# ANALYSIS OF GROUNDWATER AND STREAMFLOW DATA
# WESTERN DAKOTAS REGION OF SOUTH DAKOTA

## TASKS 3.E. AND 4.D.: ARTIFICIAL RECHARGE POTENTIAL

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 South Dakota and the Upper Big Sioux River in South Dakota and Iowa. The output contained in this report is restricted to that part of South Dakota lying west of the Missouri River. Another series of reports cover the area east of the Missouri River. The following 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.

E. Determine potential artificial recharge capabilities of all aquifers by open pit or surface spreading, injection well method, and low head dams.

TASK 4 -- Update, expand, and detail the "Ground Water Resources of Western South Dakota" by Rahn, 1979, exclusive of the Black Hills area. The Black Hills area is covered in TASK 3.

D. Determine potential artificial recharge capabilities of all aquifers by open pit or surface spreading, injection well method, and low head dams.

# ARTIFICIAL RECHARGE

## Objectives

Artificial recharge is a means of augmenting the natural infiltration of surface water into a ground-water reservoir and has been used for a variety of purposes (Lehr, 1982):

1. Ground-water (well field) management
2. Reduction of land subsidence
3. Renovation of waste water
4. Improvement of ground-water quality
5. Storage of stream waters during periods of high or excessive flow
6. Reduction of flood flows
7. Increasing well yield

8. Decreasing the size of areas needed for water-supply systems

9. Reduction of salt-water intrusion or leakage of mineralized water

10. Increasing stream flow

11. Store fresh water derived from rain and snowmelt. If the existing ground water is saline, the less dense fresh water lens will float on the saline water.

12. Secondary recovery of oil

The U.S. Army Corps of Engineers involvement in water projects requires that they serve multiple-use purposes. While artificial recharge might be used in western South Dakota for all purposes listed above, except number 11, practical considerations limit the discussion to items 1, 5, 6, 7, and 8. These pertain primarily to well field management and flood flow control.

## Types of Artificial Recharge

Artificial recharge can be classified into two general categories:

1. Infiltration of water into an aquifer under atmosphere pressure, and
2. Injection of water into an aquifer at some pressure greater than the pore pressure in an aquifer (injection wells).

The first type is usually accomplished by two methods. These are either:

a. The use of a man-made recharge or infiltration basin or canal, or

b. The use of dams on a drainageway, stream, river, or lake.

There are technical and operational problems associated with all types of artificial recharge, but a discussion of difficulties and their remedies are beyond the scope of this report.

### Surface Spreading

Assuming the aquifer has capacity to be recharged (i.e., the aquifer is not full or the rate of use is equal to or greater than the recharge rate), the surface-spreading method can be used anywhere the aquifer is near the land surface, and/or there is sufficient permeable material connected to the aquifer. Surface-spreading basins are generally man-made structures into which water is periodically placed and allowed to infiltrate into the underlying aquifer. Surface-spreading methods can also be used in stream channels when stream bed alluvium is sufficiently permeable and the water table is below the stream bed.

Primary criteria for location of a spreading basin are ground-water gradient, aquifer characteristics, depth to top of the aquifer, the presence of any low permeability layers, and proximity to a dewatered portion of the aquifer.

## Low-Head Dams

Because normal streamflow passes over an aquifer relatively quickly, low-head dams are a useful way to delay the water and allow more time for infiltration into the aquifer. Using a low-head dam to augment well-field yield assumes that adequate stream flow is available whether by natural or man-made causes. Low-head dams are most effective when ground-water levels are kept low. This can be caused by pumping or weather variations that reduce natural recharge. The required low water table may be induced by pumping or seasonal weather variances causing water-table depletions.

The presence of an aquifer at or near the land surface, the ground-water gradient, aquifer characteristics, the presence or absence of any low permeability layers, and proximity to a dewatered portion of the aquifer are all criteria to consider when locating a low-head dam.

Low-head dams can be located along drainageways, streams, and rivers where topography and cultural features will allow construction. The dam should cause ponding of water a few feet in depth. Structures can also be used on lakes to increase the lake's capacity and to increase infiltation into any aquifer that may be hydraulically connected to the lake.

## Injection Wells

Injection wells are a possible method of artificial recharge to any aquifer. Water is pumped through these wells into an aquifer using some pressure greater than the aquifer's pore pressure. This type of recharge is used primarily where aquifers are under confined hydrologic conditions or in aquifers under unconfined hydrologic conditions where:

1. The water level is deep,

2. The ground water is separated from the land surface by restricting layers, or

3. Cultural features or surface topography makes recharge basins impractical (Bouwer, 1978).

Development of artificial recharge using the injection well method as well as all other methods, requires detailed site-specific testing and evaluation, and is dependent on many variables. Furthermore, economics of injection well development probably preclude this method as a viable alternative at this point in time in western South Dakota. Thus, this method of artificial recharge will not be discussed further in this TASK.

## Retention Time

When artificially recharging an aquifer, the intent is to have the recharged water remain in the aquifer or in a particular area of the aquifer long enough to be of use. This is called retention time and is dependent upon the geohydrologic setting. For porous media, the retention time can be estimated within a set of limits from standard hydrologic data. These conditions would apply to all alluvial as well as the unconsolidated upland aquifers outside the Black Hills area.

In limestone and dolomite aquifers in general, and in particular the carbonate aquifer complex in the Black Hills area, secondary porosity has developed through fracturing and solution. For water moving in these aquifers, retention time and direction of flow is extremely variable and unpredictable. For this reason the following discussion on retention time refers only to the alluvial aquifers and the upland aquifers outside the Black Hills area. Retention time in the carbonate aquifer complex will be discussed more thoroughly later in this report.

Determination of retention time requires prior knowledge of an aquifer's hydrologic characteristics and usage patterns. More commonly, however, only the grain size of aquifer material and the general ground-water gradient are known. Consequently, an approxmiate relationship between grain size and hydraulic conductivity is used to estimate retention time (table 1).

The actual rate at which a particle of water will travel in an aquifer can be estimated if the following parameters are known:

1. Hydraulic conductivity (K) of the aquifer (table 2),
2. Ground-water gradient (i) in the aquifer, and
3. Effective porosity (n) of the aquifer.

## TABLE 1

Travel time (in days) of water through varying distances with varying hydraulic conductivities. (Assuming a hydraulic gradient of 5 ft/mi and an effective porosity of 15 percent).

| Distance (in miles) | Hydraulic Conductivity (feet/day) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 45 | 105 | 235 | 265 | 335 | 465 | 700 | 800 | 900 | 1400 |
| 0.25 | 4646 | 1991 | 890 | 789 | 624 | 450 | 299 | 261 | 232 | 149 |
| 0.50 | 8659 | 3711 | 1658 | 1470 | 1163 | 838 | 557 | 487 | 433 | 278 |
| 0.75 | 13939 | 5974 | 2669 | 2367 | 1872 | 1349 | 896 | 784 | 697 | 448 |
| 1.00 | 18586 | 7965 | 3559 | 3156 | 2497 | 1799 | 1195 | 1045 | 929 | 597 |
| 1.50 | 27878 | 11948 | 5338 | 4734 | 3745 | 2698 | 1792 | 1568 | 1394 | 896 |
| 2.00 | 37171 | 15931 | 7188 | 6312 | 4993 | 3597 | 2390 | 2091 | 1859 | 1195 |
| 3.00 | 55757 | 23896 | 10677 | 9468 | 7490 | 5396 | 3584 | 3136 | 2788 | 1792 |
| 4.00 | 74342 | 31861 | 14236 | 12624 | 9986 | 7194 | 4779 | 4182 | 3717 | 2390 |
| 5.00 | 92928 | 39826 | 17795 | 15780 | 12483 | 8993 | 5974 | 5227 | 4646 | 2987 |

## TABLE 2

Relationship between grain size class and hydraulic conductivity

| Grain size class | Range of hydraulic conductivity (ft/day) |
|---|---|
| Clay or silt | < 20 |
| Sand, very fine | 10- 80 |
| Sand, fine | 70- 140 |
| Sand, fine to medium | 70- 400 |
| Sand, medium | 130- 400 |
| Sand, fine to coarse | 70- 600 |
| Sand, medium to coarse | 130- 800 |
| Sand, coarse | 400-1,000 |
| Sand and gravel | 400-1,200 |
| Sand, coarse, and gravel | 400-1,400 |
| Gravel | 800-2,000 |

Table after Koch (1980)

This rate of movement can then be applied to actual situations and the length of time (t) that it will take for a particle of water to travel a given distance (d) can be calculated. The method of calculation is as follows:

$$t = \frac{d}{\frac{K\,(i)}{n}}$$

Table 1 lists the time in days that it would take for a particle of water to move a given distance at a given hydraulic conductivity assuming a ground-water gradient of 5 feet per mile and an effective porosity of 15 percent. The hydraulic conductivities listed across the top of the table are the midpoints for the different grain size classes of very fine sand through gravel.

As an example, consider that alluvial aquifers are comprised of material ranging in grain size class from medium sand to coarse sand and gravel. This type of aquifer material would have hydraulic conductivities ranging from 265 to 900 feet/day (table 2). Assuming that average distance of travel for recharge water ranges from 0.25 to 0.75 miles from the recharge point to a discharge point means that retention time would range from 232 to 2,367 days if the gradients were 5 ft/mi. Most artificial recharge situations, however, would result in gradients exceeding 5 ft/mi. Because time is inversely proportional to the gradient, doubling the gradient would reduce the time by one-half. Thus, under artificial recharge conditions where higher gradients are maintained, the travel times shown in table 1 would be some factor less than shown. As in the example shown, retention time or distance traveled per unit of time can be estimated for any set of actual conditions by substituting known parameters into the time equation.

## ARTIFICIAL RECHARGE OUTSIDE THE BLACK HILLS AREA

Outside the Black Hills there are two types of aquifers that could be considered for artificial recharge: (1) upland aquifers and (2) flood plain alluvial aquifers. Upland aquifers consist of the Arikaree Group, Fort Union Group, Fox Hills Formation, Hell Creek Formation, and Ogallala Group. For location of these units, see figure 1. Distribution of the flood plain alluvial aquifers are shown on figure 2.

### Upland Aquifers

Conceptually there are three general methods whereby recharge to the upland aquifers could be enhanced:

1. Construction of numerous small structures to locally contain precipitation so that more of it would infiltrate into the ground-water system;

2. Pump water from main-stream sources (dams or natural stream flow) to upland infiltration facilities; and

3. Construct main-stream dams located so that pool elevation in the reservoir would provide sufficient gradient to induce recharge into an adjacent upland aquifer that had potential or existing storage capacity.

The construction of numerous relatively small upland structures is rejected for the purpose of this report. These types of structures and facilities in general, would not provide multi-purpose functions as mandated for Corps of Engineers projects. Furthermore, detailed site specific information would be required. This type of data is generally absent throughout western South Dakota.

Pumping water from other sources to the upland aquifer areas is rejected because of high costs involved in building an intake structure, transmission facility, infiltration facility, and providing operation and maintenance for all of the above. Substantial power requirements would also be required using this scenario.

Conceptually, option number three is very attractive. First, a major-stream dam and reservoir would serve the multiple-use criteria mandated by Corps of Engineers. Secondly, recharge would occur naturally at normal pool elevations. This scenario would require little additional capital investment, and operation and maintenance costs would be minimal.

However, site selection is absolutely critical for this type of proposed recharge facility. There are two site criteria that must be met before this type of recharge system will work. First, there must be an aquifer adjoining the reservoir with adequate thickness and permeability to meet the recharge needs. Second, the water table in the aquifer must be lower than the normal pool elevation to provide a regional ground-water gradient away from the reservoir site. Under the right conditions the second criteria could be artificially produced by pumping wells in the upland aquifer area. However, water-table gradient, saturated thickness, and aquifer permeability are factors that would be critical in the site selection process.

## Evaluation of Proposed Dam Sites for Artificial Recharge

During the course of the investigation evaluate of water resources in western South Dakota, several potential dam sites outside the Black Hills area were proposed by the U.S. Army Corps of Engineers. These dams are listed on table 3 and their loca-

## TABLE 3

### List of proposed dams-reservoir sites in western South Dakota outside Black Hills area

| Dam-Reservoir | County | Location |
|---|---|---|
| Clarks Fork Creek | Harding | Sec. 23, T. 19 N., R. 6 E. |
| Iron Lightning | Ziebach | Sec. 12, T. 14 N., R. 18 E. |
| Brennen | Pennington | Secs. 35 and 36, T. 1 N., R. 8 E. |
| Mud Buttes NW | Butte | Secs. 8 and 9, T. 11 N., R. 2 E. |
| Little White | Todd | Sec. 9, T. 36 N., R. 32 W. |
| Pine Creek | Mellette | Sec. 5, T. 41 N., R. 28 W. |
| Rapid Creek | Pennington | Sec. 36, T. 1 S., R 11 E. |

tions are shown on figure 3.

The previous section of this report described three methods whereby artificial recharge could be used to enhance recharge to the upland aquifers. The first two methods were rejected. The third method, natural infiltration of reservoir water into an adjacent aquifer, will be used to evaluate each site according to the two critical site criteria previously described.

Ideal hydrogeologic conditions for using reservoir water to artificially recharge an adjacent aquifer are shown in figure 4a. In this case permeable unsaturated material is present adjacent to the reservoir and the regional water table is at or below stream level. Maximum head conditions exist under these conditions.

Another condition, which is less than ideal but which may be satisfactory, is shown in figure 4b. In this case, the natural regional water table is towards the reservoir. At normal pool elevation the reservoir head is high enough to reverse the regional gradient so that continuous outflow occurs. However, the head difference between pool elevation and the regional gradient is less than that in the previous illustration shown in figure 4a. Therefore, other conditions being equal, the artificial recharge potential is less.

The third set of hydrogeologic conditions is shown on figure 4c. This condition generally prevails along the drainages in western South Dakota. In this instance, the normal pool elevation will not be high enough to reverse the regional water table. Once infiltration has progressed to equilibrium, no more infiltration will occur. In this case, the additional stored ground water has only increased the effective size of the reservoir but does not contribute to the regional ground-water storage.

The conditions illustrated in figure 4c might be suitable for recharging the regional ground-water system if pumping could be used to lower the regional water table sufficiently to permanently reverse the gradient (fig. 4d). This condition would depend on pumping rate, aquifer thickness, aquifer permeability, relative elevation of reservoir water level and ground-water table, and distance of pumping center from reservoir. Lack of data precludes a detailed site evaluation to determine if this type of recharge is feasible in western South Dakota.

<u>Clarks Fork Creek Reservoir</u> -- The Mouth of Bull Creek geologic quadrangle (Petsch, 1956) shows the valley floor, valley sidewalls, and upland area cut into the Hell Creek Formation. The Hell Creek Formation in this quadrangle is described as bentonitic clay or mudstone and shale, peat shale, uncemented well compacted sandstone, and occasional lignite and carbonaceous shale. Rahn (1981a) describes the Hell Creek's water-yielding capabilities as small to moderate. He also cites well production data

indicating only modest yields to wells. The very limited lithologic data suggests low permeability aquifer material that would not favor substantial recharge from the proposed reservoir.

Data showing regional ground-water levels are unavailable for this area; therefore, a comparison with the proposed normal pool elevation of 1,762 feet cannot be made.

Clarks Fork Creek is downcut about 150 feet below the adjacent uplands. The proposed reservoir has a maximum depth of about 40 feet. Therefore, unless the regional water table was more than 110 feet below land surface, there could be no gradient reversal of the ground-water flow.

Because of the low permeability of the aquifer material and probable water-table conditions the artificial recharge potential at this site is classified as none to low.

<u>Iron Lightning Reservoir</u> -- The proposed dam and Iron Lightning Reservoir is located on the mainstem of the Moreau River. The valley floor and valley wall are cut into the Iron Lightning member of the Fox Hills Formation (Fournier, 1969). The Iron Lightning member is composed of thinly bedded shale, graywacke, and carbonaceous material which becomes sandier towards the top. Rahn (1981a) reports low specific capacities and transmissivities from wells in the Fox Hills Formation although they probably are higher than those generally encountered in the Hell Creek Formation.

The upland areas near the site of this reservoir are 150 to 200 higher than the flood plain of the Moreau River. Normal pool depth of the proposed reservoir is about 70 feet. Thus, unless regional water tables are more than 80 feet below land surface, regional recharge cannot occur. Rahn (1981a) states that the regional water table in the Fox Hills Formation is close to the land surface so regional recharge from the reservoir is unlikely.

Due to lack of data, actual geohydrologic conditions at the dam site are unknown. However, due to the relatively large size of the proposed Iron Lightning Reservoir and the possibility of moderately permeable zones within the Fox Hills Formation, there is a possibility of significant recharge to the adjacent aquifers. Thus, more detailed studies at this site might be warranted.

<u>Brennen Reservoir</u> -- The site of the Brennen reservoir is contained within the Pierre Shale, Niobrara Chalk, and possibly the Carlile Shale according to the State Geologic Map of South Dakota compiled by Petsch (1953). All three formations are low permeable materials and are not aquifers. Locally the Niobrara can be an aquifer where secondary permeability has developed. On-site investigation would be required to determine whether significant

water loss to the Niobrara might be expected. For the purposes of this report, the Niobrara has not been considered a regional aquifer.

Mud Butte NW Reservoir -- The Mud Butte NW Reservoir is completely contained within the Pierre Shale according to the State Geologic Map of South Dakota (Petsch, 1953). The Pierre Shale is a low permeable material and is not a regional aquifer. Therefore, artificial recharge from reservoir water at this location is not feasible.

Little White Reservoir -- The Little White Reservoir is contained primarily in the Arikaree Formation according to the geologic quadrangle map (Sevon, 1960). The exact elevation of the contact of the Arikaree with the overlying Valentine (Ogallala) Formation is unknown; however, a few feet of Valentine might be inundated at normal pool elevation. Zones within the Arikaree may be permeable enough to be good aquifers; however, these are usually located in the lower part of the formation. At this location only the low permeable upper Arikaree is present. The regional water table is reported to be at an approximate elevation 2,900 feet or nearly 200 feet above the normal pool elevation (Kolm and Case, 1983). These conditions are similar to those shown in figure 4c. Because the regional water table is so much higher than the normal pool elevation pumping of wells could not lower the regional water table enough to cause the required gradient reversal.

Pine Creek Reservoir -- The Pine Creek Reservoir is completely contained within the Pierre Shale according to the State Geologic Map of South Dakota (Petsch, 1953). The Pierre Shale is a low permeable material and is not a regional aquifer. Therefore artificial recharge from reservoir water at this location is not feasible.

Rapid Creek Reservoir -- The Rapid Creek Reservoir is completely contained within the Pierre Shale according to the State Geologic Map of South Dakota (Petsch, 1953). The Pierre Shale is a low permeable material and is not a regional aquifer. Therefore, artificial recharge from the reservoir water at this location is not feasible.

## Alluvial Aquifers

In western South Dakota three major limitations of alluvial aquifers restrict their practical development for artificial recharge. The aquifers are generally thin, have a water table near land surface, have insufficient retention times or, there may be a combination of any of these characteristics.

## Limitations

**Thin aquifers** -- Thin aquifers are those generally less than 25 feet thick. Because they are thin, storage capacity is limited. The storage capacity limitation does not favor an artificial recharge design that is dependent on periodic events, such as flood flows, because flood flows may naturally fill the alluvial aquifers to capacity. Thus, there often is no need for additional facilities for collection of flood-flow waters. Flood flows could be beneficial if there were sufficient storage facilities to retain the water until it was needed later in the year. Because of limited available drawdown in thin aquifers, standard vertical wells may limit the extraction rates. This limitation can be partially alleviated by using a greater number of vertical wells, or by the installation of some type of horizontal collection system such as an infiltration gallery.

**Aquifers With Shallow Water Tables** -- Alluvial aquifers with shallow water tables (less than 15 feet) have a limited storage capacity for artificial recharge. Pumping will enhance the storage capacity by lowering the water table, but in doing so will diminish the saturated thickness. An additional limitation of a shallow aquifer is the small head difference between the original water table and the water table in the recharge facility.

**Retention Time** -- Retention time is determined primarily by aquifer permeability, distance to discharge point, and hydraulic gradient. Alluvial aquifers in western South Dakota follow stream courses (discharge point) which are long and narrow. Thus, flow distance from a potential recharge site would be short, thereby reducing retention time.

## Application to Western South Dakota

Using very limited data, Rahn (1981a) estimated that saturated alluvium averages 20 feet in thickness in western South Dakota. He stated that outside of the Black Hills most of the alluvium was finer-grained with low to moderate permeabilities. Thus, outside the Black Hills, nearly all alluvial aquifers are characterized by at least two of the limiting factors. Many are characterized by all three. Because of these limitations, alluvial aquifers in western South Dakota generally are not good potential sources for developing artificial recharge projects because large amounts of water cannot be "banked" for long storage periods.

In spite of the limitations for developing artificial recharge in alluvial aquifers in western South Dakota a potential does exist, especially if a dependable water source can be found. A dependable water source could be provided by a dam upstream such as those proposed in table 3, existing dams, or a perennial stream. The practical application of such a system, in the absence of significant available underground storage, would depend on many factors such as:

1. Use patterns and use volumes,

2. site-specific geohydrologic conditions, and

3. economics of building control and operation structures versus using the surface water directly.

The maximum increased sustained yield of a well field can be determined only after detailed hydrologic and engineering studies are performed for site-specific situations. The virtual nonexistence of data in western South Dakota precludes this type of analysis at this time.

## ARTIFICIAL RECHARGE WITHIN BLACK HILLS AREA

Within the Black Hills area there are two classes of aquifers that could be considered for artificial recharge:

1. The carbonate aquifers, specifically the Madison and Minnelusa Formations, and

2. Alluvium.

The Madison-Minnelusa complex could also include the Englewood and Minnekahta Limestones. The alluvium considered for artificial recharge is that contained within the present stream valleys.

### Carbonate Aquifer Model

A working conceptual model of the hydrologic system is a prerequisite first step towards developing an artificial recharge model. The physical model is shown on figures 5 and 6. In this model the Central Black Hills region is composed primarily of igneous, metamorphic, and older sedimentary rocks surrounded by a periperhal band of generally high permeable carbonate rocks (the carbonate aquifer), and an overlying sequence of younger sedimentary rocks (fig. 6). Relatively, the rocks overlying and underlying the carbonate aquifer are less permeable than the carbonate aquifer and function as aquitards.

A geologic cross section showing the relationship of these units is shown in figure 6. Of particular note in this model is the zone of reduced permeability in the carbonate aquifer at some distance from the outcrop area. It should also be noted that this zone of reduced permeability in actuality may be a transition zone several miles wide and may be located at various distances from the outcrop area. This concept is suggested by Rahn and Gries (1973) and it is specifically described by Huntoon (1985).

The hydrologic model of the carbonate aquifer is succinctly described by Rahn and Gries (1973, p. 17):

> "--- a simple system is envisioned whereby precipitation recharge and sinkhole recharge supplies water that moves through the carbonate aquifer and discharges as springs."

This concept and the gross water budget is shown diagrammatically in Rahn and Gries (1973, fig. 11, p. 16). In the water budget the sinkhole recharge is about 44 cfs and spring discharge at the outer margin of the carbonate aquifer is about 190 cfs. The additional 146 cfs discharged from springs is derived from precipitation recharge. Some additional quantity "x" is lost to ground-water recharge and flows basinwards through the reduced permeability zone. In the model, ground-water movement is generally southward except in the northern Hills region (Rahn and Gries, 1973, pl. 3). Supported by dye tests and other data, Rahn and Gries (1973, p. 12) further concluded:

> " This dye test is very important in terms of understanding the Black Hills hydrology. It shows that water that disappears into sinkholes in one drainage basin may reappear as springs -- Namely Type 2 springs -- in a completely different drainage area. Ground water can and does travel through the Paleozoic carbonate aquifer with little regard for the surface topography."

Dye tests and water temperature measurements were not very helpful in determining travel time of water within the entire carbonate aquifer. However, the nature of the flow system and several of the dye tests do indicate a short travel time.

The hydrologic model described above, in conjunction with spring-discharge data and other water measurements, suggests that the system is in equilibrium and the carbonate aquifer is normally "full" of water. The amount of water in storage may vary slightly from year to year in response to precipitation and use, but apparently the system cannot "store-up" excess water for long periods of time, nor will drought cause permanent declines in spring discharge.

## Artificial Recharge Model for Carbonate Aquifers

A concept for artificial recharge in the Black Hills was presented by Rahn (1981b, p. 3). The following paragraph is an excerpt from that report.

> It is a well known fact that numerous Cheyenne tributaries such as Spring Creek, Boxelder Creek, and Elk Creek lose most of their normal flow to the limestone belt surrounding the eastern edge of the Black Hills. Occasional flood discharge pass beyond the

> limestone belt, however, and carry out to the prairie. This flood water is essentially a resource lost to western South Dakota because it flows to the Missouri River. It is believed that this limestone formation can be artificially recharged by diverting or temporarily storing the flood events. The increased recharge to the limestone subsequently can be withdrawn from wells at the outer edge of the limestone, in or near the "Red Valley," to serve as the source of a gravity-feed aqueduct which can be routed easterly towards prairie communities.

This report provides an excellent technical conceptual model for using excess flood flows for artificial recharge at specific sites. However, if the hydrologic model described in the previous section is assumed correct, then several questions must be addressed before implementation of an actual recharge project:

1. Are man-made structures required to capture the flood flow volumes necessary to augment the water supply or will adequate water be recharged naturally during flood events?
2. Will the recharge water (either natural or man-induced) travel to the selected well-field?
3. If it does travel to the well field, how long will it remain in storage in the well field area, and
4. This model dictates large-scale pumping to lower the water table sufficiently to provide storage capacity for the induced recharge. This magnitude of water depletion would undoubtedly reduce or deplete certain spring discharges and/or stream flow. Where and to what magnitude would these effects be noticed and would they be acceptable?

## Recharge Requirements

Reaches of many streams in the Black Hills area seldom flow due to stream loss into the carbonate aquifers. In some cases only flood events ever result in stream flow crossing the carbonate aquifer. During flood events substantial stream loss (recharge) occur naturally. A couple of examples will illustrate the magnitude of potential water loss from these events.

Figure 7 is a hydrograph showing stream flow at two locations on Boxelder Creek, one above the carbonate aquifer outcrop (near Nemo) and one below the carbonate aquifer outcrop near Rapid City. These data are taken from U.S. Geological Survey streamflow records and covers a 100-day event from April 16 through July 31, 1983. Streamflow loss between the two sites averaged nearly 37 cfs (7,300 acre-feet) for this one time event on this single stream. Some of this streamflow loss may have been temporarily stored in the alluvium rather than percolating downward to the carbonate aquifer; however, this amount is thought to be insignificant.

The U.S. Geological Survey reported that during May, 1984, when Spearfish Creek flowed its entire course, stream loss across the carbonate aquifer was 43 cfs (Kyllonen and Peter in press), or if projected for 100 days, as in the preceeding example, a total of 8,600 acre-feet. In both cases cited above, the final destination and retention time of the stream-loss water is unknown.

There are numerous other streams in the Black Hills area with hydrologic characteristics similar to the examples cited above. Thus, substantial flood water or higher than normal runoff would be recharged under natural conditions.

## Travel Path

Dye tests (Rahn and Gries, 1973) were used to try and determine the travel path and final destination of stream-loss water in several drainage basins. The test results showed that dyes injected at sink-hole sites re-emerged downstream , traveled underground into another drainage basin, or were never found at any monitoring points. In one test where the dye emerged in a different drainage basin, only a small percentage of the dye could be accounted for. Although there is little conclusive data, the hydrologic model and available data suggests that the travel path and final destinations of most stream-loss water is unknown at present.

## Retention Time

Retention time of stream-loss water and precipitation recharge water moving through the carbonate aquifers is poorly documented. The same dye test mentioned above showed that some stream-loss water remained in the ground-water system for about 6 months; however, the amount returned was estimated to be only a small percentage of that lost. Other dye tests showed retention times of hours or days, while in still other tests there was no confirmation of re-emergence of stream-loss water at all. Again, the hydrologic model and the average spring discharge rate of 190 cfs at the outer boundary of the carbonate aquifer indicate that a substantial percentage of the stream-loss water and precipitation recharge water does not remain in the carbonate aquifers for a long period of time.

### Spring Discharge and Streamflow Depletion

Large-scale pumping of wells to lower the water table in the carbonate aquifer would certainly decrease streamflow and spring discharge in the area of influence pumped well(s). There is little data available to determine the magnitude and extent of these losses throughout the carbonate aquifer in the Black Hills area. However, a flowing well drilled into the carbonate aquifer at the McNenny Fish Hatchery caused reduction in discharge of a nearby spring by about 400 gpm (unpublished U.S. Geological Survey records, Rapid City, South Dakota Sub-District Office). Similar streamflow losses could also occur under other heavily pumped areas. The actual magnitude and extent of spring discharge reduction and streamflow loss due to pumping well(s) is unknown. However, these hydrologic responses would occur and the stream environment and downstream water rights would be affected to some degree.

### Conclusions

The recharge model as proposed by Rahn and Gries (1973) and discussed in this report is technically feasible. It could, in fact, temporarily salvage thousands of acre feet of flood water that might otherwise flow past the carbonate aquifer and join the other prairie streams flowing to the Missouri River. However, with the very limited data available, quantification of the unknowns (recharge requirements, travel path, retention time, and spring discharge and stream-flow depletion) would have to be determined before any specific project could be implemented.

The only model that could be used with any certainty would be one where non-leaky above ground storage structures were located upstream from known sinkhole areas, and well(s) were located downstream in spring areas known or proven to be directly connected to the sinkhole area. Controlled releases then could be transmitted from the sinkhole area to the well field via the carbonate aquifer. However, in this model the carbonate aquifer functions merely as a pipeline rather than as a storage reservoir. It might be more practical to use a man-made pipeline in this instance.

## <u>Evaluation of Proposed Dam Sites for Artificial Recharge</u>

During the course of the investigations to evaluate water resources in western South Dakota, the U.S. Army Corps of Engineers proposed several potential dam sites in the Black Hills area. They are listed on table 4 and their locations are shown in figure 8.

## TABLE 4

List of proposed dams-reservoir sites in western South Dakota in the Black Hills area

| Dam-Reservoir | County | Location |
|---|---|---|
| Boxelder Creek Reservoir | Pennington | Sec. 19, T. 2 N., R. 7 E. |
| French Creek Reservoir | Custer | Sec. 28, T. 3 S., R. 4 E. |
| Elk Creek Reservoir | Meade | Sec. 21, T. 4 N., R. 5 E. |
| Whitewood Creek Reservoir | Lawrence | Secs. 4 and 5, T. 5 N., R. 4 E. |

## Boxelder Creek Reservoir

The proposed Boxelder Reservoir is in an area where the floor and the side walls of the reservoir would be entirely in the Minnulusa Formation, a part of the carbonate aquifer system. This location lies in a reach of the stream where both springs and stream losses are prevalent. At the proposed reservoir site water loss is anticipated, especially when considering the added 100 feet of head from the pool elevation. Thus, water loss could be significant and artificial recharge would be enhanced.

Actual water loss from the reservoir cannot be calculated. The travel path and retention time are also unknown, although some of the water probably flows south and emerges in the Rapid Creek drainage basin (Rahn and Gries, 1973). While the reservoir site may have high potential for artificial recharge, the travel path and other unknowns would have to be determined by detailed geologic and hydrologic studies in the area.

## French Creek Reservoir

According to the State Geologic Map (Petsch, 1953), the French Creek Reservoir is contained within Precambrian metamorphic rock. These rocks generally have low porosity and permeability (Rahn, 1981a). Because of these characteristics there would be no potential for regional artificial recharge from a reservoir at this site.

## Elk Creek Reservoir

According to the State Geologic Map (Petsch, 1953), the Elk Creek Reservoir is contained entirely within the Madison Formation, a part of the carbonate aquifer system. Outside the proposed reservoir but within the same general area, springs and caves are present in the carbonate aquifer. Rahn (1981b) indicated several potential artificial sites within 4 to 5 miles of this location. Thus, it seems likely that the Elk Creek Reservoir site would have potential as an artificial recharge site. However, a detailed hydrologic and geologic study would be required to determine travel path and retention time of the recharge water.

## Whitewood Creek Reservoir

The proposed Whitewood Creek Reservoir is located near the Madison-Minnelusa contact, both being part of the carbonate aquifer system. Hydrologically and geologically this site would probably have a recharge potential as do the other sites situated on the carbonate aquifer. Rahn (1981b) did not consider Whitewood Creek as a potential artificial recharge basin due to distance from possible aqueduct origin, small stream size, pollution and housing and highway relocation factors. Of these, the pollution factor is probably the most important. The U.S. Geological Survey is in its first fiscal year of a 5-year study to determine the geochemistry of the sediments and water in Whitewood Creek. The results of this study should be made available before any large development takes place on Whitewood Creek.

## Alluvial Aquifers

The concept of artificially recharging alluvial aquifers in the Black Hills is subject to the same limitations as those outside the Black Hills. Since these limitations have already been discussed in a previous section of this report, they will not be repeated here.

One difference between the alluvial aquifers within the Black Hills area and those outside is their relative permeability. The alluvial aquifers within the Black Hills are generally highly permeable as contrasted with those outside the area (Rahn, 1981a). This factor enhances the use of an infiltration gallery or a low-head dam-infiltration gallery combination. Either method would capture more of the available streamflow, but they would not normally capture significant quantities of flood flow and retain it for a long period of time. Thus, any streams in the Black Hills with adequate flow and proper geologic and hydrologic conditions within the alluvium could be artificially recharged. Lack of geologic and hydrologic data is the limiting factor for proposing specific sites for artificial recharge in the alluvium.

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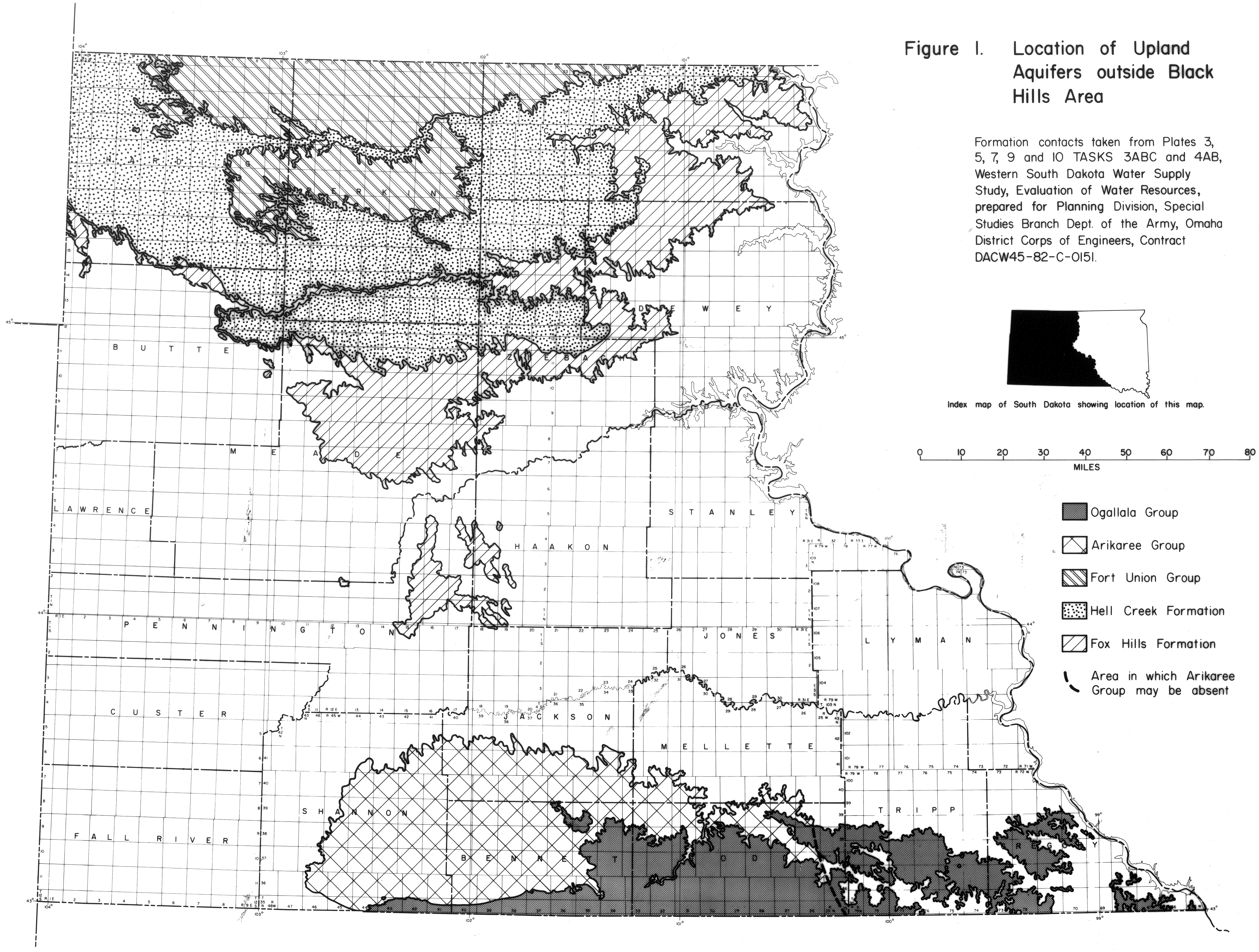
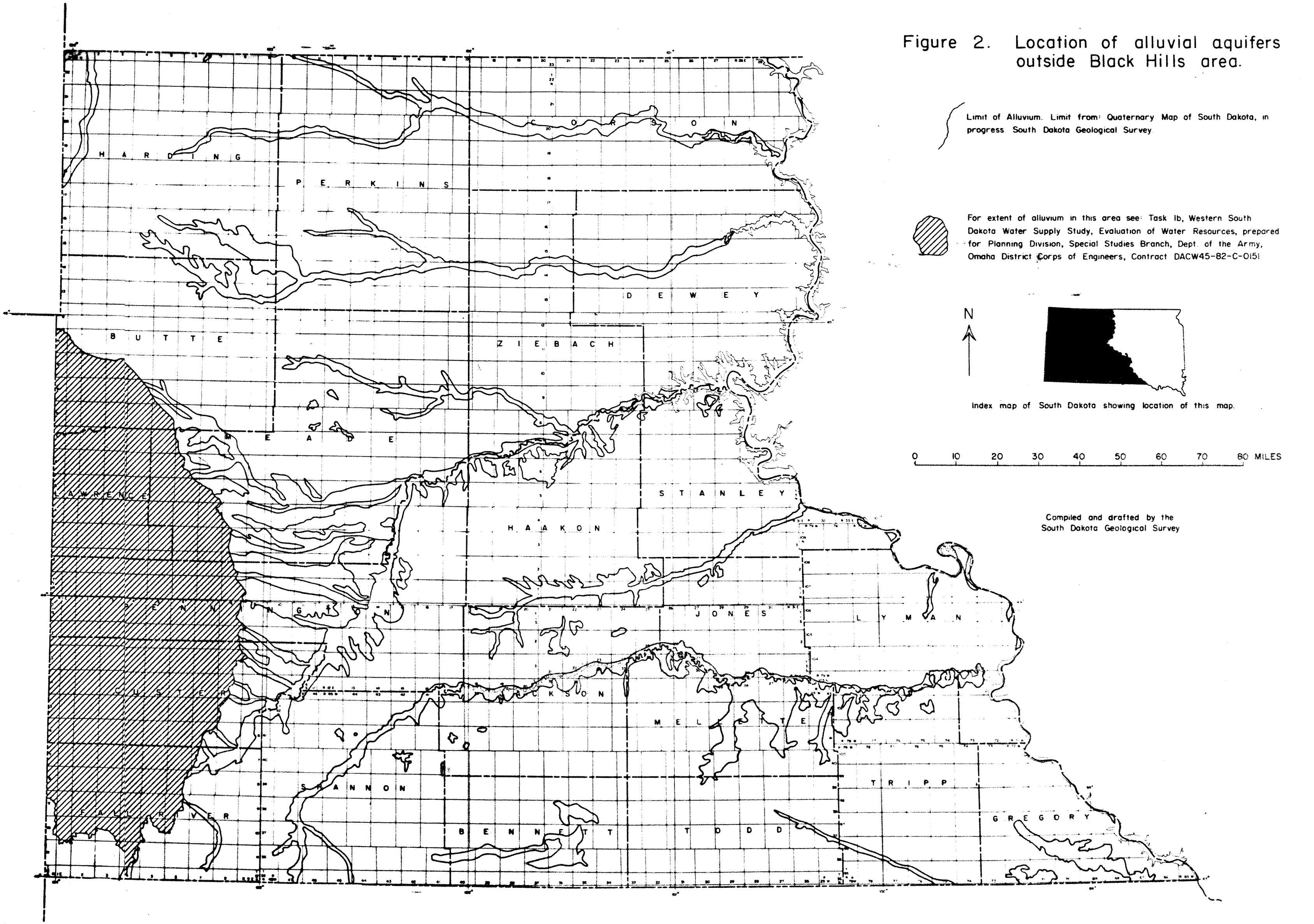


Figure 1. Location of Upland Aquifers outside Black Hills Area

Formation contacts taken from Plates 3, 5, 7, 9 and 10 TASKS 3ABC and 4AB, Western South Dakota Water Supply Study, Evaluation of Water Resources, prepared for Planning Division, Special Studies Branch Dept. of the Army, Omaha District Corps of Engineers, Contract DACW45-82-C-0151.

Figure 2. Location of alluvial aquifers outside Black Hills area.



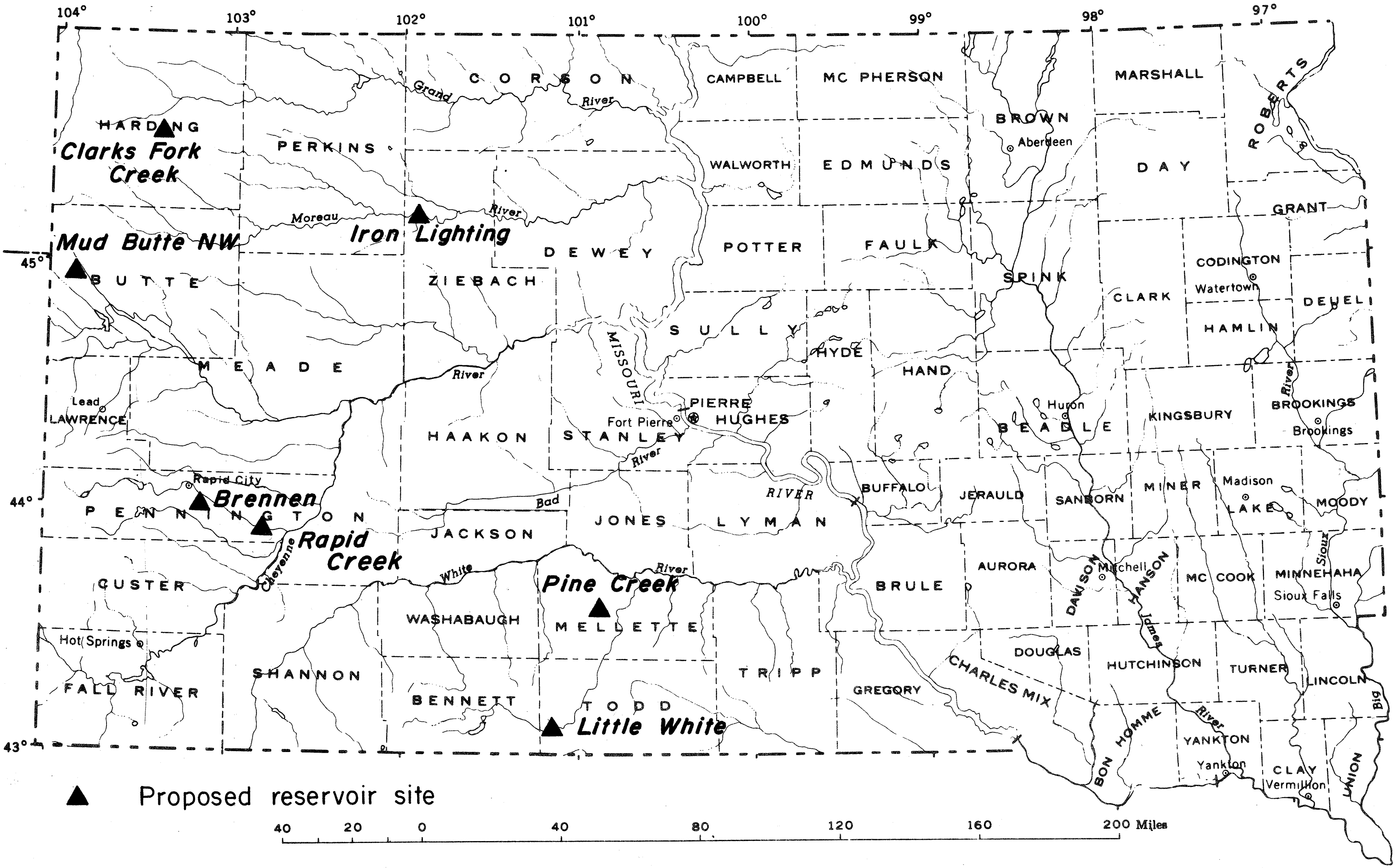


Figure 3. Location of proposed reservoirs in western South Dakota outside the Black Hills.

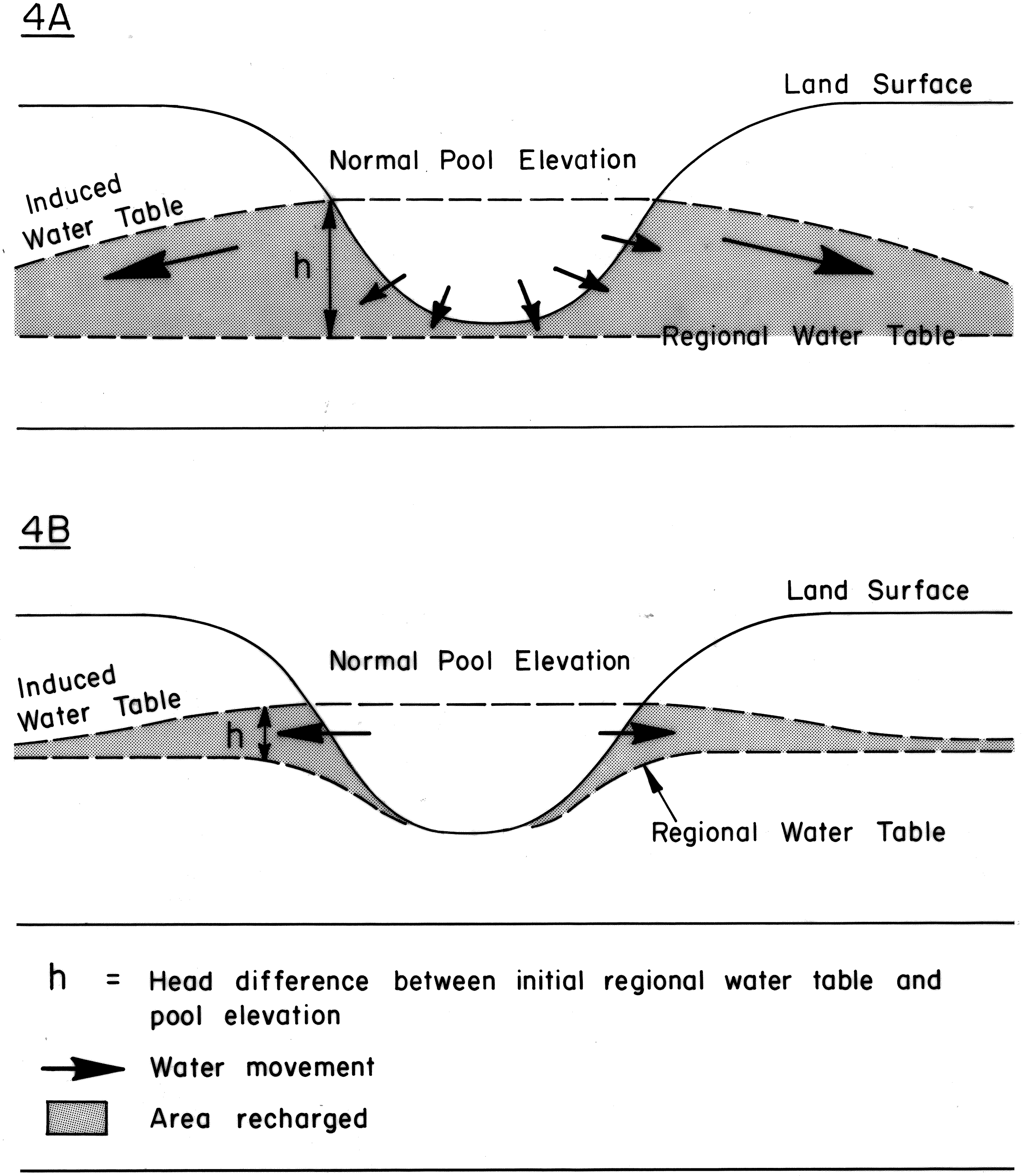
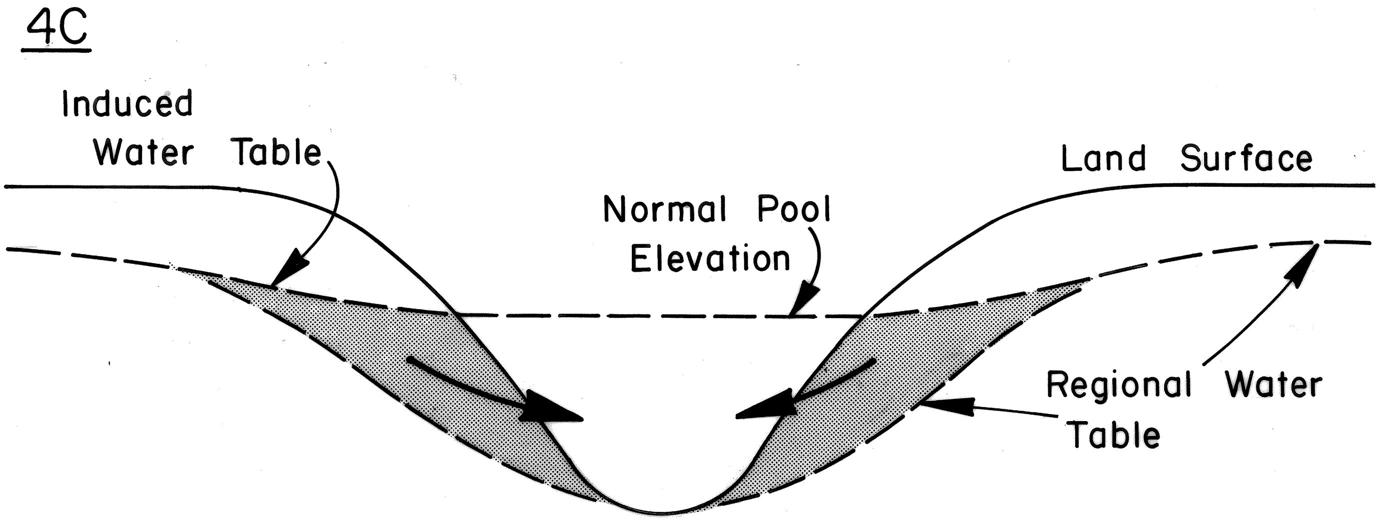
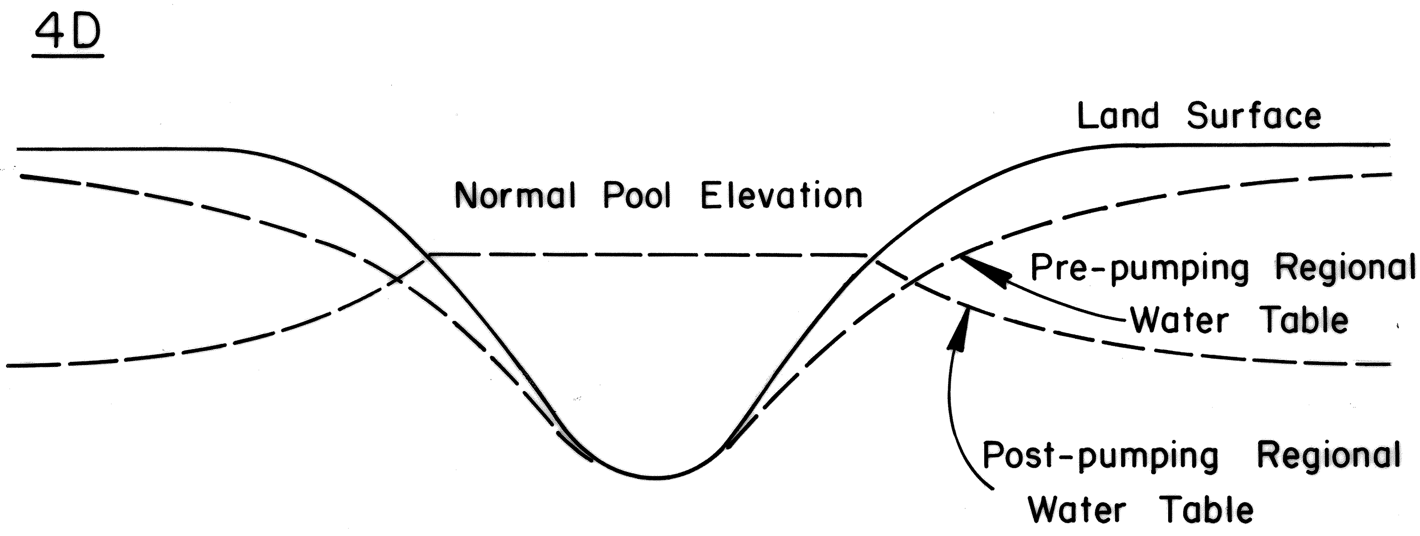


Figure 4. Hydrogeologic conditions at reservoir sites.



In this case regional ground water flow is towards reservoir.



h = Head difference between initial regional water table and pool elevation

→ Water movement

▨ Area recharged

Figure 4. continued

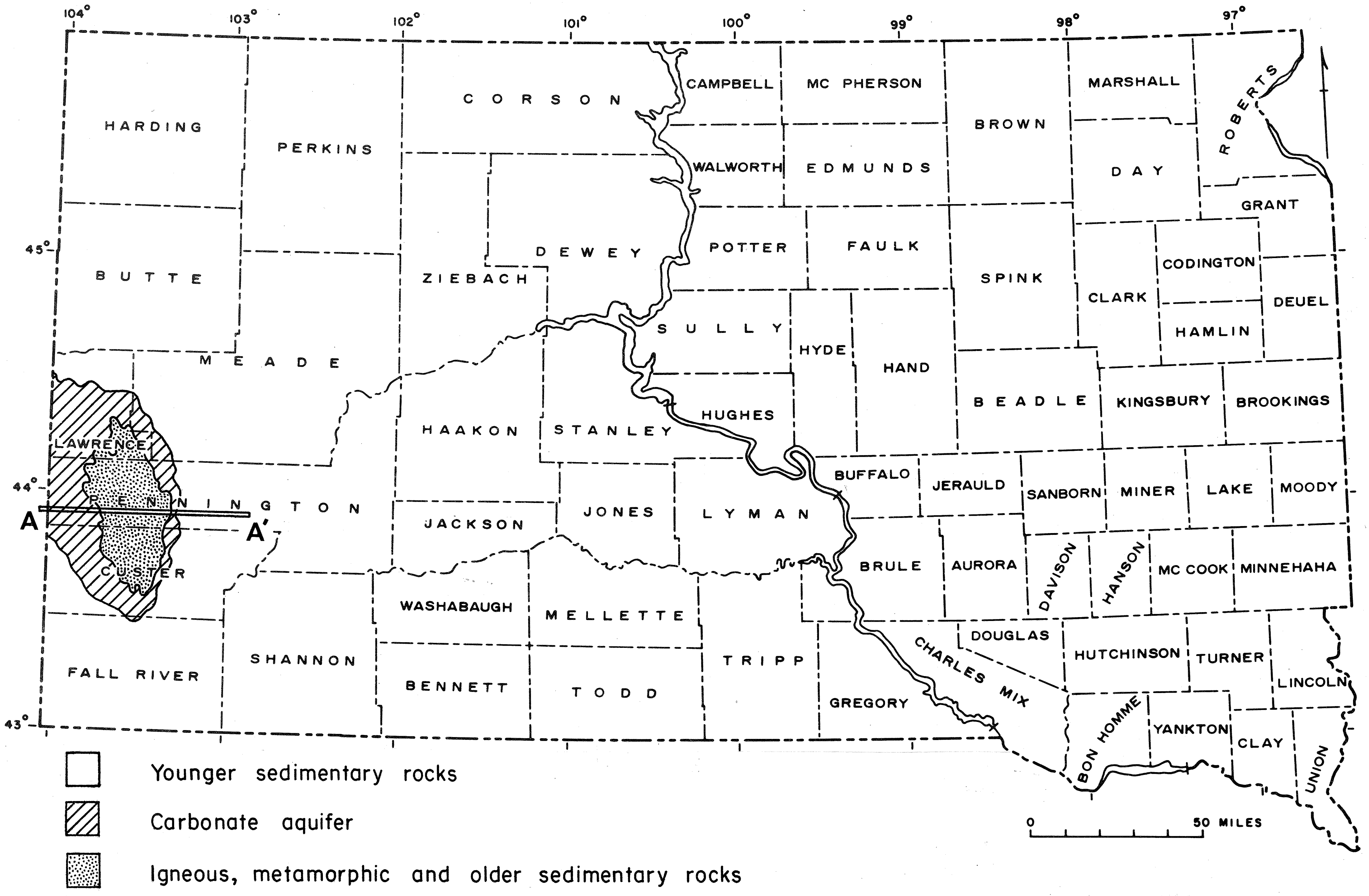


Figure 5. Idealized map view of Black Hills Model

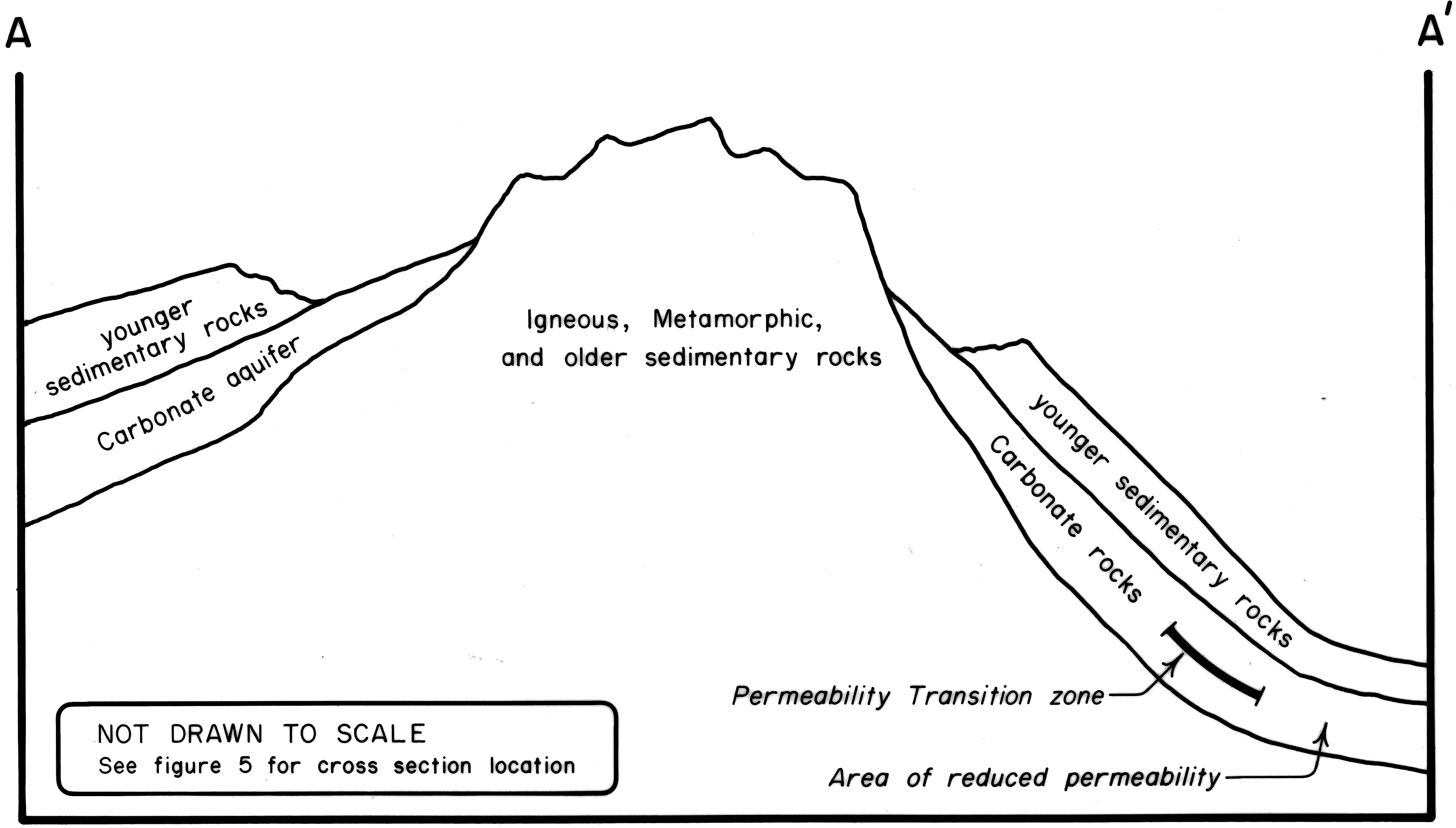


Figure 6. Idealized cross section of Black Hills hydrologic model.

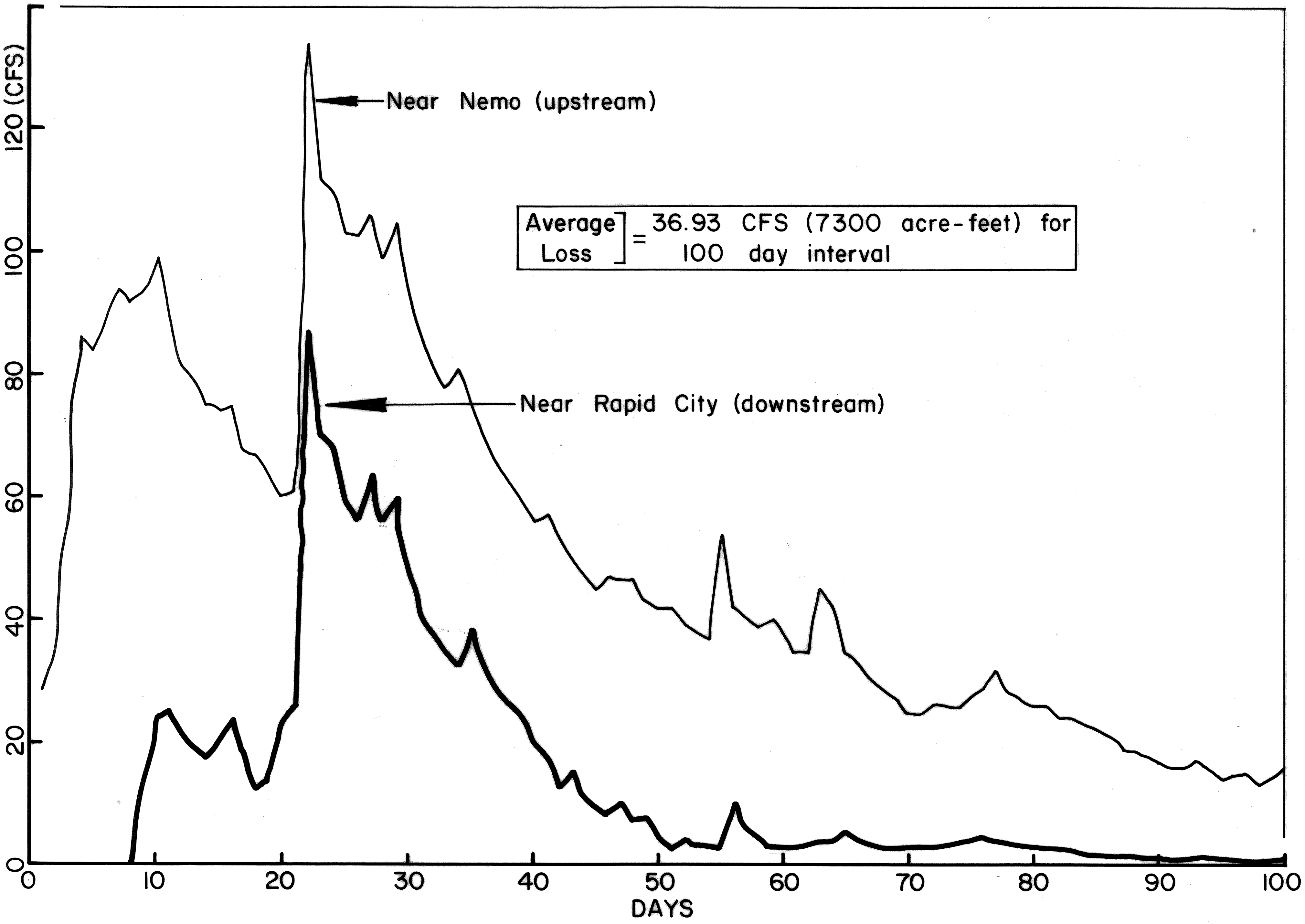


Figure 7. Hydrograph showing streamflow on Boxelder Creek.

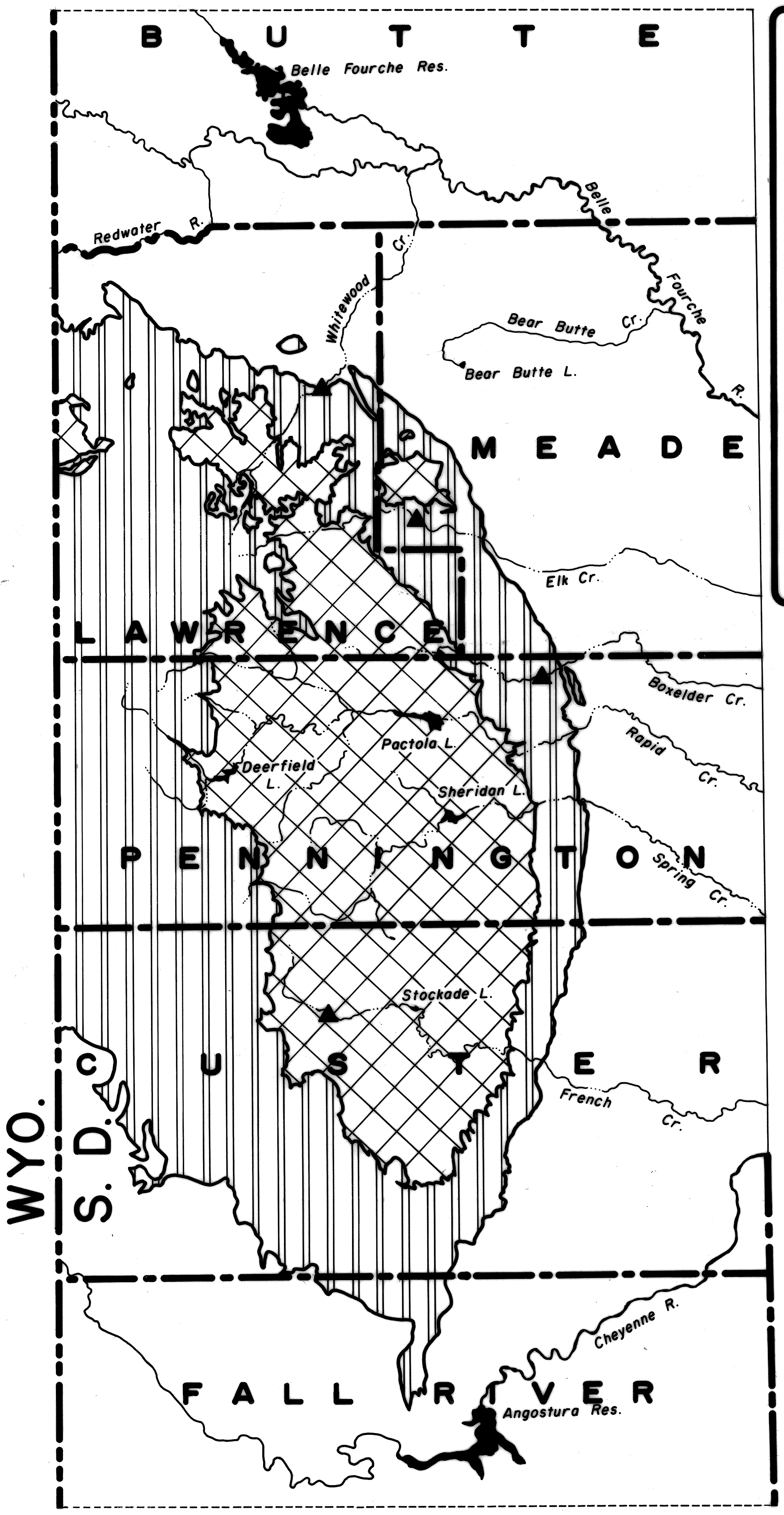


Figure 8. Location of proposed reservoir sites in the Black Hills.