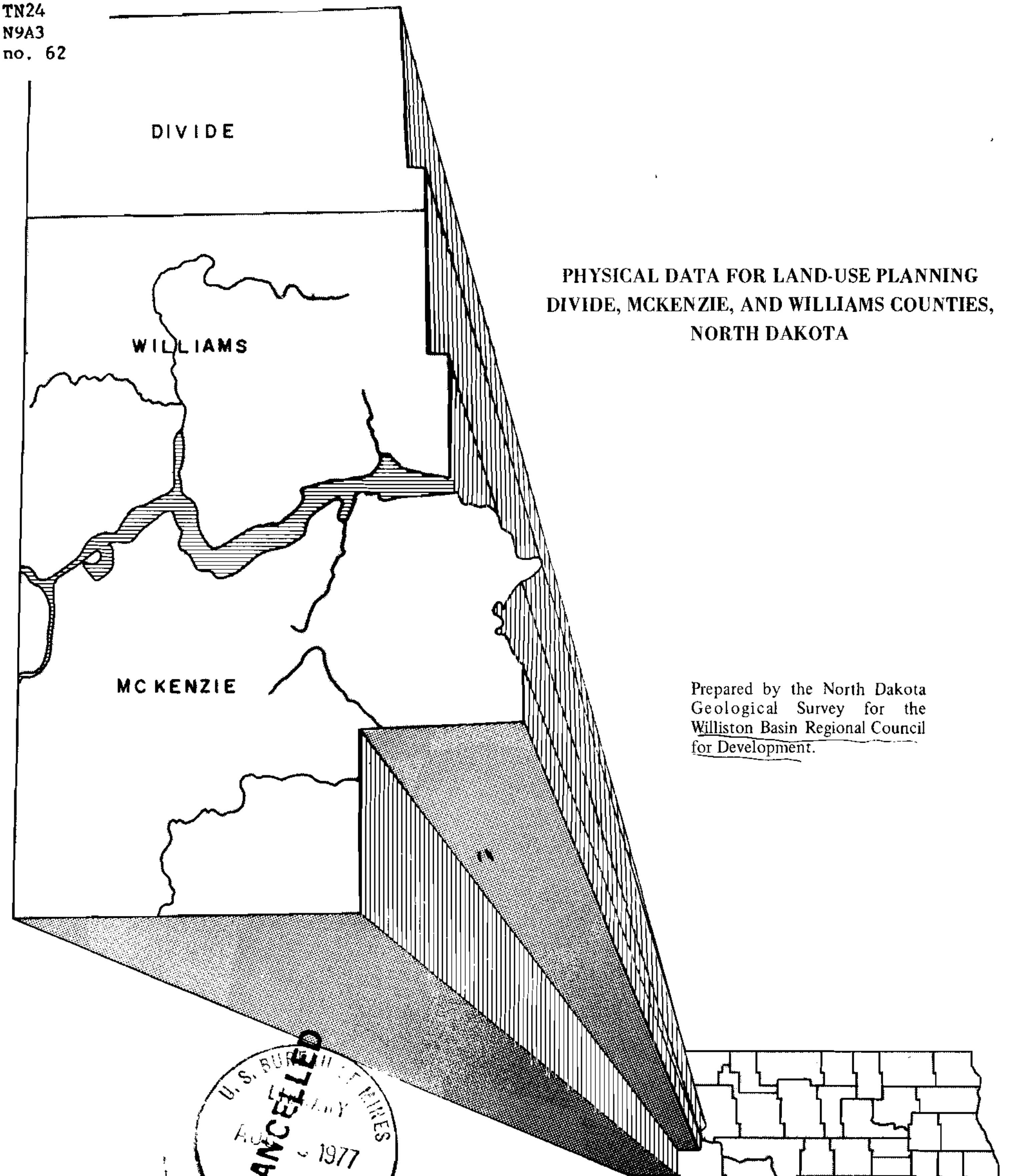

PHYSICAL DATA FOR LAND-USE PLANNING DIVIDE, MCKENZIE, AND WILLIAMS COUNTIES, NORTH DAKOTA

Prepared by the North Dakota Geological Survey for the Williston Basin Regional Council for Development.

NORTH DAKOTA GEOLOGICAL SURVEY
REPORT OF INVESTIGATION 62
1977

PHYSICAL DATA FOR LAND-USE PLANNING

DIVIDE, MCKENZIE, AND WILLIAMS COUNTIES, NORTH DAKOTA

By Erling A. Brostuen

NORTH DAKOTA GEOLOGICAL SURVEY
REPORT OF INVESTIGATION 62

A compilation of available data on the surficial materials, mineral resources, and groundwater resources of Divide, McKenzie, and Williams Counties, North Dakota. Interpretive data regarding suitability of soils for cultivation and irrigation and the potential for pollution of groundwater are included.

This report was prepared by the North Dakota Geological Survey for the Williston Basin Regional Council for Development.

The preparation of this report was financed in part through a Federal grant from the Department of Housing and Urban Development, under the Urban Planning Assistance Program, authorized by Section 701 of the Housing Act of 1954, as amended.

Printed by Kaye's Inc. 1977

NORTH DAKOTA GEOLOGICAL SURVEY

E. A. Noble, State Geologist

This report on Physical Data for Land-Use Planning is one of the items in the Regional Council's 1976-77 Work Program and is intended to be used as a general reference in the inventory and analysis of Soil, Mineral, and Water Resources in Divide, McKenzie, and Williams Counties.

The report was prepared under the Regional Council's sponsorship by Mr. Erling A. Brostuen of the North Dakota Geological Survey in Grand Forks, North Dakota. The Regional Council wishes to extend its appreciation and thanks for the excellent job Mr. Brostuen and his staff have done in preparing this report.

Regional Council

Mr. Milton Nygaard	*County Commissioner*	*Divide County*
Mr. George Larsen	*Mayor*	*Divide County*
Mr. Bill Fortier	*Soil Conservation Dist.*	*Divide County*
Mr. Henry Madison	*County Commissioner*	*McKenzie County*
Mr. Arne G. Sanford	*Mayor*	*McKenzie County*
Mr. Roger Sanders	*Soil Conservation Dist.*	*McKenzie County*
Mr. Lloyd A. Johnson	*County Commissioner*	*Williams County*
Mr. Carl L. Larsen	*Mayor*	*Williams County*
Mr. Cecil Daniel	*Soil Conservation Dist.*	*Williams County*
Ms. Diane Bervig	*Mayor (Williston)*	*Williams County*
Mr. Tony Moran	*Trenton Indian Services*	*At Large*

Roger Sanders, Chairman
Williston Basin Regional Council for Development
Williston, North Dakota 58801

CONTENTS

ILLUSTRATIONS

INTRODUCTION

The area included in this report, Divide, McKenzie, and Williams Counties, is located in northwestern North Dakota. It is bounded on the north by the United States-Canadian boundary, on the west by the Montana-North Dakota state line, and on the south by the Eleventh Standard Parallel. The irregular eastern boundary consists of surveyed lines and a portion of the Missouri River channel. Divide County has an area of 1 303 square miles, Williams County has 2 032 square miles, and McKenzie County, the largest county in North Dakota, has an area of 2 721 square miles.

Principal streams in the three-county area include the Missouri, Yellowstone, Little Missouri, and Little Muddy Rivers in McKenzie and Williams Counties and Long Creek in Divide County.

This report was prepared for the Williston Basin Regional Council for Development to provide physical data for land-use planning. Most of the data in the report was derived from existing sources of information with some modifications as a result of subsequent fieldwork. The data in the report are general and are to be used only as guidelines for generalized planning. More detailed work will be required to refine boundaries and subunits for detailed land-use decisions. The maps included with the report are to be used only at the published scale. The report should be used only as it is augmented by consultation with geologists, soil scientists, hydrologists, and engineers who are familiar with the properties of materials in the three counties.

This report includes a discussion of the materials that make up the surface of the three-county area and the mineral, agricultural, and water resources. A discussion of the general pollution hazard for groundwater and a more specific discussion of the pollution hazard in the Williston area are also included.

Topographic maps at a scale of 1:24 000 are available for a portion of the area, but much of the area has not yet been mapped at that scale. Topographic maps at a scale of 1:250 000 with a 100-foot contour interval are available for the entire area. Groundwater and geological studies have been completed for Williams and Divide Counties, but not for McKenzie County. General soils maps are available for the entire area.

MATERIALS

The surface materials of the three-county area have been separated into seven units based on their physical characteristics (pl. 1). The Divide County portion of plate 1 is based on a geologic map by Hansen (1967), soils maps by the North Dakota State Agricultural Experiment Station (1963), and additional field investigations. The Williams County portion is based on a geologic map by Freers (1970), soils maps by the North Dakota State Agricultural Experiment Station (1963), and additional field investigations. The McKenzie County portion is based primarily on personal knowledge of the area, but also on field investigations and soils maps by the North Dakota State Agricultural Experiment Station (1963).

Characteristics of Map Units

Bedrock

Bedrock exposed at the surface in the study area consists of the Tongue River, Sentinel Butte, and Golden Valley Formations, all of Tertiary age. The Golden Valley Formation forms the caprock in part of the Blue Buttes area in eastern McKenzie County, and it is also found in the Lone Butte and Grassy Butte areas. The Tongue River and Sentinel Butte Formations consist of alternating beds of clay, silt, sand, and lignite. Bedrock is exposed along the major drainages and their tributaries in Williams and McKenzie Counties as far south as the limit of glaciation, which approximately coincides with the Twelfth Standard Parallel. South of this limit, bedrock forms the surface material. Divide County has a thick cover of glacial materials, with little bedrock exposed except for small, isolated exposures of the Tongue River Formation in the northeastern corner of the county.

Preglacial gravel

Gravel deposited prior to glaciation includes the Wiota and Flaxville gravels as well as gravel deposited along the preglacial Little Missouri River channel. The Wiota and Flaxville gravels are similar, consisting mainly of well-rounded water-worn pebbles two inches or less in diameter. Chert and quartzite comprise about 70 to 80 percent of the deposits with the remainder made up of rhyolite and carbonates. They are often poorly sorted but can be used as aggregate in concrete. The gravel along the ancient Little Missouri River channel consists of some chert and quartzite with a large percentage of local rock types such as clinker (scoria), shale, and sandstone fragments. It is used as road surfacing material and also serves to a degree as concrete aggregate.

Glacial deposits

Till is widespread over the three-county area. It contains a mixture of all particle sizes from clay through boulders. The till ranges in thickness from a few inches near the limit of glaciation to over 200 feet thick in northern Williams County to 600 feet in parts of Divide County. It is thickest in the ancient bedrock valleys and thinnest on the bedrock highs.

Clay and silt are found in eastern Divide County and in Williams County where they were deposited as glacial lake sediments. Clay and silt are also found in northeastern McKenzie County near Keene. Sand dunes are found in the Hofflund area in Williams County and in scattered locations in northeastern Divide County.

Sand and gravel are found in all the counties in the study area. It was deposited as glacial outwash, and it is found along all the major drainages and meltwater channels. Sand and gravel are also found in the buried preglacial river channels. The glacial sand and gravel differs from the preglacial sand and gravel in both origin and rock type. It is composed generally of angular to subrounded granitic and carbonate fragments. It also contains high percentages of shale, which makes it less desirable than the preglacial gravel for concrete aggregate.

Alluvium

The alluvium that occurs along the stream and river channels in the three-county area is postglacial. The largest deposits are located along the Yellowstone, Missouri, Little Missouri, and Little Muddy Rivers. The alluvium consists of bedded silt, sand, clay, and gravel.

GROUNDWATER RESOURCES

The groundwater resources of the study area are shown on plate 2. Information on water quality, yield, and aquifer characteristics for Divide and Williams Counties has been obtained from Armstrong (1967; 1969). Similar information is not available for McKenzie County. The groundwater resources of McKenzie County are inferred, based on our knowledge of preglacial, interglacial, and postglacial drainages. Water analyses reported by Armstrong (1967; 1969) indicate that water quality varies from place to place. The U.S. Public Health Service standards for drinking water state that more than 500 parts per million of total dissolved solids is not desirable if better water is available, and most of the groundwater in the study area exceeds that amount. Much of the water is also marginal to unsuitable for irrigation. It is imperative that all water be analyzed to determine its suitability for its intended purpose.

Bedrock Aquifers

The entire three-county area is underlain by several bedrock aquifers. Generally, the water produced from these aquifers is of inferior quality and ranges from unsuitable to undesirable for human consumption. The only bedrock aquifers discussed in this report are those in the Cretaceous and Tertiary Systems. These aquifers are generally found at depths of less than 5 000 feet. They are not shown on plate 2.

Cretaceous aquifers include the Dakota Group and the Fox Hills and Hell Creek Formations. Water from the Dakota Group is of poor quality with total dissolved solids ranging from 8 500 parts per million to 11 000 parts per million.

This water is unsuitable for irrigation, stock watering, or human consumption, but it is being utilized as source water for secondary recovery in the unitized oil fields. It may also have application in the solution mining of potash and sodium chloride and as cooling water for power generation and lignite conversion plants. As fresh water resources become harder to find and as demand increases, water from the Dakota Group may eventually be considered for desalinization.

The Fox Hills and the Hell Creek Formations are the uppermost members of the Cretaceous System. Little is known of the quality of the water found in these two formations, but samples from a well in McKenzie County indicate that the water there is a soft, sodium bicarbonate type with 1 320 parts per million total dissolved solids. It also contains 5.7 parts per million flouride, which greatly exceeds the Federal standards for human consumption.

Tertiary aquifers include the Cannonball and Ludlow Formations and the Fort Union Group. No samples have been obtained from these two aquifers in the study area, but a sample of Cannonball water from Burke County was high in dissolved solids, particularly chloride.

Aquifers in the Tongue River and Sentinel Butte Formations are undifferentiated in this report. Water quality varies greatly in the shallower wells in the Fort Union Group. In the deeper horizons, the water is more uniform in quality, generally of a sodium bicarbonate type. Most farm wells in the Fort Union Group are completed in the uppermost sand lens. Wells completed in lignite commonly have a higher specific capacity than wells completed in sand. The pumping rate from either type of aquifer is usually less than 50 gallons per minute. Water from these aquifers can be suitable for livestock watering, but it is not recommended for human consumption if better water is available. It is unsuitable to marginal for irrigation.

Glacial Drift and Alluvial Aquifers

Glacial drift and alluvial aquifers occur in all three counties (pl. 2). They vary in productive capacity from 0 to more than 500 gallons per minute. The groundwater studies for Williams County (Armstrong, 1967) and Divide County (Armstrong, 1967) indicate that much of the water from these two types of aquifers has a high salinity hazard and is marginal or unsuitable for irrigation purposes. Because of the variation in water quality, it is important that any water be analyzed to determine its suitability for its intended use.

Skjermo Lake aquifer

The Skjermo Lake aquifer is located in northwestern Divide County. It appears to be associated with a buried preglacial channel of the Missouri River. Properly completed wells in this aquifer should yield from 50 to over 500 gallons of water per minute. Water in the Skjermo Lake aquifer is of better quality than most groundwater in Divide County. The water is suitable for irrigation except in the western part where it ranges from marginal to unsuitable.

Buried Missouri channel aquifers

The buried Missouri channel aquifers occupy the preglacial channel of the Missouri River in west-central and southwestern Divide County and northwestern Williams County. The water-bearing deposits can be divided into two units, the Grenora aquifer and the northeastern unit. The boundary between these units is poorly defined. Water quality varies across the aquifers, but it is generally marginal to unsuitable for irrigation. Properly completed wells can produce from 50 to over 500 gallons per minute.

Buried Yellowstone channel aquifers

The buried Yellowstone channel aquifers occupy a valley eroded by the preglacial Yellowstone River. They extend from the international boundary in northeastern Divide County southwestward to the Divide-Williams County line and thence in a generally southerly direction to the confluence of the Little Muddy River with the Missouri River. In Williams County, the extension of the Yellowstone channel aquifers is known as the Little Muddy aquifer. The aquifers that occur in the buried Yellowstone valley range from a few feet below the surface to over 500 feet deep. Some of the water from these aquifers is suitable for irrigation, but water quality varies both vertically and horizontally. Properly completed wells may produce from 50 to over 500 gallons per minute.

Wildrose and West Wildrose aquifers

The Wildrose and West Wildrose aquifers, located in southeastern Divide County, extend into northeastern Williams County where they are probably hydraulically connected to the Little Muddy aquifer. Water from these aquifers appears to have a high salinity hazard, which may make them marginal to unsuitable for irrigation. Properly completed wells in the Wildrose aquifer may yield from 50 to 500 gallons per minute. In the central portion of the West Wildrose aquifer, properly completed wells may yield more than 500 gallons per minute.

Ray aquifer

The Ray aquifer occupies a portion of the preglacial Little Missouri River channel in Williams County. It extends from approximately six miles southeast of Ray in a northwesterly direction, eventually joining the Little Muddy aquifer southeast of Zahl. Properly completed wells may yield from 50 to over 500 gallons per minute. The water has a high to very high salinity hazard and is marginal to unsuitable for irrigation.

Hofflund aquifer

The Hofflund aquifer is located in southeastern Williams County adjacent to the Missouri River. It occupies a portion of the preglacial Little Missouri River channel and terraces of the modern Missouri River. Water quality varies from place to place with the better quality water located on the west side. It has a high salinity hazard and is marginal to unsuitable for irrigation.

Trenton aquifer

The Trenton aquifer underlies approximately 26 000 acres of floodplain and terrace along the Missouri River southeast of Williston. Water quality varies from place to place but is generally best near the Missouri River. On the north side of the aquifer the water is high in dissolved solids with very high sodium and salinity hazards. It is doubtful that any of this water would be utilized for irrigation due to the availability of better quality water from the Missouri River.

McKenzie County aquifers

Groundwater data for McKenzie County is not yet available. Water quality and production rates are unknown, except for isolated cases. The aquifers in McKenzie County (pl. 2) are inferred, based on preglacial, interglacial, and postglacial drainage, and they are included in this report only to indicate areas with possible groundwater potential. The Yellowstone and Indian Hill aquifers are probably similar in productive capacity to the Trenton and lower Little Muddy aquifers. The Little Missouri and buried Little Missouri aquifers can also be expected to be good prospects for groundwater production. The Cartwright, Camp Creek, Bennie Pierre, and Hay Draw aquifers occupy interglacial channels of the Yellowstone River and may not contain sufficient coarse materials to serve as aquifers with high specific capacity.

MINERAL RESOURCES

Minerals in the study area which are currently being produced or in which interest has been indicated include petroleum, lignite, potash, sodium chloride, sodium sulfate, uranium, sand, and gravel (pl. 3).

Petroleum

Oil and gas have been produced in the study area since the early 1950s. Following the discovery of oil near Tioga, production developed quickly. Most of the production is from fields located on the Nesson anticline, a geologic structure located in eastern McKenzie and Williams Counties and extending northward into Divide County. There are currently 839 producing oil wells in the study area. Of the total, 36 are located in Divide County, 379 in McKenzie County, and 424 in Williams County. Monthly production of crude oil in the study area is approximately 800 000 barrels. Most of this oil is processed at refineries located at Williston and Mandan, North Dakota. Natural gas produced with the oil is processed at plants located at Tioga, Boxcar Butte Field, and Redwing Creek Field.

It is becoming increasingly difficult and expensive to search for new oil reserves. Although exploration and development continue on the Nesson anticline, the search is being carried on in other areas as well. The structures and stratigraphic traps tend to be deeper and smaller with no surface evidence of their existence. As a result, sophisticated methods must be used to determine their possible location. Final evaluation of a prospect can be accomplished only by drilling a well. The entire three-county area can expect to be impacted by exploration and production for many years.

Lignite

Lignite coal has been mined in the study area since the coming of the earliest white settlers. Lewis and Clark note in their journal, dated April 21, 1805, while in the vicinity of present-day Williston, the occurrence of lignite, stating "the coal being of better quality and affording a hot and lasting fire, emitting very little smoke or flame."

Lignite has been mined commercially in all three counties, but commercial mining has now ceased. It is possible, however, that small amounts of lignite are being mined by individuals for personal use. Leonardite, an oxidized form of lignite, is being mined and processed near Williston in Williams County. Leonardite is not used as a fuel but as a mud additive in the drilling of oil wells and as a soil conditioner. It also has application as a raw material in the chemical industry.

Both underground and strip mining methods have been used. Strip mining is considered to be the only practical method for large volume operations and is the only method being considered for commercial operations at this time. It has a much higher recovery factor than subsurface methods and is much safer.

Estimated reserves of lignite in the three-county area are given in table 1. These estimates are in millions of short tons. They are calculated in measured reserves, indicated reserves, and inferred reserves. Measured reserve calculations are based on information gained from outcrop measurements, drill hole records, and mine workings. Indicated reserves are calculated from specific measurements and projection of visible data for considerable distances. Inferred reserve calculations are based largely on knowledge of the geologic characteristics of coals in the area and are supported by few or no measurements. Data presented in table 1 has been modified from Brant (1953).

Table 1. *Estimated lignite reserves in beds more than 2½ feet thick for Divide, McKenzie, and Williams Counties (in millions of short tons).*

County	Measured Reserves	Indicated Reserves	Inferred Reserves	Totals
Divide	140	1 040	7 085	8 265
McKenzie	1 170	4 525	26 485	32 180
Williams	515	3 265	23 155	26 935
Regional Totals	1 825	8 830	56 725	67 380

Strippable lignite reserves may be defined as those recoverable using existing technology and limited by existing economic conditions. Thus, strippable lignite reserve estimates will be considerably less than the estimated lignite reserve figures. Calculations of strippable reserves were based on the following criteria: (1) seam thickness greater than 5 feet; (2) stripping ratio of 10 feet or less of overburden per foot of coal; or (3) stripping ratio of less than 10 yards of overburden per ton of coal. (A lignite density factor of 1 750 tons per acre foot was used.) The criteria for determining strippable reserves will vary with energy demand and economic conditions, resulting in either an increase or decrease in estimated tonnages. The locations of areas with strippable reserves are shown on plate

3. The estimated strippable lignite reserves for the three-county area are given in table 2. These are calculated using the criteria mentioned above. It should be pointed out that the data available to make these calculations is limited. Information developed by the coal industry is proprietary and is not generally available to the public or governmental agencies unless it is voluntarily submitted. As more data is available, new strippable reserves may be located.

Table 2. *Estimated strippable lignite reserves (in millions of short tons).*

County	Deposit	Strippable Reserves	Maximum Overburden
Williams	Avoca	380	75 feet
Williams	M&M	100	120 feet

A total of 1 553 acres of land have been disturbed by strip mining in the three-county area (pl. 3). Of this total, 1 445 acres are in Divide County, 48 acres in Williams County, and 60 acres in McKenzie County. The coal in these disturbed areas was mined prior to the adoption of the current strip mining regulations and reclamation was not required at that time.

Uranium

Uranium associated with lignite has been commercially produced in southwestern North Dakota and northwestern South Dakota, but production was discontinued in 1967. There has been no production in any of the counties within the study area. Uranium is found in thin lignite or carbonaceous beds overlain or underlain by sandstone, which acted as an aquifer. Uraniferous groundwater passing into and through the lignite deposited the uranium. The uranium must be separated from the lignite and this is accomplished by mining the lignite and burning it, thereby concentrating the uranium in the ash. The ash is then further processed by conventional methods to separate the uranium.

Exploration for uranium is now taking place in western North Dakota. The usual exploration procedure is to drill testholes through the lignite and sand beds and then run a gamma ray logging device to determine the presence of radioactivity. The counties within the study area can expect to be impacted by uranium and lignite exploration for some time to come.

New mining methods for uranium now being developed involve the leaching or solution mining of the uranium. This involves sinking wells into the ore body and pumping a solvent into it. The solvent leaches out the uranium and returns it to the surface where the uranium is separated from the solvent. It is hoped that these new methods will have application in the mining of uranium in North Dakota where they may enable thin deposits to be exploited. The thickness of overburden would not be an important limiting factor in production.

Potash

Potash in the form of the mineral sylvite is found interbedded with sodium chloride (rock salt) in the Prairie Formation of Devonian age rocks in the study area. The southern limit of the Prairie Formation is shown on plate 3. Depths to the top of the formation vary from approximately 9 000 feet in northern Divide County to approximately 12 500 feet in east-central McKenzie County. There is presently no commercial potash production in North Dakota, but interest is high due to the increasing prices of imported potash.

The three potash zones that have been named within the Prairie Formation are the Mountrail member, the Belle Plaine member, and the Esterhazey member. The aggregate thickness of these zones is shown in figure 1.

The solution method is the only feasible means of mining potash at the depths at which it is found in the study area. Wells would be drilled to the potash zones and completed with casing and tubing. Water would then be pumped down the annular space between the casing and tubing; and the dissolved potash, in the form of brine, would be circulated to the surface where the potash would be

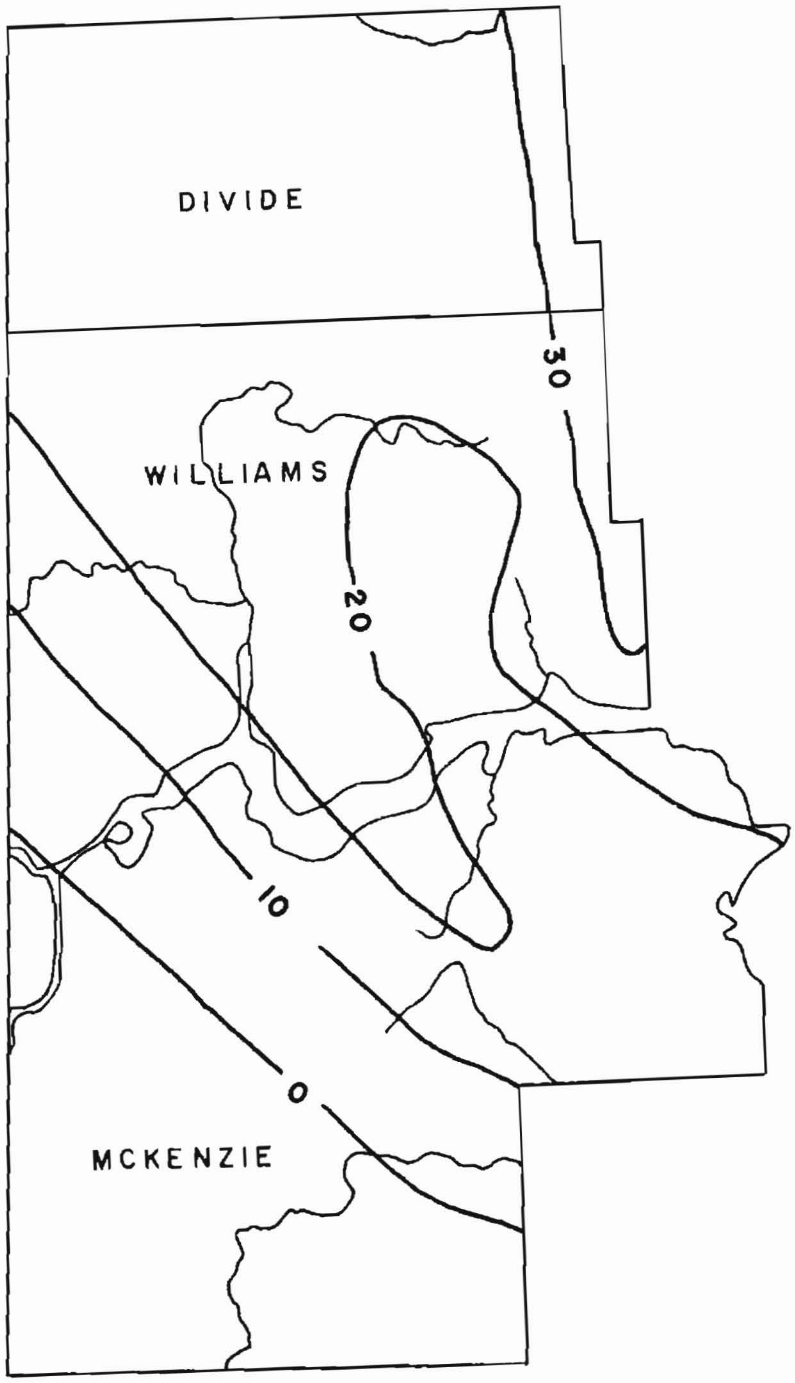

Figure 1. Aggregate thickness in feet of potash zones in the Prairie Formation.

separated and processed.

Sodium Chloride

Sodium chloride is currently being mined by the solution method at Williston from the Charles Formation of Mississippian age rocks. The mines at Williston are reportedly the deepest salt wells in the world. One of the most abundant minerals in the three-county area, the salt is found in the Prairie Formation of Devonian age, the Charles Formation of Mississippian age, the Opeche Formation of Permian age, the Spearfish Formation of Triassic age, and the Triassic Dunham Salt.

Prairie Formation

The salt beds of the Prairie Formation underlie the entire study area with the exception of southwestern McKenzie County. The Prairie Formation ranges in thickness from over 400 feet in northeastern Divide County down to zero in southwestern McKenzie County (fig. 2). It also contains the potash beds mentioned above.

Charles Formation

The Charles Formation contains six salt beds. The combined thickness of these beds ranges from over 400 feet in central McKenzie County to less than 100 feet in northern Divide County (fig. 3).

Opeche Formation

The salt bed of the Opeche Formation underlies the southern three-fourths of Williams County and all of McKenzie County. It ranges in thickness from over 100 feet in southern McKenzie County to zero in northern Williams County (fig. 4). Currently there is no production from this formation.

Spearfish Formation

The Pine Salt bed of the Spearfish Formation underlies parts of all three counties but is absent in northwestern Williams County and all but the extreme southeastern part of Divide County. It is thickest in south-central McKenzie County where it may reach a thickness of over 150 feet (fig. 5).

Dunham Salt

The youngest of the salt beds is the Dunham Salt, which is found in all of the counties in the three-county area. It is absent in northwestern Williams County and all but the extreme southeastern part of Divide County. The Dunham Salt ranges in thickness from over 50 feet in central Williams County to zero in Divide and northwestern Williams County (fig. 6).

Sodium Sulfate

Sodium sulfate is found in natural deposits as the mineral mirabilite or Glauber's salt. It occurs as lake deposits primarily within a six-mile-wide zone extending from the international boundary in northwestern Divide County southward to the Grenora area in northwestern Williams County (pl. 3). Another small deposit is located in south-central Divide County. There is no current production in the study area. The largest use of sodium sulfate in this country is by the Kraft paper industry. Sodium sulfate is also used in glass, detergents, paints, textiles, medicines, and a variety of chemicals. Estimated reserves are shown in table 3.

Table 3. *Estimated resources of Glauber's salt in Divide and Williams Counties (in short tons).*

Group and Lake	County	Reserves
Westby		
Westby A	Divide	903 000
Westby B	Divide	3 813 000
Westby C	Divide	390 000
McCone	Divide	1 500 000
North	Divide	500 000
Miller	Divide	2 750 000
Grenora		
Grenora No. 1	Divide	980 000
Grenora No. 2	Divide and Williams	5 500 000
Stink	Williams	1 233 000
Miscellaneous		
Horseshoe	Williams	87 000
Stady E	Divide	1 846 000
Total		19 502 000

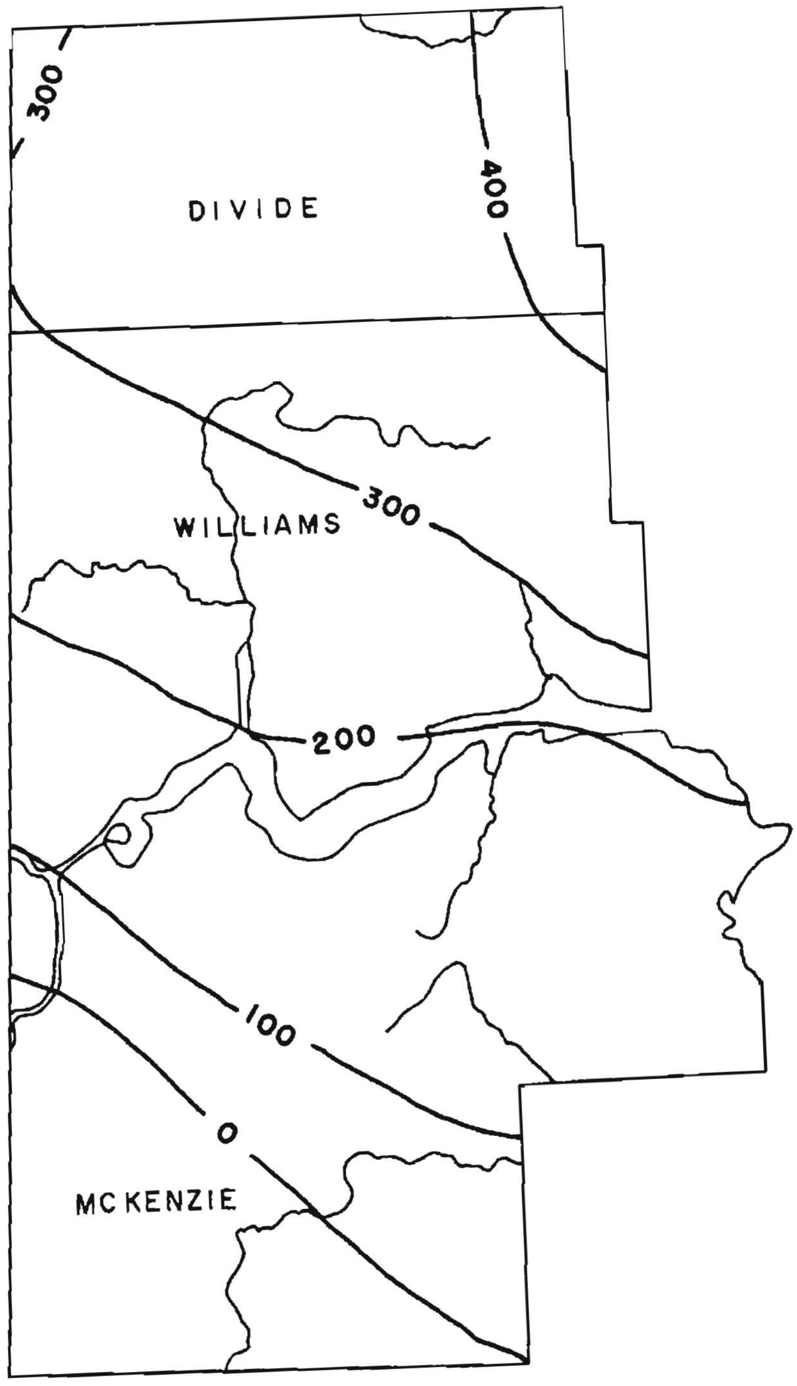

Figure 2. Thickness map of the Prairie Formation in feet.

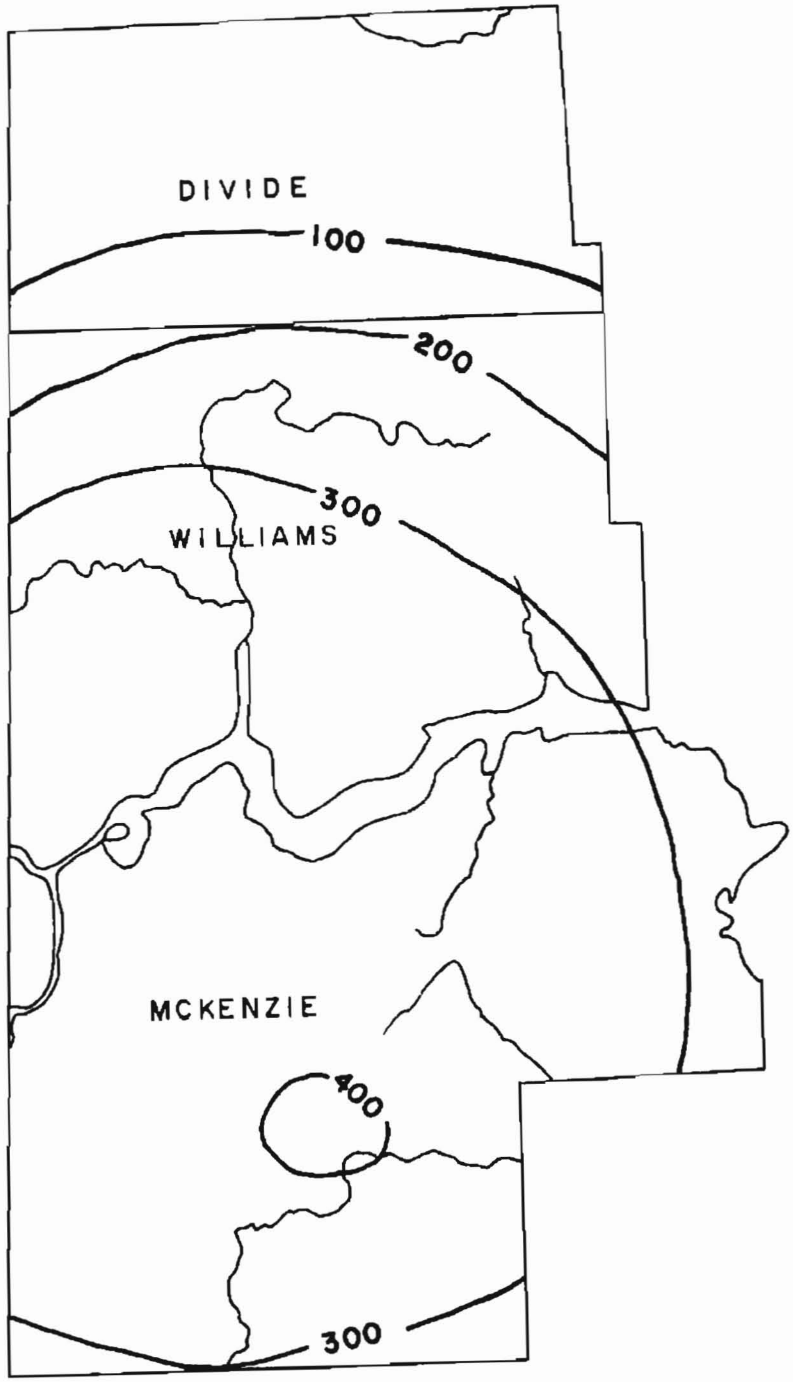

Figure 3. Aggregate thickness in feet of six salt beds in the Charles Formation.

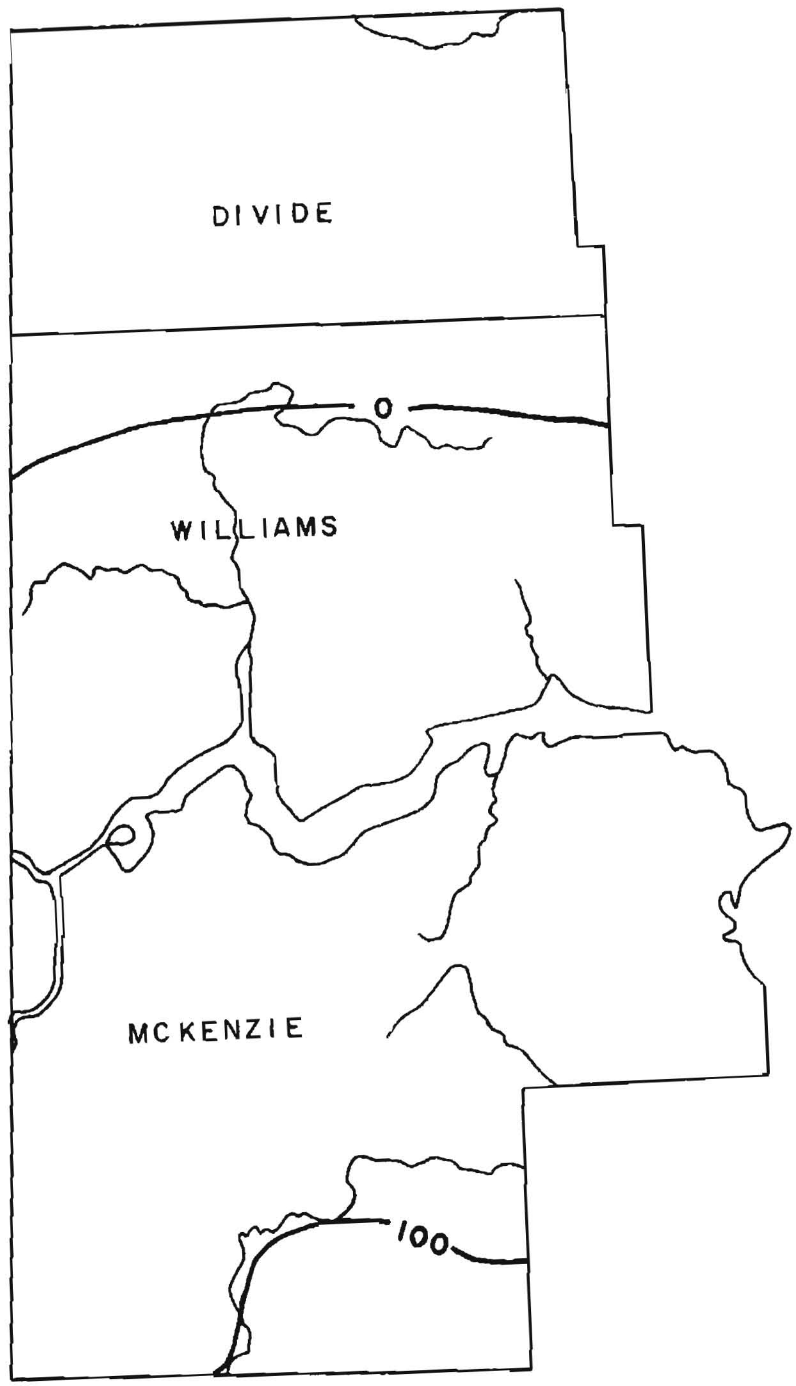

Figure 4. Thickness in feet of the salt bed in the Opeche Formation.

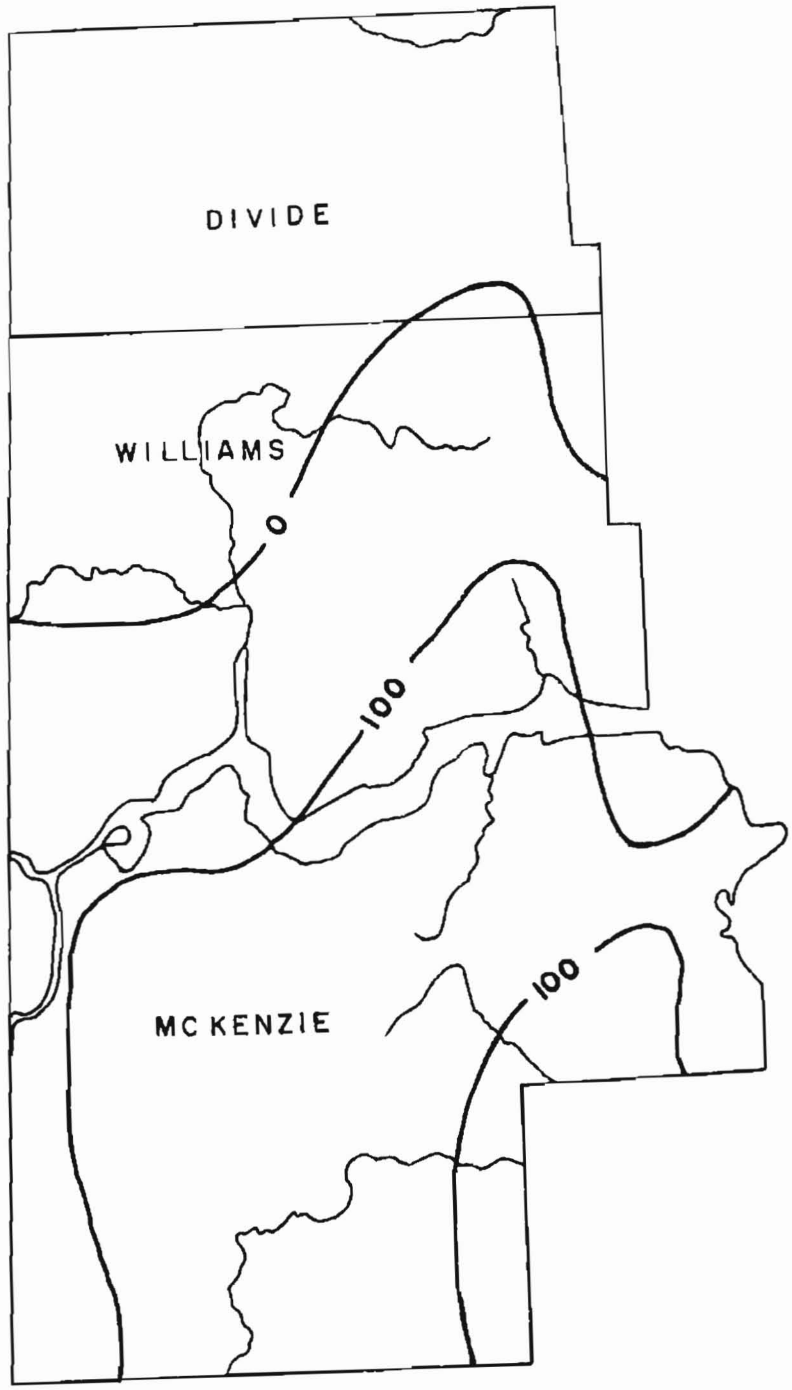

Figure 5. Thickness in feet of the Pine Salt in the Spearfish Formation.

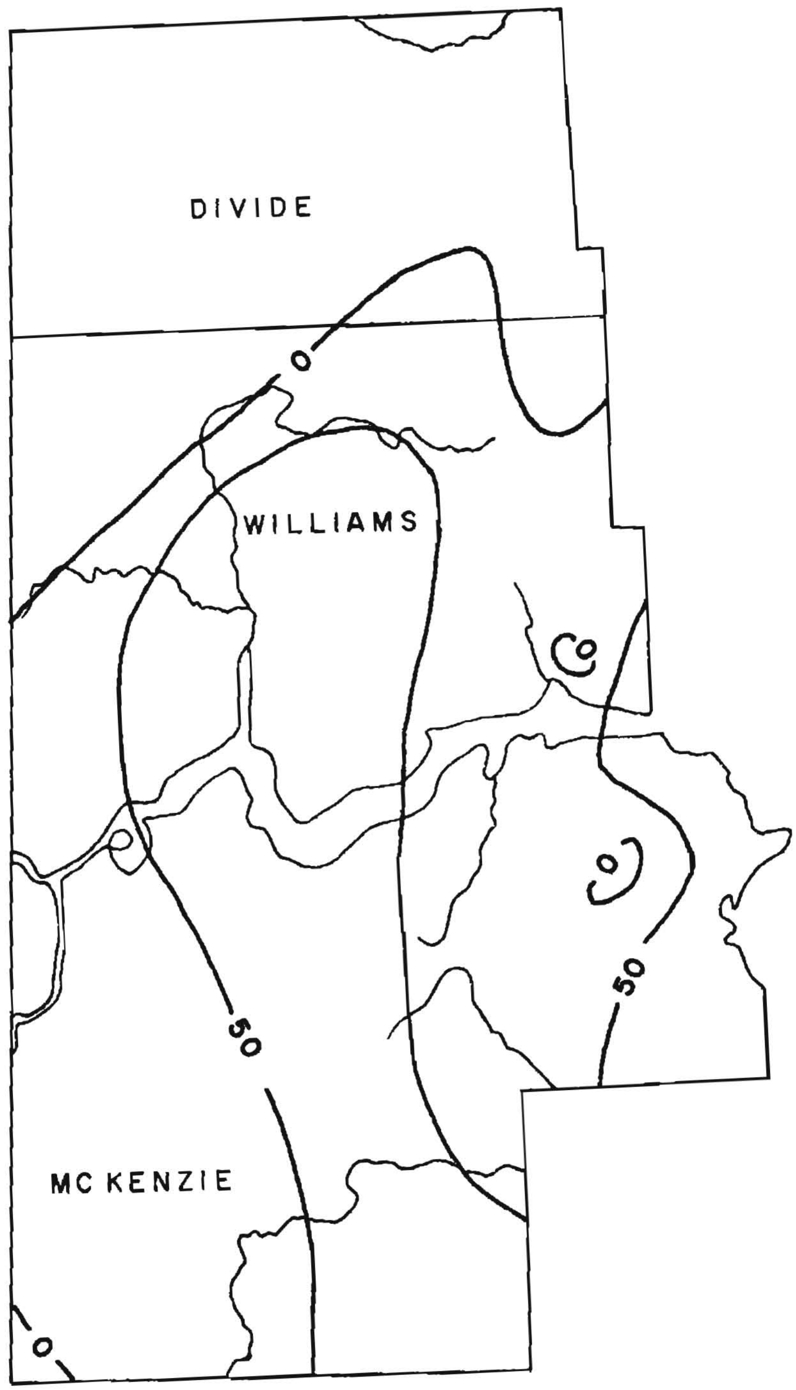

Figure 6. Thickness in feet of the Triassic Dunham Salt.

Sand and Gravel

Sand and gravel production is the third largest mineral industry in North Dakota and is the leading employer of all mineral industries in the state. Sand and gravel is used principally as aggregate for concrete and road paving. Highway construction is the largest user, followed by the building industry.

Sand and gravel are found throughout the study area. Most of the gravel in Divide and Williams Counties is glacial in origin except for the western-type gravel deposits found along river terraces of the preglacial Yellowstone River in Williams County in the Williston area. Most of the gravel in McKenzie County was deposited by ancient and modern streams, although some of the gravel is of the western type, consisting of chert and quartzite.

Gravel of glacial origin tends to be better sorted than the preglacial western gravels and tends to contain more carbonate and shale, making it less desirable for use as aggregate. Gravel deposits are shown on plate 3. Location and thickness for gravel in Divide and Williams Counties were based on Hansen (1967) and Freers (1970). Gravel deposits in McKenzie County are inferred and are based on knowledge of ancient and modern stream drainage.

AGRICULTURAL RESOURCES

Agriculture is by far the main industry in the study area. The suitability of the soils for raising crops is an important factor to be taken into account when planning for use of the land. Two maps included in this study are related to the suitability of the soils for agriculture. Plate 2 shows areas with a potential for irrigation in conjunction with ground and surface water. Plate 4 shows the suitability of the soils for cropland. The soils are rated in three categories: excellent to good, medium to fair, and poor to unsuitable. The general soils maps for the study area (North Dakota State Agricultural Experiment Station, 1963) and the Soil Survey Report (Patterson and others, 1968) were used in constructing these maps.

The quality ratings for cropland assume dryland farming and are based principally on the estimated production of small grains, primarily hard spring wheat; the rating is the weighted average for the various soils in the area. Average or typical crop management practices are assumed in the cropland ratings. These cropland ratings are an estimate of the comparative productivity of soils within a single county. They should not be used to compare soil quality between counties or from one part of the state to another.

The suitability of soils for irrigation takes into account the soil types and topography. Generally, only those soils consisting of coarser grained materials providing adequate drainage are considered as having potential for irrigation in this study. Soils consisting essentially of till, such as the Williams type, have been excluded, but it is possible that some of these may be irrigated successfully, providing that proper water management is practiced and that satisfactory water is available.

Water of irrigation quality is not generally available from groundwater sources in the study area. Two indices are used to show the suitability of water for irrigation. They are the SAR (sodium-adsorption ratio) and specific conductance. The SAR is related to the sodium hazard, and the specific conductance is related to the salinity hazard. Much of the groundwater in the area is of marginal quality and should be used with caution; some water is unsuitable for irrigation. Any water that is to be used for irrigation purposes must be analyzed to determine its suitability and compatability with the soil that is to be irrigated. High sodium and high salinity hazard waters may be used successfully with ideal soil conditions and drainage in conjunction with proper water management.

GROUNDWATER POLLUTION HAZARD

Aquifers in this section are grouped according to their susceptibility to surface pollution. Four classes of groundwater pollution susceptibility are shown on plate 5.

Areas with a low probability of pollution are unmarked. They include areas where bedrock consisting of a sand or lignite serving as an aquifer is buried sufficiently beneath till so that pollution, except by improperly cased wells, is improbable.

Areas with high permeability and high topographic position, but not considered to be major aquifers, are shown as having a moderate pollution hazard. They may serve as part of a recharge area for a major aquifer or they may be closely associated with local aquifers being used for stock watering or domestic purposes.

Areas in which aquifers are overlain by a few feet to a few tens of feet of impermeable or low permeability material are shown to have a moderate to high pollution hazard.

Areas in which highly permeable material such as sand and gravel may directly overlie or be a part of a major aquifer are shown as having a high pollution hazard.

Throughout the three-county area there exist aquifers that serve as a water source for domestic and stock watering purposes. The improper disposal of waste and the improper casing of water supply wells will nearly everywhere result in pollution. The analysis of water samples from a number of wells located in barnyards or feed lots indicate a high incidence of pollution as indicated by high nitrates. This is usually the result of improperly cased wells or old abandoned wells that serve as conduits for barnyard wastes to the aquifer.

POLLUTION HAZARD IN THE WILLISTON AREA

A more detailed study was made of the pollution potential in the Williston area because of the higher population density, proximity to known major aquifers, and the greater availability of well data.

Plate 6 is a surface geologic map of the Williston area illustrating the materials found on the surface. Plate 7 illustrates the known major aquifers in the area. Plate 8, consisting of stratigraphic sections, illustrates the complex and porous nature of the sediments underlying the area.

On plate 6, the oldest sediments shown are the Tertiary Fort Union beds (orange, Tfu). The Fort Union Group is represented here by the Sentinel Butte Formation consisting of sand, silt, clay, and lignite. The lignite beds are water-bearing and are used locally as a water source.

The Quaternary Epoch is represented by the Wiota Gravel and by Pleistocene glacial and post-glacial deposits. The Wiota Gravel (violet, Qw) is exposed in SEsec 19 and SWsec 20, T154, R101 and consists of brown quartzitic gravels deposited along the channel and terraces of the pre-glacial Yellowstone River, which flowed along the present course of the Missouri and Little Muddy Rivers. The gravel may be 6 to 18 feet thick, and it is overlain by glacial drift in many areas.

Glacial drift is represented by sheet moraine (green, S) and outwash (yellow, O or OT) on the outwash terraces.

The sheet moraine consists mostly of till, a heterogeneous mixture of clay, silt, sand, gravel, and boulders. It is thickest along the pre-glacial valleys. Outwash consists of sand and gravel deposited along and within glacial melt-water channels by the action of relatively fast-flowing streams.

The floodplain alluvium (gray, A) consists of silt, sand, and gravel. It was deposited by the Missouri and Little Muddy Rivers.

The pollution hazard for the Tertiary Fort Union aquifers will only be touched on, inasmuch as in the Williston area they consist almost entirely of lignite beds buried at considerable depths below the glacial and post-glacial materials. The lignite beds are exposed on the valley walls east of the city. A possibility of pollution of these aquifers does exist if they contact contaminated water-bearing silt, sand, or gravel. Contamination is also possible from improperly cased wells that may pass through a contaminated zone before penetrating the aquifer, or allowing surface pollutants such as barnyard waste to enter the well bore.

Generally, the pollution hazard is greatest in areas labled O, OT, and A on plate 6. The alluvial floodplain and outwash areas consist of highly permeable materials. This high permeability results in high groundwater availability, but it is also the reason for the high pollution hazard.

Plate 7 shows that a major aquifer underlies the entire city of Williston and the immediate surrounding area. This aquifer can yield from 50 to over 500 gallons of water per minute.

Till has a much lower permeability than alluvium or outwash due to its clay content. The permeability varies with sand and gravel content, and it may contain stringers of sand or gravel (pl. 8), which may be water-bearing or act as conduits to water-bearing units.

Cross-section C-C' illustrates the possibility of porosity zones within the till or sheet moraine unit. Well 154-101-2 cdd contains a three-foot gravel unit near the surface. This section also shows how stratigraphy changes from west to east across the Little Muddy valley. With the exception of the gravel unit in the above-mentioned well, the materials to a depth of 68 feet are largely till and silt with relatively low permeability. The log of well 154-101-12 bbb shows the stratigraphy becoming more complex with porous and permeable beds occurring at increasingly shallow depths (pl. 8). Plate 6 shows that this area is located near the boundary of the sheet moraine (till) and outwash materials. The potential for pollution increases as the sheet moraine thins and the till and sand and gravel units become interbedded.

All cross sections illustrate the complexity of the stratigraphy. Many units with limited extent are difficult to correlate over any distance. This is common in any area with floodplain alluvium and outwash materials, because particle size of the material is highly variable.

The city of Williston and the immediate surrounding area are situated on highly porous and permeable materials which constitute a major aquifer. Consequently, the hazard for pollution of groundwater is high from septic tanks, cesspools, and sewage lagoons, particularly in areas colored yellow and gray on plate 6. In areas colored green, the potential is less. Due to the possible presence of buried Quaternary gravels and outwash deposits within the green area, each site should be evaluated prior to the construction of any waste-disposal facility. In all areas, site-specific evaluation should be carried out prior to construction of any waste-disposal facility. It is also important that all wells be properly cased to prevent contamination of aquifers.

BIBLIOGRAPHY

Anderson, S. B., and Hansen, D. E., 1957, Halite deposits in North Dakota: N. Dak. Geol. Survey Rept. Inv. 28.

Armstrong, C. A., 1965, Geology and ground water resources of Divide County, North Dakota, part II, ground water basic data: N. Dak. Geol. Survey Bull. 45, 112 p.

Armstrong, C. A., 1967, Geology and ground water resources of Divide County, North Dakota, part III, ground water resources: N. Dak. Geol. Survey Bull. 45, 56 p.

Armstrong, C. A., 1967, Geology and ground water resources of Williams County, North Dakota, part II, ground water basic data: N. Dak. Geol. Survey Bull. 48, 132 p.

Armstrong, C. A., 1969, Geology and ground water resources of Williams County, North Dakota, part III, hydrology: N. Dak. Geol. Survey Bull. 48, 82 p.

Brant, R. A., 1953, Lignite resources of North Dakota: U.S. Geol. Survey Circ. 226, 78 p.

Carlson, C. G. and Anderson, S. B., 1965, Sedimentary and tectonic history of North Dakota part of Williston basin: Am. Assoc. Petroleum Geologists Bull. v. 49, no. 11, p. 1833-1846.

Crosby, E. J., 1973, Sodium sulfate in North Dakota: N. Dak. Geol. Survey Bull. 63, p. 151-154.

Fowkes, W. W. and Frost, C. M., 1960, Leonardite: a lignite byproduct: U.S. Bur. Mines Rept. Inv. 5611, 12 p.

Freers, T. F., 1970, Geology and ground water resources of Williams County, North Dakota, part I, geology: N. Dak. Geol. Survey Bull. 48, 55 p.

Hansen, D. E., 1967, Geology and ground water resources of Divide County, North Dakota, part I, geology: N. Dak. Geol. Survey Bull. 45, 90 p.

Landis, E. R., 1973, Coal *in* Landis, E. R. (ed.), Mineral and Water Resources of North Dakota: N. Dak. Geol. Survey Bull. 63, p. 45-52.

Larrabee, D. M., 1947, Preliminary map of construction materials in the south half of Williams County, North Dakota: U.S. Geol. Survey Open File Report.

North Dakota Geological Survey, 1976, Official Oil in North Dakota, Second Half 1975.

Patterson, D. D., Johnsgard, G. A., Sweeney, M. D., and Omodt, H. W., 1968, Soil survey report county general soils maps North Dakota: Agri. Ex. Station, Bull. 473, North Dakota State University, 150 p.

Smith, J. B., Pollard, B. C., and Knox, C. C., 1973, Strippable lignite reserves in North Dakota *in* Landis, E. R. (ed.), Mineral and Water Resources of North Dakota: N. Dak. Geol. Survey Bull. 63, p. 52-57.