradley (1956) estimated 2.6 inches per year in the Sand Hills; McGuiness (1963) estimated a range of 1.0 to 2.5 inches per year; Newport (1959) estimated recharge ranging from a fraction of an inch to 5 inches, depending on soil and subsoil types; and Rahn and Paul (1975) estimated 2.5 inches per year. In general the ranges estimated by these other investigators compare favorably with the range of estimates of 1.88 to 3.4 inches per year calculated for this study.

A two-dimensional, finite-difference computer model was developed for the High Plains aquifer in south-central South Dakota (Kolm and Case, 1983). As previously mentioned they defined the High Plains aquifer as the Arikaree Formation and the overlying Ogallala and Sand Hills Formations. From results of the model study Kolm and Case (1983) estimated annual recharge to range from 1.3 inches in the western portion of the study area to 1.8 inches in the eastern portion. They attributed this difference in recharge to the difference in precipitation across the study area.

Kolm and Case (1983) determined that ground-water inflow (recharge) to the High Plains aquifer was 113,000 acre-feet per year. Outflow (discharge other than stream flow) was determined to be 135,000 acre-feet per year. Thus, for the purposes of this study, net ground-water recharge from subsurface flow was assumed equal to zero. Large scale ground-water withdrawals could increase the amount of water available for pumping by decreasing the outflow and increasing the inflow. However, since the digital model did not simulate transient conditions or separate the Arikaree and Ogallala, there was no estimate made for the amount of this possible "salvaged" water.

RECHARGE TO AQUIFERS OF NORTHWEST SOUTH DAKOTA

Insufficient data are available to quantify the average annual recharge rate to the Fox Hills and Hell Creek Formations and the Fort Union Group. Collectively, these sediments are probably less permeable than the Arikaree-Ogallala. Also in that part of the State where these formations are present the annual precipitation ranges from about 14 to 16 inches (fig. 2), whereas 17 to 22 inches of average annual precipitation is received where the Arikaree-Ogallala groups occur.

With available data the only method that can be used to calculate recharge to the Fox Hills and Hell Creek formations and the

Fort Union Group is the base flow recession analysis technique. This analysis can only be used with the Moreau River because the flow in the Grand River is controlled by the Shadehill Dam.

Stream flow records for the Moreau River were analyzed using data from U.S. Geological Survey gaging stations no. 3605 located 2.4 miles southeast of Whitehorse and no. 3595 located 13.5 miles northwest of Faith. Their locations were such that flow characteristics of the whole basin were sampled. Analysis of base flow from these two locations yielded recharge values of 0.25 and 0.29 inches per year. These values are comparable to the 0.25 inches calculated for the Arikaree Group using base flow in the White River. It should be recalled that in that instance it was suggested that a substantial portion of the base flow might be derived from the alluvium rather than from the Arikaree sediments. Likewise, the Moreau River could derive a substantial portion of its baseflow from alluvium rather than from the Fox Hills and Hell Creek Formations.

Because the Fort Union Group drains primarily into the Grand, which is a controlled river, no estimate of recharge has been calculated for this aquifer.

RECHARGE TO ALLUVIUM OUTSIDE BLACK HILLS AREA

Like the Black Hills area, there also are no quantitative data available for recharge rates to alluvium in stream valleys outside the Black Hills. Again, some general comparisons can be made between the surficial glacial outwash deposits in eastern South Dakota and the alluvial deposits.

Alluvial deposits in the stream valleys outside the Black Hills area are generally fine grained and are composed of silty, clayey sand (Rahn, 1981). Therefore, they are less susceptible to infiltration of precipitation than are the coarse-grained alluvium in the Black Hills area or the surficial outwash deposits of eastern South Dakota. Furthermore, inspection of the annual average precipitation for western South Dakota (fig. 2) shows that much of the area outside the Black Hills receives less than 18 inches annual precipitation. Thus, neither geologic conditions or annual precipitation values are as favorable for recharge in this area as are those areas of surficial glacial outwash deposits in eastern South Dakota, or alluvium in the Black Hills.

In the southeast corner of western South Dakota annual precipitation ranges from 18 to 24 inches (similar to eastern South Dakota) but the alluvium is generally finer grained than the glacial outwash and thus is not as susceptible to recharge as the glacial outwash.

Because of the dissimilarities of geologic conditions and/or precipitation between eastern South Dakota and western South

Dakota (outside the Black Hills), an estimate for annual average recharge to the alluvium is not appropriate. However, it seems likely that both the upper and lower range of values for recharge is less than the 2 to 5.6 inches/year calculated for eastern South Dakota and estimated for alluvium in the Black Hills.

GENERAL CONCLUSIONS

In western South Dakota recharge to the ground-water system apparently is controlled primarily by the combination of annual precipitation and areas where permeable rocks are at the land surface. A favorable combination of factors for recharge exists in two locales. First is where the sedimentary rocks in the Black Hills (especially the central and northern Hills) are exposed, and second, in the southeast part of western South Dakota where the Ogallala Formation is present. The remainder of the bedrock aquifers in western South Dakota probably experience little or no net recharge as determined by base flow stream recession analysis. Significant observation well response in these areas could be interpreted as reflecting aquifer recharge, however, most of the ground-water recharge is apparently lost to evaporation-transpiration processes before it reaches major streams where it could be recorded as base flow.

The coarser-grained alluvium in the Black Hills area probably experiences recharge rates similar to the areas of surface glacial outwash material in eastern South Dakota. Outside the Black Hills, the alluvium is finer grained, and, except for the southeast part of the study area, experiences less annual precipitation. The probable net effect, although not quantifiable, is less annual recharge. It is suggested that a major portion of the base flow in streams (other than those associated with the Ogallala Group) may be provided by drainage of the alluvium.

In South Dakota the Arikaree is generally finer grained than in Nebraska where it is a significant aquifer. The lower hydraulic conductivity of the Arikaree results in a different hydrologic response than that experienced by the Ogallala. Because of its lower hydraulic conductivity, the upper Arikaree may act as an aquitard to vertical water movement between the water bearing zones of the two aquifers. Recharge-discharge characteristics of the Arikaree, as evidenced by base flow analysis, are certainly different than those from the Ogallala. For these reasons and others beyong the scope of this report, it is suggested that in South Dakota the two aquifers should be treated as separate hydrologic units.

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APPENDIX A

Methodology for calculation of recharge using observation well data

As part of TASK 4 (Hedges and others, 1982), a computerized data base management system (ADABAS) was developed for the purpose of storage, retrieval, and manipulation of observation well data. From this data base selected observation wells were chosen to analyze water level fluctuations. To accomplish this, water level information was transferred from the data base to a separate SAS (Statistical Analysis System) file where the data were manipulated by pre-programmed statistical methods. The method used to calculate recharge in each group of wells was:

1. Identify all wells completed in the Ogallala and the Arikaree Groups.

2. Totalling water level rises for each well for the total length of records (in years).

3. Combining the total increase in water levels for all wells from a specific aquifer or management unit.

4. Obtaining the total number of record years for the observed aquifer or management unit.

5. Dividing the total rise in water levels in all wells by the total number of record years. The resulting value is the average annual water level rise for that series of wells.

6. Finally, the average annual increase in water levels were converted to inches and multiplied by the specific yield value (0.15) to obtain the average annual recharge, in inches, to each aquifer.

APPENDIX B

Methodology for calculation of recharge using base flow recession analysis

In relatively undeveloped areas, ground water is in dynamic equilibrium with the regional hydrologic system. That is, if a volume of water is recharged to an aquifer, an equal volume will be discharged. The water level in aquifers will remain steady and the volume of ground water in storage will remain constant. The aquifer transmits the ground water from recharge areas to discharge areas (Fetter, 1980). The discharged ground water enters the regional surface drainage system and provides a base flow which when combined with direct runoff from precipitation accounts for the total volume of streamflow. If, within a particular drainage basin, the following assumptions are made:

1. the surface water and gorund water divides coincide,
2. all the aquifers within the basin are hydraulically connected, and
3. all the discharged ground water enters the streams within the basin,

the base flow component of streamflow will represent the volume of ground-water recharge to the basin when it is at dynamic equilibrium.

Several techniques have been used to separate surface runoff and base flow components of a stream hydrograph. Most are based on an interpretation of recession or depletion curves. The method of base flow separation and estimation of ground-water recharge used in this report for the Little White, White, and Moreau River Basins was taken from Fetter (1980) and Meyboom (1961). The base flow recession curve can be expressed by the general regression equation:

where $[Q_t = Q_o e^{-ct}]$

Q_t = flow at some time [t]
Q_o = flow at start of recession
c = recession constant
t = time since recession began

If the stream hydrograph is made by plotting the logarithm of discharge against time a linear relationship may be obtained. The best straight line connecting successive points of minimum stream discharge is considered to approach true baseline conditions.

A complete baseflow recession begins with the first minimum value on the recession curve and ends with the first spring flood. The amount of recharge that occurs between two consecutive ground-water recessions may then be calculated by the following:

Recharge (R) occurring between two consecutive base flow recessions 1 and 2 = total potential ground water discharge of base flow recession 2 − total remaining potential ground water discharge at the end of base flow recession 1

$$R = \frac{Qo_2 t_2}{2.3} - \frac{Qo_1 t_1}{2.3 \ 10^{\frac{t}{t_1}}}$$

where

Qo_1 = baseflow at start of recession 1
t_1 = time for base flow to go from Qo_1 to $0.1\ Qo_1$
t = length of recession 1
Qo_2 = base flow at start of recession 2
t_2 = time for base flow to go from Qo_2 to $0.1\ Qo_2$

Once the ground-water recharge is calculated by the above referenced method the total consumptive ground-water use in the basin must be added to derive an estimate of the total ground-water recharge. Consumptive ground water use can be estimated from TASK 6 and surface water use can be estimated from records from the Division of Water Rights. Because these records and estimates are incomplete, the total consumptive use estimate is probably a conservative value.