NORTH DAKOTA GEOLOGICAL SURVEY

E. A. Noble, State Geologist

BULLETIN 49

NORTH DAKOTA STATE WATER COMMISSION

Milo W. Hoisveen, State Engineer

COUNTY GROUND WATER STUDIES 10

GEOLOGY AND GROUND WATER RESOURCES

of

TRAILL COUNTY

Part 3 – GROUND WATER RESOURCES

by

H. M. Jensen and R. L. Klausing

Geological Survey

United States Department of the Interior

Prepared by the North Dakota Geological Survey
In cooperation with the North Dakota State
Water Commission, the United States Geological Survey,
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This is one of a series of county reports published cooperatively by the North Dakota Geological Survey and the North Dakota State Water Commission. The reports are in three parts; Part I describes the geology, Part II presents ground water basic data, and Part III describes the ground water resources. Parts I and II have been published previously.

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GEOLOGY AND GROUND WATER RESOURCES OF

TRAILL COUNTY, NORTH DAKOTA

PART 3 - GROUND WATER RESOURCES

By H. M. Jensen and R. L. Klausing

ABSTRACT

Ground water in Traill County is obtainable from sand and gravel deposits associated with the glacial drift of Pleistocene age and from sand and (or) sandstone beds in the Dakota Group of Late Cretaceous age.

The principal aquifers are the Dakota, Hillsboro, Galesburg, Elk Valley, and Belmont aquifers. The Dakota aquifer, which is the largest and most productive aquifer in the county, yields more than a million gallons of highly mineralized water per day. The Hillsboro and Galesburg aquifers offer the most potential for future development. Individual well yields from the Hillsboro and Galesburg aquifers may be as much as 500 and 250 gallons per minute, respectively.

Aquifers of less importance are present in the glacial drift, but they are relatively thin and of small areal extent. These aquifers yield adequate supplies of water for average domestic and livestock uses.

INTRODUCTION

Purpose and Scope

The purpose of the investigation was to determine the occurrence, availability, and quality of ground water in Traill County (fig. 1). This report describes the location and extent of the various sources of ground water in the county, describes the chemical quality of the water available from each source, and evaluates the potential of each ground-water source for future development.

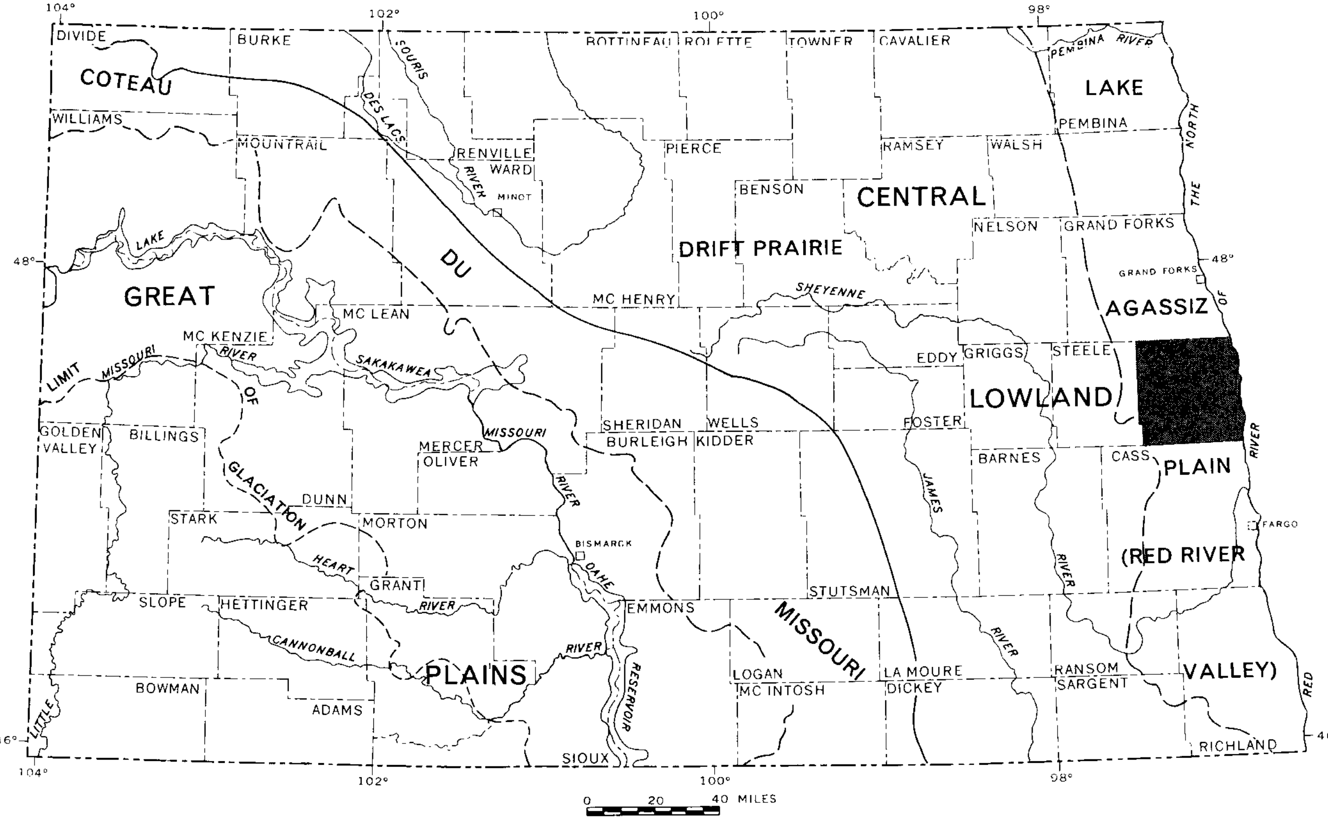

FIGURE 1. Physiographic divisions in North Dakota and location of report area.

The investigation was made cooperatively by the U.S. Geological Survey, North Dakota State Water Commission, North Dakota Geological Survey, and Traill County Water Management District. The results of the investigation are presented in three separate parts of the bulletin series of the North Dakota Geological Survey and the county ground-water studies series of the North Dakota State Water Commission. Part 1 (Bluemle, 1967) is an interpretive report describing the geology; Part 2 (Jensen, 1967) is a compilation of the ground-water basic data; and Part 3 (this report) is an interpretive report describing the ground-water resources.

The geologic nomenclature used in this report is that of the North Dakota Geological Survey and, in some instances, differs from that of the U.S. Geological Survey.

Location and Extent

Traill County, in east-central North Dakota, is bordered on the east by the Red River of the North, which forms the boundary between North Dakota and Minnesota; on the north by Grand Forks County; on the west by Steele County; and on the south by Cass County (fig. 1). The county has an area of approximately 861 square miles and the population, according to the 1960 census (U.S. Bureau of the Census, 1960), was 10,583.

Topography, Drainage, and Climate

The county is in the western lake section of the Central Lowland physiographic province of Fenneman (1946) and lies almost wholly in the Red River valley (fig. 1). The southwestern corner of the county is in the Drift Prairie as defined by Simpson (1929, p. 5). The boundary of the Drift Prairie and the Red River valley is generally marked by an escarpment; however, in Traill County, the escarpment is very subdued and is hardly noticeable.

The Red River valley is a broad, flat, fertile plain formerly occupied by glacial Lake Agassiz. The principal landforms within the valley are the deltas and beaches. The Elk Valley delta, a prominent landform in the northwestern part of Traill County, and the Galesburg delta (Bluemle, 1967, p. 7), a prominent landform in the southwestern part of the county, rise as much as 50 feet above the lake plain. Beaches several feet in height cross the deltas and lake plain in a general north-south direction.

The Red River of the North is the master stream that drains the County, and the Goose and Elm Rivers and Buffalo Coulee are major tributaries (pl. 1, in pocket). The channels of the tributaries are deeply incised in the western part of the county, but are rather shallow near the Red River. Elsewhere, drainage is immature and temporary ponds and sloughs collect the spring snowmelt and runoff following heavy rains.

The climate of the area is subhumid. The average annual precipitation recorded by the U.S. Weather Bureau at Hillsboro is 20.05 inches. Recorded temperatures range from 40°F below to 104°F above zero. The mean annual temperature is 40.9°F (U.S. Weather Bureau, 1937-67).

Well-Numbering System

Wells, springs, and test holes referred to in this report are numbered according to a system based on their location in the public land classification of the United States Bureau of Land Management. The system is illustrated in figure 2. The first numeral denotes the township north of a base line, the second numeral denotes the range west of the fifth principal meridian, and the third numeral denotes the section in which the well is located. The letters a, b, c, and d designate, respectively, the northeast, northwest, southwest, and southeast quarter section, quarter-quarter section, and quarter-quarter-quarter section (10-acre tract). For example, well 148-53-15daa is in the NE¼NE¼SE¼ sec. 15, T. 148 N., R. 53 W. Consecutive terminal numerals are added if more than one well is recorded in a 10-acre tract.

Previous Investigations and Acknowledgments

The first major study of the ground-water resources of Traill County was made by Simpson (1929, p. 240-241), who reported more than 400 flowing wells tapping the Dakota aquifer and shallow gravel

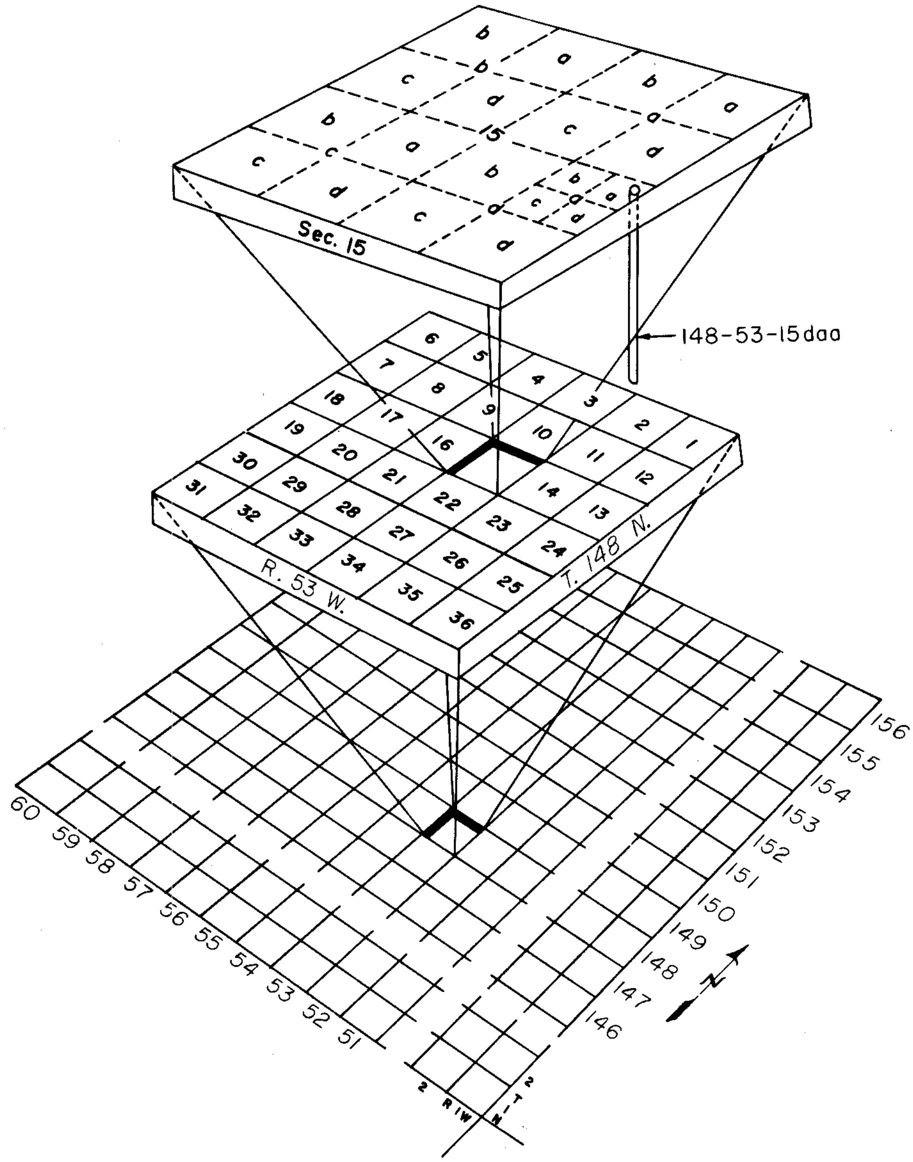

FIGURE 2. System of numbering wells, springs, and test holes.

deposits in the glacial drift. Dennis (1947), Dennis and Akin (1950), Adolphson (1962), Jensen (1962), Jensen and Bradley (1963), Beeks (1967), and Naplin (written commun., 1969) presented information about the occurrence of ground water in the vicinities of several municipalities in Traill County.

Information on the chemical quality of the ground water was given by Abbott and Voedisch (1938), and Robinove, Langford, and Brookhart (1958).

The cooperation of the rural residents of the county, municipal and county officials, and well drillers that supplied data pertinent to the wells in the county is gratefully acknowledged. Mr. Ralph Byars, utilities superintendent at Hillsboro, furnished pumpage data for the Hillsboro municipal wells. Alan Kahil, former geologist with the North Dakota State Water Commission, logged most of the test holes drilled as part of this investigation.

PRINCIPLES OF GROUND-WATER OCCURRENCE

The ultimate source of all ground water is precipitation. After the precipitation falls on the earth's surface, part is returned to the atmosphere by evaporation, some runs off to the streams, and the remainder sinks into the ground. Much of the water that sinks into the ground is held temporarily in the soil and is returned to the atmosphere either by evaporation or by transpiration. The water that infiltrates downward to a saturated zone (zone of saturation) becomes ground water.

Ground water moves under the influence of gravity from areas where water enters the ground (recharge) to areas where water leaves the aquifer (discharge). Ground-water movement is generally very slow; it may be only a few feet per year. This rate of movement is governed by the permeability of the deposits through which the water moves and by the hydraulic gradient or slope of the water table or piezometric surface.

Definitions

The upper surface of the zone of saturation is called the water table. This surface is irregular and is controlled by the topography, geology, and hydrology of the area. Water-table conditions refer to a ground-water environment that is not confined by overlying impermeable beds, and the water is free to move in response to gravity. If an aquifer is overlain by relatively impermeable beds, the water is confined under pressure exerted by water at higher elevations and by the confining beds and the water level will rise above the level at which it is first encountered; wells supplied from this type of aquifer are said to be artesian.

Porosity is the ratio of the volume of the open or pore space in a rock to its total volume and is an index of the storage capacity of the material.

Permeability refers to the ease with which a fluid will pass through porous material, and is determined by the size and shape of the pore spaces in the rock and their interconnection. Gravel, well-sorted medium or coarse sand, and fractured lignite beds generally are highly permeable. Well-cemented deposits and fine-grained materials such as silt, clay, and shale usually have low permeability, and may act as barriers that impede the movement of water into or out of more permeable rocks.

The coefficient of permeability is the rate of flow in gallons per day through 1 square foot of the aquifer under a unit hydraulic gradient. Thus, the field coefficient of permeability is equal to the transmissivity divided by the thickness of the aquifer. The field coefficient of permeability is measured at the prevailing water temperature.

Transmissivity is a measure of the rate of flow through porous material and is expressed as the number of gallons of water that will move in 1 day under a unit hydraulic gradient (1 foot per foot) through a vertical strip of the aquifer 1-foot wide extending the full saturated height of the aquifer.

The storage coefficient is the volume of water released from or taken into storage per unit of surface area of the aquifer per unit change in the component of head normal to that surface. Under artesian or confined conditions, the storage coefficient is equal to a very small fraction of the porosity. However, under water-table or unconfined conditions, the storage coefficient is much larger and is practically equal to the specific yield, which is the ratio of the volume of water released by gravity drainage to the volume of the material drained. The specific yield may be as much as half the total porosity.

The water level in a well fluctuates in response to recharge to and discharge from the aquifer. Atmospheric pressure changes and land surface loadings also cause minor water-level fluctuations in confined aquifers. The static level is the water level in the well when it is not being pumped. When water is withdrawn from a well, the water level near the well is lowered; the water-level surface around the well resembles a cone called the cone of depression. The amount of water-level drawdown, or the difference between the static and pumping levels, is controlled by the hydraulic properties of the aquifer, the physical characteristics of the well, and the rate and duration of pumping. During constant and uniform discharge from a well, the water level declines rapidly at first and then continues to lower at a decreasing rate as the cone of depression expands.

Specific capacity, which is a measure of well performance, is determined by dividing the rate of pumping, in gallons per minute, by the drawdown, in feet. Specific capacity is expressed as gallons per minute per foot of drawdown.

The water level in a pumping well must decline in order that water may flow from the aquifer to the well. The amount of water-level decline may become serious if (1) it causes water of undesirable quality to move into the aquifer, (2) the yield of the well decreases because of interference from other wells or from aquifer boundaries, (3) the pumping lift increases to the point where pumping becomes uneconomical, or (4) the water level declines below the top of the screen. When pumping is stopped, the water level rises in the well and in its vicinity at a decreasing rate until the water level again approaches the static level.

Under natural conditions, over a long period of time, the rate of discharge from an aquifer approximately equals the rate of recharge.

Withdrawal of water from an aquifer eventually causes one or a combination of the following: (1) a decrease in the rate of natural discharge, (2) an increase in the rate of recharge, or (3) a reduction in the volume of water in storage. The maximum rate of ground-water withdrawal that can be maintained indefinitely is related directly to the rate of recharge. However, recharge is regulated largely by climate and geologic controls, and may not be evaluated quantitatively without large amounts of data.

All natural water contains dissolved solids. Rainfall begins to dissolve mineral matter as it falls to the earth and continues to dissolve it as the water infiltrates through the earth. The amount and kind of mineral matter dissolved depends upon the solubility and types of rocks or other mineral matter encountered, the length of time the water is in contact with them, and the amount of carbon dioxide and soil acids in the water. Water that has been underground a long time, or has traveled a long distance from the recharge area, generally is more highly mineralized than water that has been in transit for only a short time and is withdrawn near the recharge area. Ground water usually contains more dissolved minerals than water from streams.

The dissolved mineral constituents in water are usually reported in parts per million (ppm) or grains per U.S. gallon. A part per million is a unit weight of a constituent in a million unit weights of water. Parts per million can be converted to grains per gallon by dividing the parts per million by 17.12. The unit chemical combining weight of a constituent in a million weights of water is reported as equivalents per million (epm). These units are usually not reported, but are necessary to calculate percent sodium, the sodium-adsorption ratio (SAR), or to check the accuracy of a chemical analysis.

The suitability of water for various uses is determined largely by the kind and amount of dissolved mineral matter. The chemical properties and constituents most likely to be of concern to residents of Traill County are: (1) dissolved solids and the related specific conductance, (2) sodium-adsorption ratio, (3) hardness, (4) iron, (5) sulfate, (6) nitrate, and (7) fluoride. The relative importance of the above properties and constituents of water depends primarily on the use of the water. For example, hardness has very little effect on the suitability of water for drinking, but it can make water undesirable for laundry use. Additional information may be found in "Drinking Water Standards" published by the U.S. Public Health Service (1962).

Table 1, modified from Durfor and Becker (1964, table 2), shows the major constituents in water, their major sources, and their effects upon usability. Most, if not all, of the minerals shown in the major source column are present in the glacial drift or in the bedrock directly underlying the drift in Traill County.

The chemical analyses of ground water in Traill County are listed in the appendix and are summarized in figure 3.

TABLE 1.–Major chemical constituents in water–their sources, concentrations, and effects upon usability

(Concentrations are in parts per million)

(Modified after Durfor and Becker, 1964, table 2)

Constituents	Major source	Effects upon usability	U. S. Public Health Service recommended limits for drinking water[1]
Silica (SiO_2)	Feldspars, ferromagnesium, and clay minerals.	In presence of calcium and magnesium, silica forms a scale in boilers and on steam turbines that retards heat transfer.	
Iron (Fe)	Natural sources: Amphiboles, ferromagnesium minerals, ferrous and ferric sulfides, oxides, and carbonates, and clay minerals. Man-made sources: well casings, pump parts, storage tanks.	If more than 0.1 ppm iron is present, it will precipitate when exposed to air; causing turbidity, staining plumbing fixtures, laundry and cooking utensils, and imparting tastes and colors to food and drinks. More than 0.2 ppm is objectionable for most industrial uses.	0.3 ppm
Calcium (Ca)	Amphiboles, feldspars, gypsum, pyroxenes, calcite, aragonite, dolomite, and clay minerals.	Calcium and magnesium combine with bicarbonate, carbonate, sulfate, and silica to form scale in heating equipment.	
Magnesium (Mg)	Amphiboles, olivine, pyroxenes, dolomite, magnesite, and clay minerals.	Calcium and magnesium retard the suds-forming action of soap. High concentrations of magnesium have a laxative ef-	
Sodium (Na)	Feldspars, clay minerals, and evaporites.	More than 50 ppm sodium and potassium with suspended matter causes foaming, which accelerates scale formation and corrosion in boilers.	
Potassium (K)	Feldspars, feldspathoids, some micas, and clay minerals.		
Boron (B)	Tourmaline, biotite, and amphiboles.	Many plants are damaged by concentrations of 2.0 ppm.	
Bicarbonate (HCO_3)	Limestone and dolomite	Upon heating, bicarbonate is changed to steam, carbonate, and carbon dioxide.	
Carbonate (CO_3)		Carbonate combines with alkaline earth (principally clacium and magnesium) to form scale.	
Sulfate (SO_4)	Gypsum, anhydrite, and oxidation of sulfide minerals.	Combines with calcium to form scale. More than 500 ppm tastes bitter and may be a laxative.	250 ppm
Chloride (Cl)	Halite and sylvite.	In excess of 250 ppm may impart salty taste, greatly in excess may cause physiological distress. Food processing industries usually require less than 250 ppm.	250 ppm
Fluoride (F)	Amphiboles, apatite, fluorite, and mica.	Optimum concentration in drinking water has a beneficial effect on the structure and resistance to decay of children's teeth. Concentrations in excess of optimum may cause mottling of children's teeth.	Recommended limits depend on average of maximum daily temperature. Limits range from 0.6 ppm at 90.5°F to 1.7 ppm at 50°F.
Nitrate (NO_3)	Nitrogenous fertilizers, animal excrement, legumes, and plant debris.	More than 100 ppm may cause a bitter taste and may cause physiological distress. Concentrations greatly in excess of 45 ppm have been reported to cause methemoglobinemia in infants.	45 ppm
Dissolved solids	Anything that is soluble.	More than 500 ppm is not desirable if better water is available. Less than 300 ppm is desirable for some manufacturing processes. Excessive dissolved solids restrict the use of water for irrigation.	500 ppm

[1]U. S. Public Health Service, 1962.

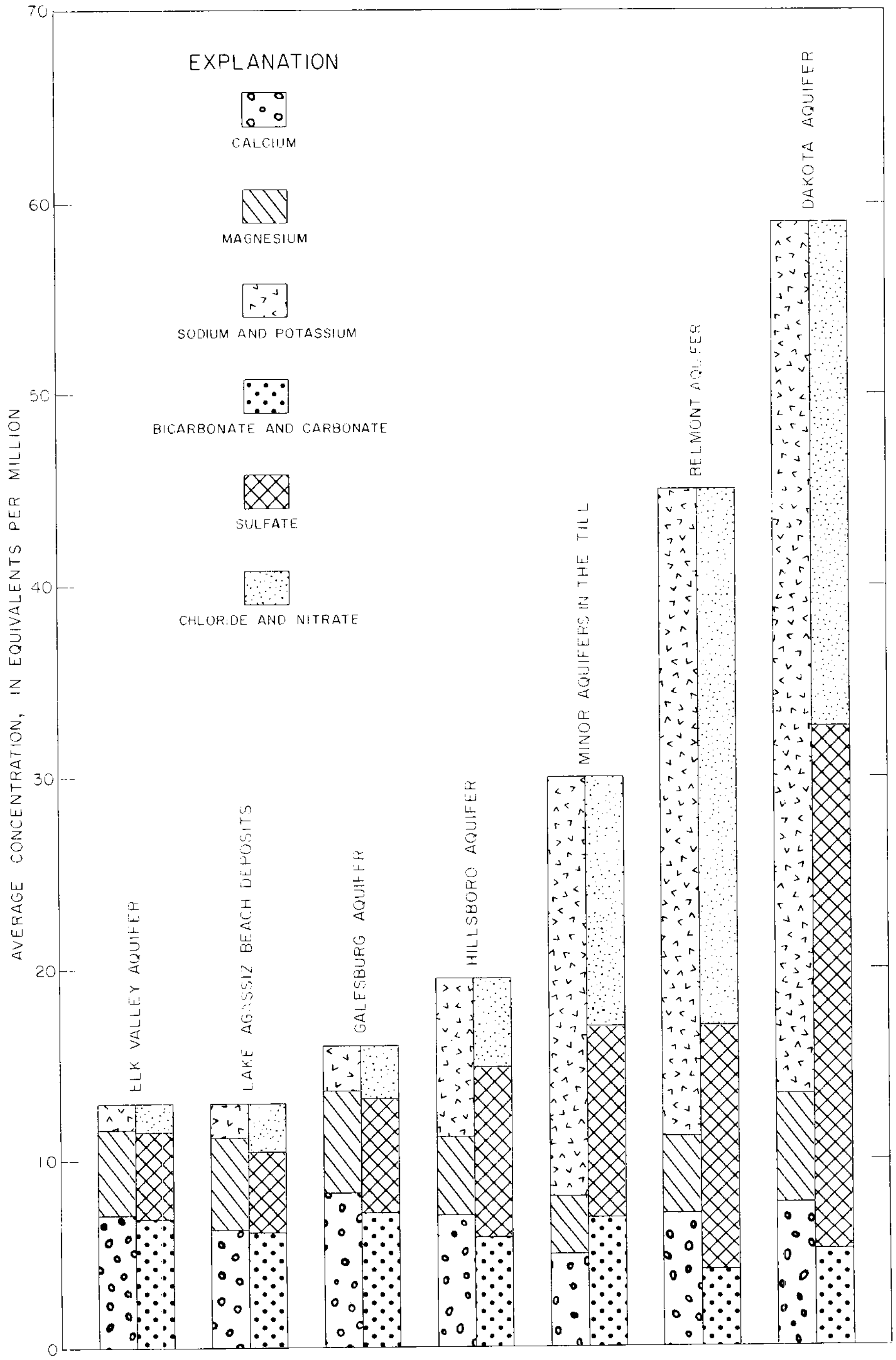

FIGURE 3. Major constituents in ground water in Traill County.

Dissolved Solids and Specific Conductance

The concentration of dissolved solids is a measure of the total mineralization of water. The dissolved-solids concentration is significant because it may limit the use of water for many purposes. In general, the suitability of water decreases with an increase in dissolved solids. The limits shown in table 1 for drinking water were originally set for common carriers in interstate commerce. Residents in areas where dissolved solids are as high as 2,000 ppm have consumed the water with no noticeable ill effects. Livestock has been known to survive on water containing 10,000 ppm. However, growth and reproduction of livestock may be affected by water containing more than 3,000 ppm of dissolved solids.

The specific conductance of water is a measure of the water's ability to conduct an electrical current; it is a function of the amount and kind of dissolved mineral matter. Specific conductance usually is reported in micromhos. An estimate of the total dissolved solids in parts per million can be obtained by multiplying specific conductance by 0.65; however, the conversion factor may range from 0.55 to 0.75, depending upon the type and amount of dissolved minerals.

Irrigation Indices

Two indices used to show the suitability of water for irrigation are SAR and specific conductance. SAR is related to the sodium hazard; the specific conductance is related to the salinity hazard. The hazards increase as the numerical values of these indices increase. Figure 4 shows the SAR versus the specific conductance indicated by analyses of water from major drift aquifers in Traill County. Most of the samples are in the low to medium range in sodium hazard, but in the high to very high range in salinity hazard. Thus, it appears that the water is of marginal quality for irrigation; however, high-sodium or high-salinity waters have been used successfully for selected crops where ideal soil conditions and drainage exist.

Another index used to evaluate irrigation water is the residual sodium carbonate (RSC). This quantity is determined by subtracting the equivalents per million of calcium and magnesium from the sum of equivalents per million of bicarbonate and carbonate. If the RSC is between 1.25 and 2.5 epm, the water is considered marginal for

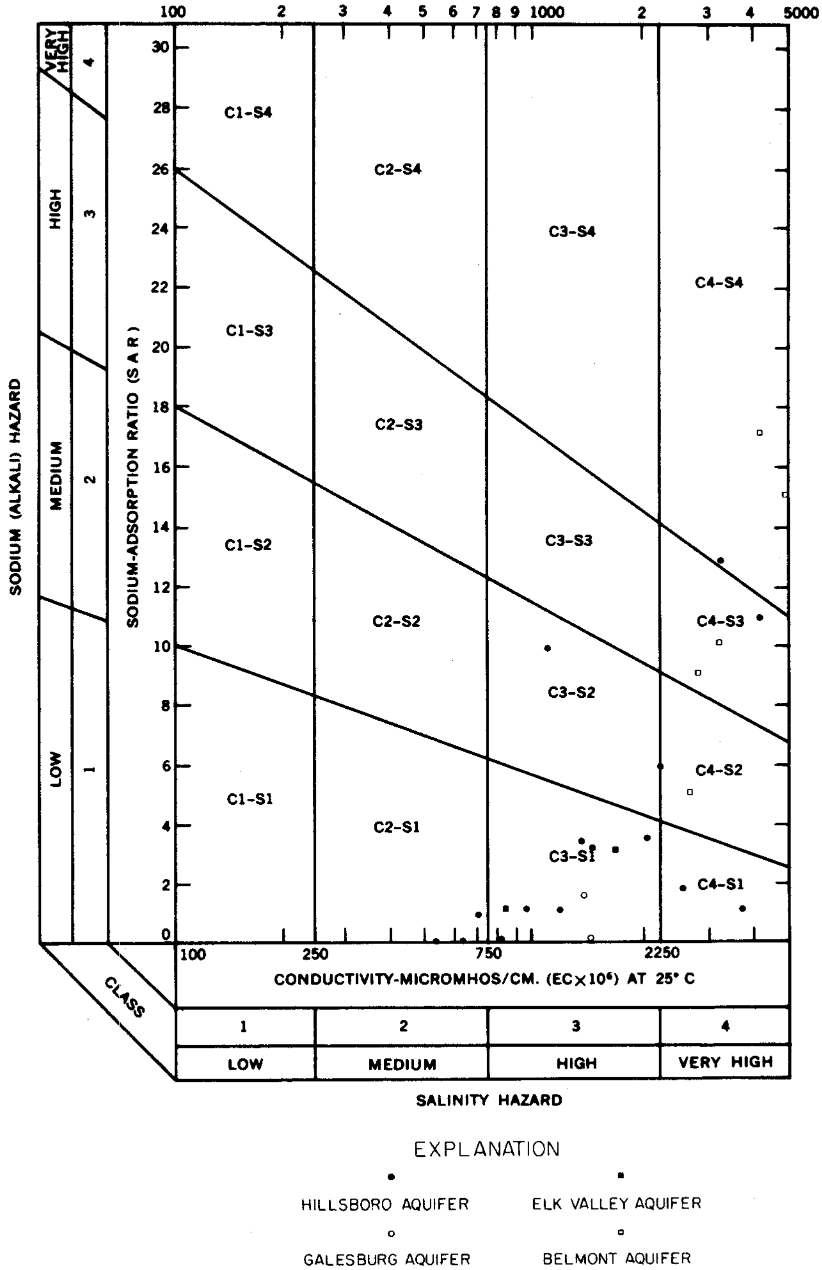

FIGURE 4. Classification of water samples for irrigation purposes.

irrigation. An RSC of more than 2.5 epm indicates that the water is not suitable for irrigation purposes. Generally the water in Traill County has an RSC index of less than 2.5 epm. Good management practices might make it possible to use successfully some of the marginal RSC water for irrigation. For further information, the reader is referred to "Diagnosis and Improvement of Saline and Alkali Soils" (U.S. Salinity Laboratory Staff, 1954).

Hardness

The hardness of water determines its usefulness for laundries and for some industries. The U.S. Geological Survey rates hardness as follows: water having a hardness of 0 to 60 ppm calcium carbonate is soft, between 61 and 120 ppm is moderately hard, between 121 and 180 ppm is hard, and more than 180 ppm is very hard. Hardness does not seriously interfere with the use of water for most purposes, but it does increase the consumption of soap. Its removal by a softening process can be profitable for domestic uses, for laundries, and for some industries. Water from the glacial drift in Traill County is generally very hard; whereas water from the Cretaceous rocks is generally soft.

PRINCIPAL AQUIFERS IN TRAILL COUNTY

The aquifers in Traill County are divided into two groups--those associated with the bedrock formations and those associated with the drift. The locations of the major aquifers and their estimated yields are shown on plate 1.

Ground Water in the Bedrock

Of the bedrock units underlying Traill County, only the sand and (or) sandstone beds of the Dakota Group of Cretaceous age (Bluemle, 1967, p. 5) appear to be of importance as sources of ground water. These water-bearing beds are herein collectively referred to as the Dakota aquifer.

Dakota aquifer

The Dakota aquifer underlies practically all of Traill County. The depth to the aquifer generally ranges from about 250 feet to more than 400 feet. Drillers' logs (Laird and others, 1952, p. 104-126) and test-hole logs (Dennis and Akin, 1950, p. 43-44; Adolphson, 1962, table 2; Jensen, 1967, table 3; and C. Naplin, written commun., 1969) show that the Dakota aquifer consists of interbedded and (or) interlensed silt, siltstone, shale, sand, and sandstone. The water-bearing deposits consist predominantly of fine to coarse sand. Individual sand beds are as much as 55 feet thick (Laird and others, 1952, p. 107) and aggregate thicknesses are as much as 62 feet (Adolphson, 1962, p. 14).

Approximately 50 percent of the wells tapping the Dakota aquifer in Traill County flow, and most of these are in the central and western parts of the county. A few of the wells tapping the aquifer in the eastern part of the county flow; however, in most wells the water level is reported to range from 10 to 60 feet below land surface.

Most of the flowing wells are flowing at rates of less than 10 gpm, (gallons per minute) but a few flows are in the 10 to 50 gpm range (Jensen, 1967, table 1). The total discharge from wells obtaining water from the Dakota aquifer is estimated to be about 1,100,000 gpd (gallons per day), or about 1,200 acre-feet per year. Most of the water is discharged by 212 flowing wells in the area west of R. 49. The reported flow from 74 of the 212 wells totaled about 250 gpm. Assuming that the total unreported flow of the remaining wells is a proportional amount, the discharge for all wells is about 700 gpm, or about a million gallons per day. There are about 200 Dakota wells that do not flow, and it is estimated that 100,000 gpd is pumped from these nonflowing wells.

Dennis and Akin (1950, p. 29) computed the hydraulic properties of the Dakota aquifer from a test on the new creamery well at Portland. The transmissivity and storage coefficients were 16,100 gpd per foot and 0.0004, respectively. The specific capacity of the well after 1 day of pumping was estimated to be 2.5 gpm per foot of drawdown. Kelly (written commun., 1969) reported that the transmissivity of the Dakota aquifer in eastern Grand Forks County, which borders Traill County on the north, is 47,000 gpd per foot and the storage coefficient is 0.0002.

Water from the Dakota is highly mineralized and generally unsatisfactory for most purposes. The water is primarily a sodium sulfate type, although sodium chloride water is common in the eastern part of the area. Dissolved solids among 29 samples range from 1,990 to 5,710 ppm and average 3,790 ppm. Sulfate ranges from 355 to 3,220 ppm and averages 1,320 ppm, and chloride ranges from 84 to 1,720 ppm and averages 916 ppm. Concentrations of the above constituents, as well as iron and fluoride, exceed recommended standards established by the U.S. Public Health Service (1962). Water from the Dakota aquifer is used chiefly for rural domestic and livestock purposes, but some is used commercially for washing potatoes at Hatton. The water is unsuitable for irrigation purposes because it is toxic to crops.

The yield of wells tapping the Dakota aquifer may be expected to range from a few gallons per minute by natural flow to 100 gpm or more if pumped.

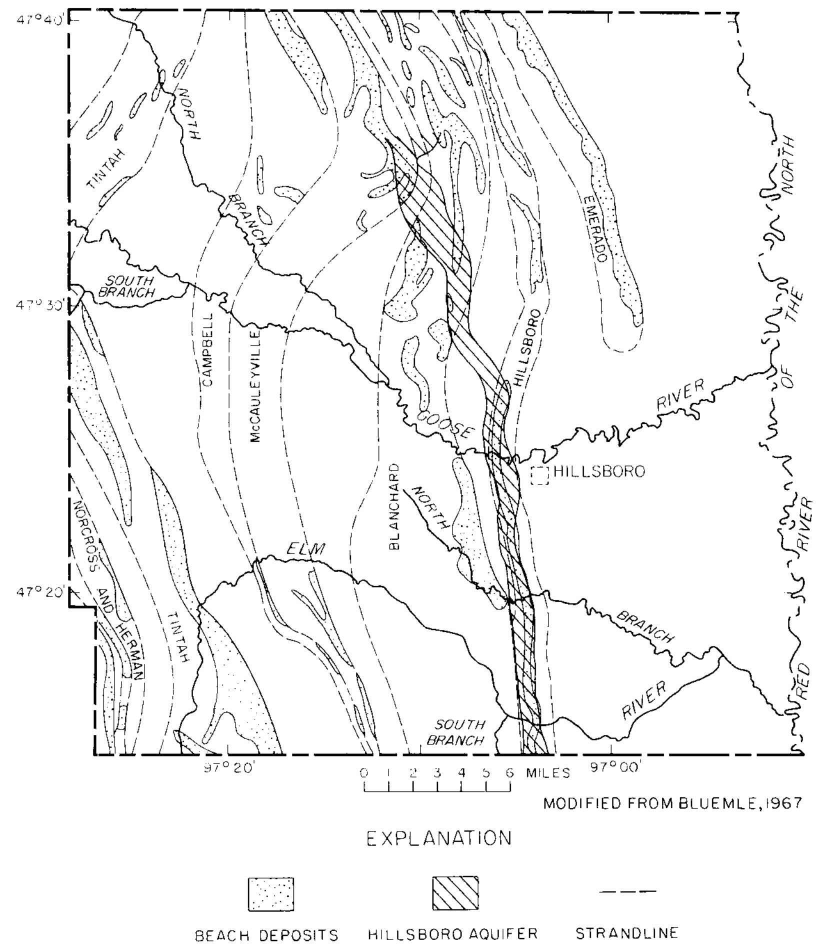

FIGURE 5. Location of Hillsboro aquifer, Lake Agassiz beaches, and strandlines.

Ground Water in the Glacial Drift

Thick deposits of drift, which were deposited from glaciers and in lakes during the Pleistocene epoch of glaciation, mantle the underlying bedrock formations. The drift, which in Traill County consists predominantly of till and lake sediments, ranges in thickness from 115 to 306 feet (Jensen, 1967, table 3). Deposits of sand and gravel associated with the drift contain the most important ground-water supplies, and about 70 percent of the wells inventoried obtain water from these sources. The larger and thicker of these deposits have been generally outlined by test drilling and the aquifers associated with these deposits have been named the Hillsboro, Galesburg, Elk Valley, and Belmont aquifers. These and a number of small, undifferentiated aquifers in the drift are described in the following sections.

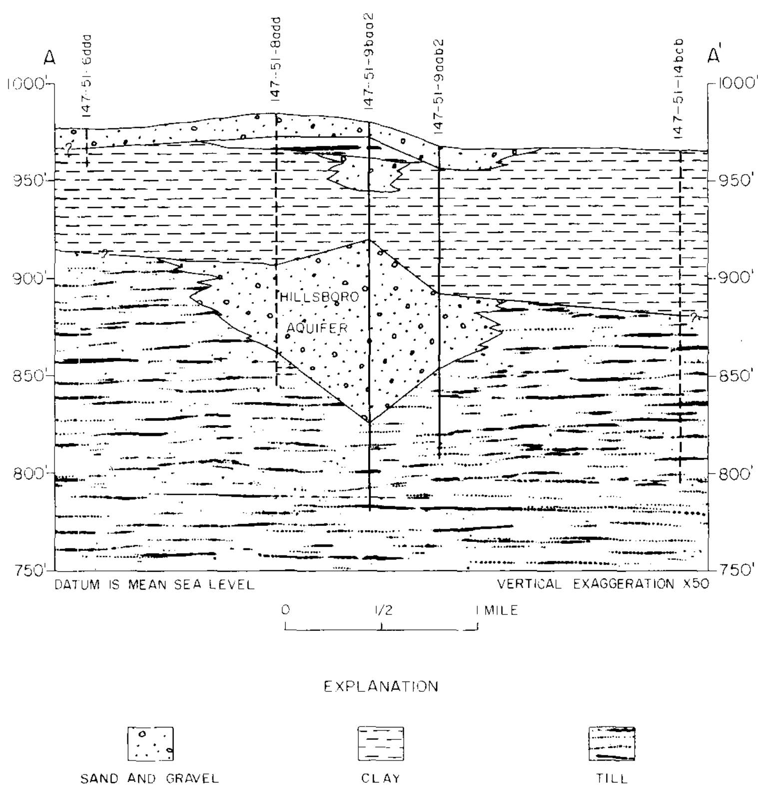

FIGURE 6. Geologic section in the Hillsboro aquifer.

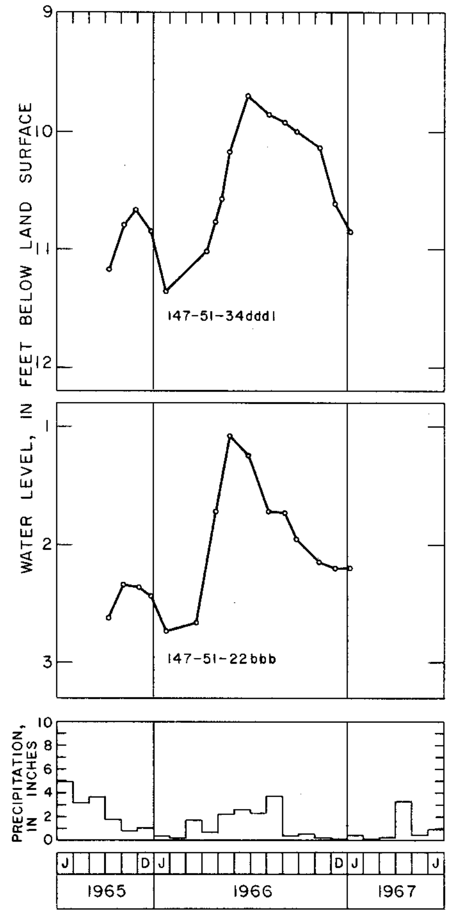

FIGURE 7. Water-level fluctuations in the Hillsboro aquifer, and precipitation at Hillsboro.

Hillsboro aquifer

The Hillsboro aquifer extends northward from the south edge of the county (144-51-36ddd) to about the southwestern part of T. 148 N., R. 51 W. near the northern edge of the county. Throughout much of its extent it underlies and appears to be related to the Hillsboro beach (fig. 5). However, near Hillsboro it deviates northwestward from the Hillsboro beach and extends beneath the Blanchard and

McCauleyville beaches. Test-drilling data indicate that the aquifer probably is associated with a narrow, sinuous deposit of sand and gravel that is at least 25 miles long and is 1 to 2 miles wide (fig. 6). The thickness of the aquifer differs considerably from place to place. In general, it ranges from about 50 to 100 feet in thickness; however, a maximum known thickness of 157 feet was penetrated in test hole 147-51-5aaa (C. Naplin, written commun., 1969). The water-bearing materials consist of very fine to coarse sand. In a few places gravel occurs in the lower part of the aquifer.

Data from a development test on well number 3 (Jensen, 1967, p. 23) in the Hillsboro well field show that the well was pumped at a rate of 250 gpm for 440 minutes. The water level in the well stabilized after 400 minutes of pumping. This suggests that equilibrium between discharge and rate of flow to the well had been reached. The specific capacity of the well after 400 minutes of pumping was 21 gpm per foot.

The Hillsboro aquifer is recharged by direct infiltration of rainfall and snowmelt, by seepage from intersecting stream channels during periods of high streamflow, and by underflow from adjacent ground-water bodies. Hydrographs (fig. 7) of water-level fluctuations in observation wells show yearly highs in May or June and lows in January-March.

Ground water is discharged from the aquifer by seepage along the valley walls of the Goose and Elm Rivers during periods of low streamflow and also by evapotranspiration in areas where the water table is close to land surface. Additional discharge is by pumping. Water pumped from the Hillsboro aquifer is used to meet domestic, livestock, municipal, and industrial needs. The municipal wells at Hillsboro are the only wells withdrawing large amounts of water from the aquifer. Estimates of pumpage from the Hillsboro well field show that about 72.8 million gallons of water are withdrawn annually (Ralph Byars, written commun., 1968).

The quality of water yielded by the Hillsboro aquifer changes with depth. Chemical analyses show that the upper part of the aquifer generally yields calcium bicarbonate type water and the lower part either calcium sulfate, sodium sulfate, or sodium bicarbonate type water. The calcium bicarbonate type waters probably represent recharge water recently derived from direct infiltration of precipitation or surface-water flow.

Dissolved solids among 16 samples analyzed range from 100 to 3,120 ppm and average 1,180 ppm (appendix). Sulfate ranges from 11 to 1,410 ppm and averages 449 ppm. The water is very hard and generally high in iron. Most of the water samples from the aquifer fall within the medium-to very high-salinity, low-sodium (C2-S1-C4-S1) classifications for irrigation water (fig. 4).

From the standpoint of areal distribution, thickness of the water-bearing materials, and the quality of water, the Hillsboro aquifer appears to have a greater potential for future development than do any other aquifers in the county. Depending upon the local thickness and permeability of the water-bearing materials, properly constructed wells tapping the aquifer probably would yield up to 500 gpm.

Galesburg aquifer

The Galesburg delta (Bluemle, 1967, p. 22) and associated offshore bar deposits of glacial Lake Agassiz cover an area of approximately 85 square miles in southwestern Traill County. However, permeable deposits thick enough to yield at least 10 gpm occupy only isolated segments of the area (pl. 1). The aquifers consist of very fine to fine sand and generally are less than 50 feet thick, except in the southern part where they may be thicker (fig. 8, section E-E').

The water-level fluctuations shown on figure 9 reflect, for the most part, seasonal variations in precipitation, water use, and evapotranspiration. The abrupt rise of the water level between the latter part of March and the end of April indicates recharge to the aquifer by infiltration of snowmelt and rainfall. This period of recharge commonly begins with the spring thaw and continues until June. The subsequent decline in the water level is caused by pumping, evapotranspiration, and decreased precipitation.

Analyses of three water samples indicate that the aquifer contains calcium bicarbonate and calcium sulfate type water. The water is very hard; the dissolved-solids contents are 1,060, 1,100, and 1,060 ppm and sulfate concentrations are 352, 361, and 153 ppm, respectively. The water is classified as C3-S1 for irrigation purposes.

At present there are no large developments in the aquifer. The relatively small amount of water pumped for domestic and livestock use has not had a noticeable effect on the regional water level in the aquifer.

In view of its large areal extent and substantial thickness, the Galesburg aquifer appears to have some potential for ground-water development, even though the permeability may be low. Although there are no data available regarding well yields, it seems probable that properly constructed wells at favorable locations in the aquifer could be pumped at rates up to 250 gpm.

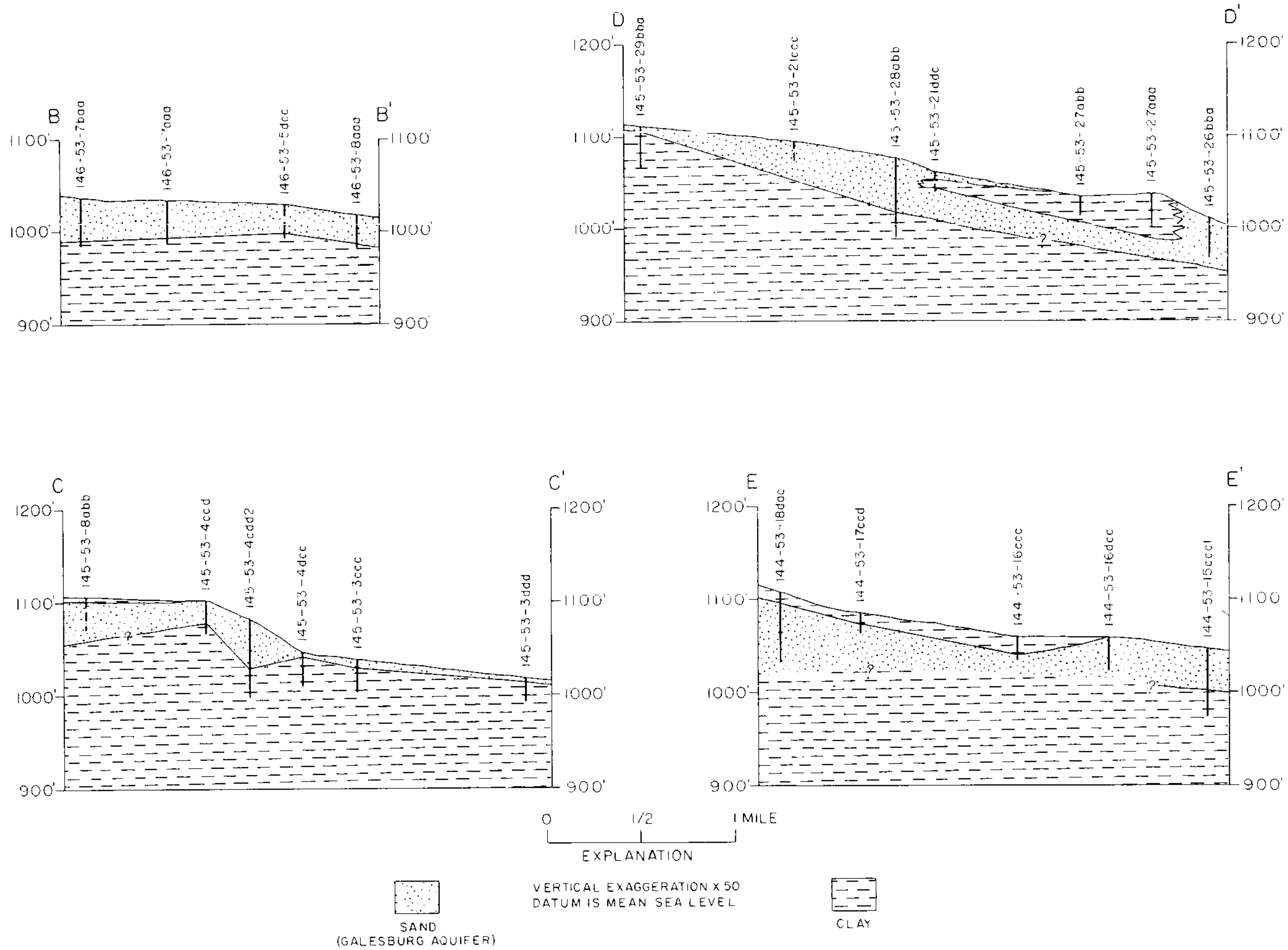

FIGURE 8. Geologic sections in the Galesburg aquifer.

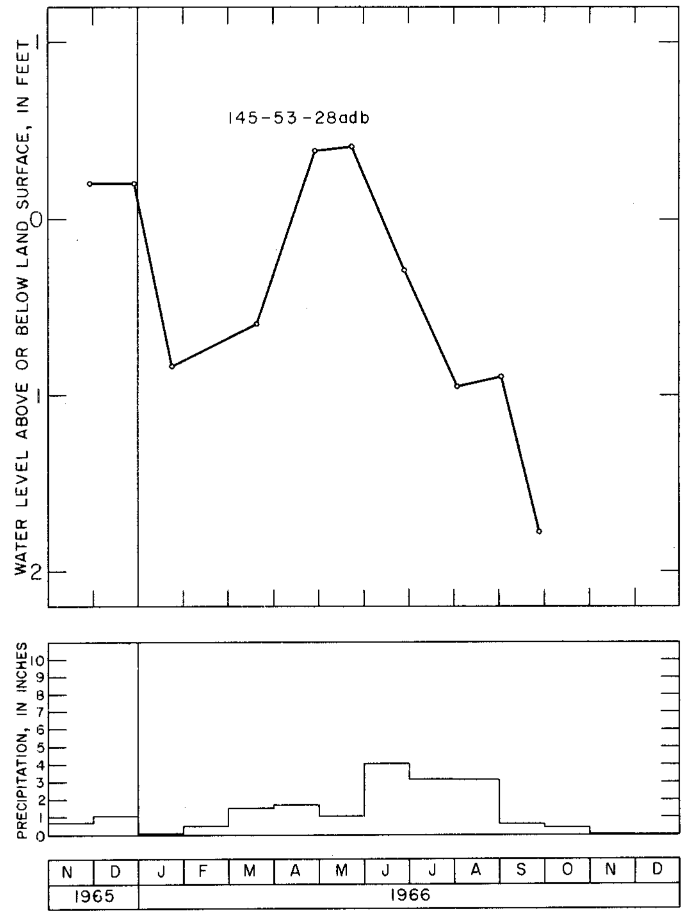

FIGURE 9. Water-level fluctuations in the Galesburg aquifer, and precipitation at Hillsboro.

Elk Valley aquifer

The Elk Valley delta of glacial Lake Agassiz occupies about 60 square miles in northwestern Traill County; however, only about one-fourth of this area (mainly in the northern part) is underlain by deposits permeable enough to yield at least 10 gpm (pl. 1). Test drilling shows that the delta deposits consist chiefly of clay and silt, but in places these deposits are interbedded with very fine to fine sand that may be as much as 65 feet thick (Adolphson, 1962, p. 16). That the Elk Valley aquifer has a low transmissivity is evidenced by a drawdown

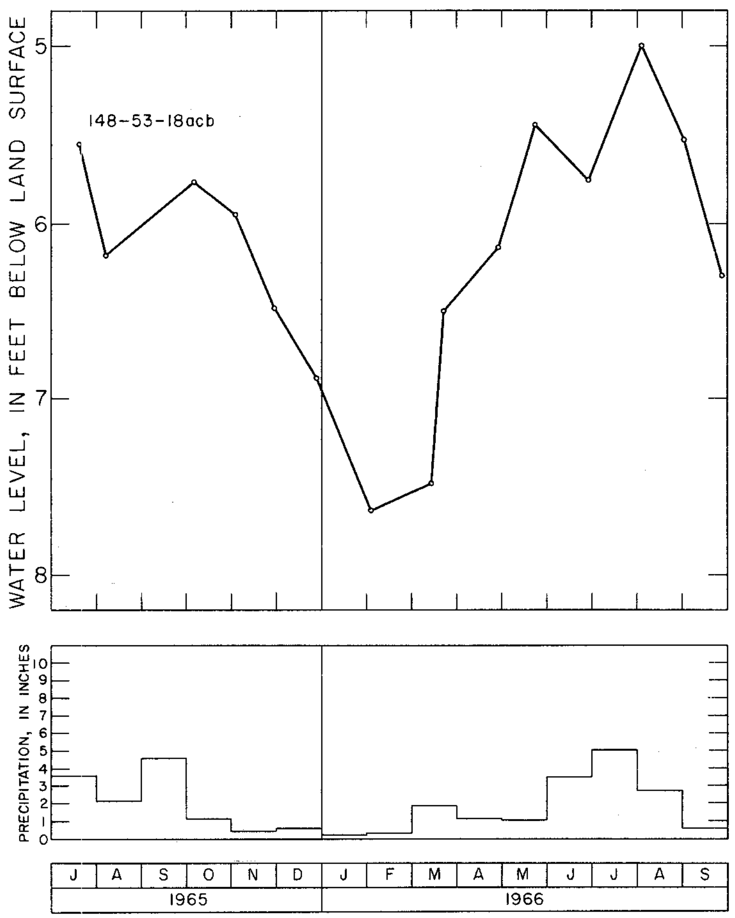

FIGURE 10. Water-level fluctuations in the Elk Valley aquifer, and precipitation at Mayville.

and recovery test made on municipal well 148-53-18acb at Hatton. The well was pumped at 25-30 gpm and had a drawdown of about 10 feet. The transmissivity at this site was estimated to be 1,000 gpd per foot.

The aquifer is recharged mainly by direct infiltration of rainfall and snowmelt. Water is discharged by pumping, evapotranspiration, and by lateral movement of ground water into adjacent deposits. The water-level fluctuations shown in figure 10 reflect seasonal variations in precipitation, water use, and evapotranspiration. The rise of the water level between mid-March and the end of May indicates recharge to the aquifer by infiltration of snowmelt and rainfall. The subsequent decline in the water level is caused by decreased precipitation, pumping, and evapotranspiration.

Analyses of three water samples indicate a calcium bicarbonate or calcium sulfate type water. Total dissolved solids are 500, 459, and 1,250 ppm and sulfates are 80, 65, and 543 ppm, respectively. The water is very hard and locally may contain objectionable amounts of iron. The water is classified as C3-S1 for irrigation purposes (fig. 4).

Belmont aquifer

The Belmont aquifer underlies about 7 square miles in the western part of T. 148 N., R. 49 W., and the eastern part of T. 148 N., R. 50 W., in northeastern Traill County. Most of the aquifer seems to underlie Belmont Township, T. 148N., R. 49 W., and the name is herein applied to the aquifer. The top of the aquifer generally lies about 150 feet below land surface (fig. 11) and the greatest known thickness is 161 feet (148-50-13add). It consists of fine to coarse gravel interbedded and intermixed with sand. The aquifer is overlain by lake deposits and till and is underlain by the Dakota aquifer. Water levels in the aquifer range from 19 to 22 feet below land surface (C. Naplin, written commun., 1969).

Chemical analyses indicate that the underlying Dakota aquifer may be the principal source of recharge. Analyses of eight water samples show that the water is a sodium chloride type. The water is very hard and the total dissolved solids range from 1,120 to 4,420 ppm and average 2,630 ppm. The chloride content ranges from 309 to 1,600 ppm and averages slightly less than 1,000 ppm. Sulfate ranges from 179 to 1,130 ppm and averages 573 ppm. Iron ranges from 0.40 to 6.3 ppm and averages nearly 2 ppm. Although the dissolved-solids content and many of the individual constituents exceed the recommended limits established by the U.S. Public Health Service, the water is used for domestic and livestock purposes in some areas because more suitable water is not available. The water is unsuitable for irrigation purposes because it has a high-salinity hazard and medium-to very high-sodium hazard (fig. 4).

At the present time, there are no large withdrawals of water from the Belmont aquifer. Farms in the area tap the aquifer for domestic and livestock uses, but the present withdrawals are small and much greater development should be possible. Any large-scale development should be preceded by additional test drilling in order to more accurately determine the aquifer extent. Although few quantitative data are available, it is estimated that yields of more than 500 gpm should be available in places. However, recharge from precipitation is likely to be slow because of the thick cover of till and lake clay. Also, excessive

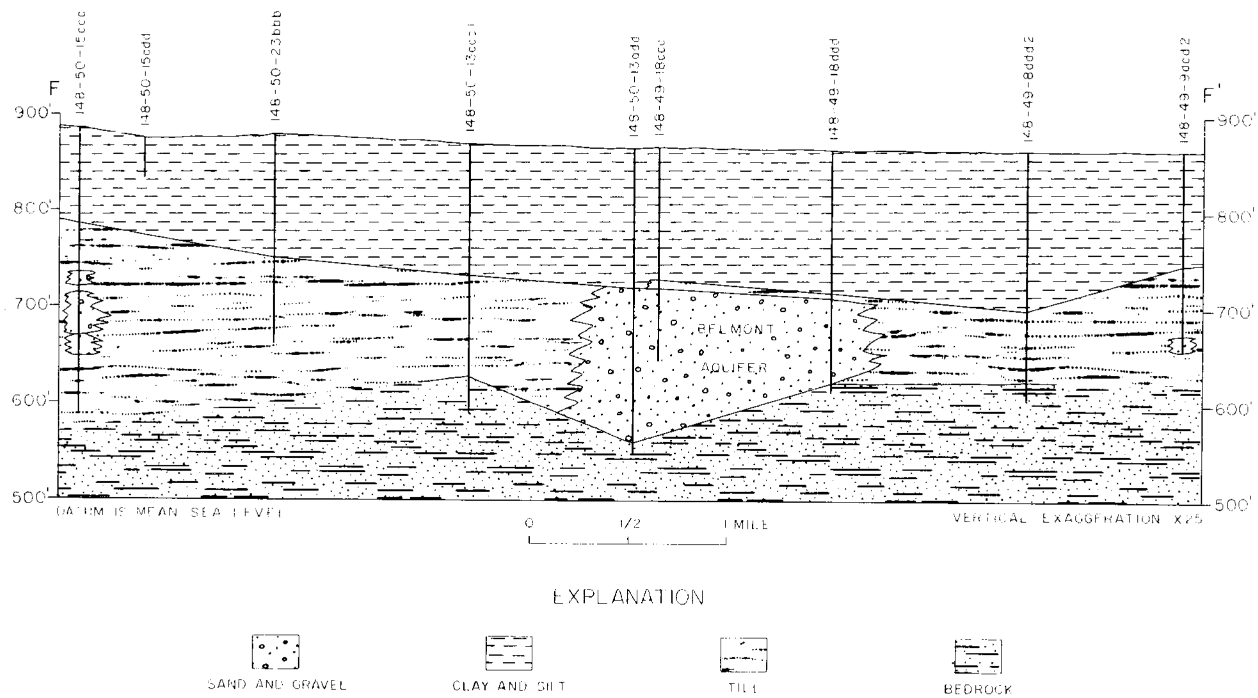

FIGURE 11. Geologic section in the Belmont aquifer.

drawdown may induce substantial upward leakage and further contamination from the underlying Dakota aquifer.

Aquifers in the Lake Agassiz beach deposits

The Lake Agassiz beach deposits are composed of sand and gravel interbedded with silt and clay. These deposits, which are shown in figure 5, are generally less than 30 feet thick, form low ridges, and have a northwesterly trend. Where the deposits are beneath the water table, they form aquifers that yield small supplies of water.

The permeable materials that comprise the beach deposits are readily recharged by direct penetration of precipitation. Water percolates downward and laterally through the deposits and eventually is discharged through wells, springs, and seeps, or by evapotranspiration. Inasmuch as the deposits are relatively thin, very little storage is available. The lack of natural storage is the cause of many shallow-well failures, and for this reason the deposits supply only small quantities of water. Well 147-50-18dcd, which is a source for commercial water hauling, yields about 10,000 gpd when precipitation is normal, but yields are generally smaller during dry periods. The well was developed by installing a cylindrical reservoir in a partially mined gravel pit in the Hillsboro beach.

The beach deposits, because of their shallow position, generally yield water of better quality than most other aquifers in the county. Analyses of eight samples show that the water is predominantly a calcium bicarbonate type. The dissolved-solids content ranges from 250 to 1,740 ppm and averages 822 ppm. Four samples have a dissolved-solids content of less than 500 ppm. Sulfate concentrations range from 22 to 645 ppm and average 204 ppm. The water is very hard and locally contains excessive iron, but it is preferred by many residents for domestic purposes. The water is classified C2-S1 for irrigation purposes.

Small sand and gravel aquifers in the till

Many wells in Traill County do not penetrate any of the aquifers previously discussed, but yield adequate supplies of water for domestic and livestock use from small, apparently isolated, bodies of sand and gravel in the till. Locally the aquifers serve as sources of water for small public supplies. The sand and gravel deposits are generally thin, small in areal extent, and randomly located at varying depths. There seems to be no reliable means of locating these aquifers except by test drilling.

The water in most of these aquifers is under artesian conditions, and the water levels in most wells stand substantially above the tops of the aquifers.

One of these small aquifers, which underlies the city of Hatton, has an areal extent of about half a square mile. Logs of test holes and wells show that it is as much as 50 feet thick (fig. 12). The aquifer materials consist of gravel and coarse sand with interbedded clay lenses.

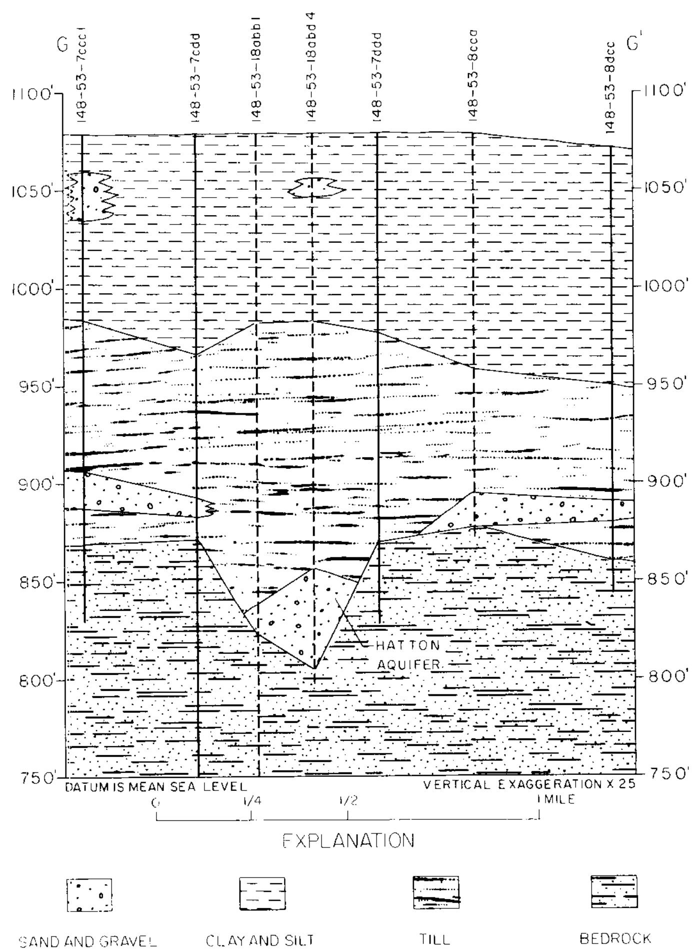

FIGURE 12. Geologic section in the small sand and gravel aquifer at Hatto

TABLE 2.--Water levels in public supply wells

148-53-18abd1 and 18abd2 at Hatton

(Data from Kirkham, Michael & Associates, 1968)

Date		Depth, in feet below land surface
	1937	30
	1942	43
	1947	44
	1954	104
January	1960	94
January	1961	112
January	1962	104
January	1963	105
January	1964	110
October	1964	120
January	1965	118
January	1966	128
January	1967	130
September	1968	143

Data from a development test on well 148-53-18abd4, which was drilled in September 1968, show that the well was pumped for 24 hours at a rate of 150 gpm (Kirkham, Michael & Associates, written commun., 1968). The drawdown was 20.1 feet and the specific capacity for the well was 7.5 gallons per foot of drawdown.

The daily pumpage from the aquifer at Hatton is about 35,000 gallons (about 50 gpm for 12-hour periods). This pumpage has caused a progressive decline of the water level in the aquifer (table 2), which indicates that discharge has exceeded recharge and that water is being withdrawn from storage.

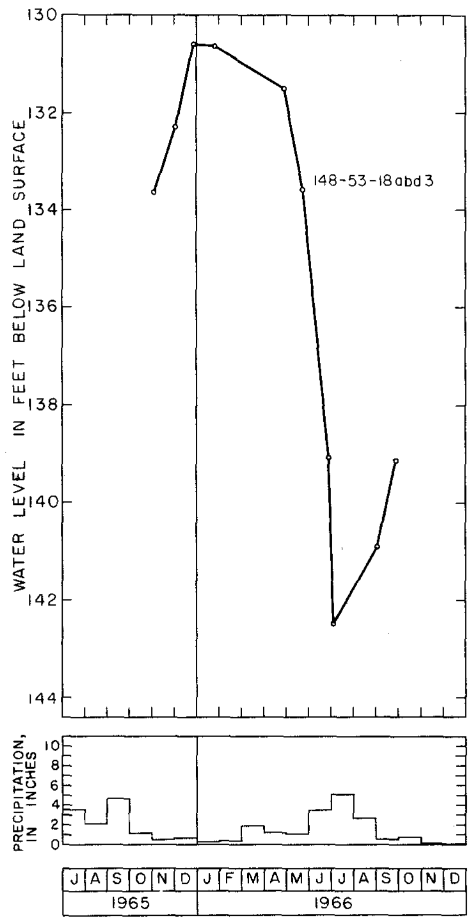

FIGURE 13. Water-level fluctuations in the small sand and gravel aquifer at Hatton, and precipitation at Mayville.

The hydrograph (fig. 13) of well 148-53-18abd3 shows that the water level is highest in December when withdrawals are least and lowest in July when they are greatest.

Few quantitative data are available on the yields of wells tapping the small sand and gravel aquifers in the till, but most wells can be expected to yield from 1 to 10 gpm. Locally, short-term yields of as much as 150 gpm may be possible. Most of the aquifers, however, are not likely to support large, sustained yields because of their small storage and lack of recharge.

Water from the small sand and gravel aquifers in the till differs greatly in chemical character. The dissolved solids in 39 samples range from 100 to 4,000 ppm (appendix) and average 1,880 ppm. The water is very hard and most of the samples contain iron in excess of 0.3 ppm. Grouping the water samples according to water type shows that about 37 percent are sodium chloride, 28 percent sodium bicarbonate, 24 percent sodium sulfate, 7 percent calcium bicarbonate, and 4 percent calcium sulfate.

UTILIZATION OF GROUND WATER

The principal uses of ground water in Traill County are for domestic, livestock, and public supply. The use of ground water for industrial and irrigation purposes is minor because of the relatively poor quality of the water and the limited quantity available.

Domestic and Livestock Use

Wells for domestic and livestock use generally are completed in the shallowest aquifer that will supply the required quantity and quality of water. They include large-diameter dug or bored wells and small-diameter drilled wells.

Most of the rural wells obtain water from the till and associated sand and gravel deposits. Well depths range from 5 to 230 feet and well yields are generally less than 10 gpm.

About one-third of the domestic and livestock wells in the county obtain water from the Dakota aquifer. Wells tapping this aquifer range in depth from about 250 feet to 665 feet, and many wells flow. Reported and measured flows generally are less than 10 gpm and average about 4 gpm.

Estimates of the amount of water pumped daily from domestic and livestock wells in Traill County are listed in the following table.

Use	Individual requirements gpd	Population or number	Total pumpage gpd
Domestic (not including communities having municipal supplies	[1]50	7,137	356,850
Cattle	[1]15	[2]18,000	270,000
Milk cows	[1]35	[2] 2,500	87,500
Hogs	[1] 5	[2] 5,800	29,000
Sheep	[1] 1.5	[2] 3,200	4,800
Poultry	[1] .10	[2]34,000	3,400
Total pumpage			751,550

[1]Murray, 1965
[2]North Dakota Crop and Livestock Statistics, 1965.

Public Supply

Four communities in the county have municipal water-supply systems. Mayville, the largest, obtains its supply from the Goose River. Portland, Hillsboro, and Hatton use ground water from wells. Residents of eight small communities in the county depend on privately owned wells or haul water from the nearest available source.

Mayville

The municipal supply for Mayville is obtained from a reservoir created by a dam on the Goose River. The base flow of the river is largely sustained by ground water seeping into the channel. The average daily pumpage is about 250,000 gpd. Maximum pumpage is during the summer months and is as high as 400,000 gpd, which is about the capacity of treatment facilities. The supply is reported to be adequate for present (1969) needs.

Portland

The water supply for Portland is obtained from a concrete reservoir-type well located in the valley of the South Branch of the Goose River. The well is 32 feet deep, 60 feet in diameter, and obtains water by seepage from an aquifer in fine-grained alluvial and lake deposits. The aquifer is hydraulically connected to the river, and is slowly recharged from that source. Pumpage from the well averages about 30,000 gpd. The supply is adequate for minimum water-use requirements; however, it is inadequate during periods of maximum water use in the summer months and in times of emergencies.

Hillsboro

The municipal water supply of Hillsboro is obtained from three wells tapping the Hillsboro aquifer. These wells, which are 115 feet deep, are located on the south bank of the Goose River, about a mile west of Hillsboro. The river channel intersects the upper part of the aquifer about a third of a mile north of the city well field, and pumping of the city wells induces recharge to the aquifer by seepage from the river. Wells nearest the river induce the largest quantities of recharge, and, as a result, yield water of the best quality.

The average pumpage during the winter months is about 100,000 gpd and during the summer months is about 250,000 gpd. Individual well yields range from 100 to 250 gpm. The municipal supply is adequate and probably could support some additional small industrial development in the area.

Hatton

Hatton obtains its water supply from three wells, which range in depth from 239 to 275 feet and tap sand and gravel deposits within the till. Pumpage from the wells averages about 35,000 gpd. The present supply is adequate to meet minimum requirements of the community; however, water-use restrictions are necessary in summer and during emergencies.

The main water problem at Hatton is lack of recharge. Since initial development of the aquifer in 1937, the water level has declined 113 feet (table 2). Test drilling in the vicinity of Hatton has not located sufficient additional supplies, and tentative plans are being considered to supplement the present supply with water from the Goose River.

Other communities

There are eight other communities in Traill County: Galesburg, Clifford, Blanchard, Caledonia, Cummings, Kelso, Reynolds, and Buxton. None have municipal supply systems, but several have nearby ground-water sources available for development.

Galesburg and Clifford are located on or near the Galesburg aquifer, and hydrogeologic data indicate that municipal water supplies probably could be developed from this source. Community wells are now being used to supply the villages for fire protection and domestic uses.

Privately owned wells supply the residents of Blanchard, Caledonia, Cummings, and Kelso. The Hillsboro aquifer, located about 2 miles west of Cummings, could be a source of supply for that community. However, additional test drilling in the vicinity of Blanchard, Caledonia, and Kelso would be necessary to locate and delineate usable aquifers in the vicinity of these communities. Local ground-water studies have been made near Reynolds (Jensen, 1962) and Buxton (Dennis, 1947; Naplin, written commun., 1969). In general, the wells in the area yield highly mineralized water from aquifers in the glacial drift and bedrock. If economical methods for desalinization of water are developed, these sources might be developed for public supplies.

Industry and Irrigation

Most ground water used for industrial purposes in the county is obtained from municipal systems. The municipal system at Hillsboro is capable of supplying the needs of additional industrial development. At present, several potato warehouses in Hillsboro use municipal water for potato washing. In addition, well 148-53-7cdd (Jensen, 1967, p. 60) yields saline water from the Dakota aquifer that is used for washing potatoes. Small quantities of water of good quality are obtained from beach deposits for bottled-water sales.

Only a small quantity of ground water has been developed for irrigation. The aquifer most capable of yielding sufficient water of suitable quality for irrigation is the Hillsboro aquifer. The quality of the water generally is in the high-salinity, low-sodium (C3-S1) class. The water probably could be used for irrigation, but special management for salinity control may be required.

SUMMARY

The important sources of ground water in Traill County are the sand and sandstone beds in the Dakota aquifer and the sand and gravel deposits in the glacial drift.

The Dakota aquifer is the main bedrock unit in the county known to yield water to wells. The aquifer consists of interbedded and (or) interlensed shale, silt, siltstone, sand, and sandstone. The water-bearing sands in the Dakota aquifer have a maximum known aggregate thickness of about 62 feet.

Although water from the Dakota aquifer is highly mineralized and generally unsuitable, it is used extensively for livestock purposes and to some extent for domestic purposes where better sources are not available. The water may be either a sodium sulfate or sodium chloride

type; however, sodium sulfate is the predominant water type. The dissolved-solids content of 29 samples of water ranges from 1,990 to 5,710 ppm and averages 3,790 ppm. Sulfate content ranges from 355 to 3,220 ppm and averages 1,320 ppm.

Four main aquifers were recognized in the glacial drift. They are the Hillsboro, Galesburg, Elk Valley, and Belmont aquifers.

The Hillsboro aquifer consists of a narrow, sinuous deposit of sand and gravel that is about 25 miles long and 1 to 2 miles wide. It has a maximum known thickness of 157 feet and probably is the most productive glacial drift aquifer in the county. Water from the Hillsboro aquifer is very hard and the dissolved-solids content of 16 samples averages 1,180 ppm. Sulfate averages 449 ppm. The predominant water types are calcium bicarbonate and sodium bicarbonate.

The Galesburg and Elk Valley aquifers consist chiefly of surficial very fine to fine sand that may be as much as 65 feet thick. Water from the aquifers is very hard. The dissolved-solids content in 6 samples from the 2 aquifers ranges from 459 to 1,250 ppm. Sulfate content ranges from 65 to 543 ppm. The predominant water types are calcium bicarbonate and calcium sulfate.

The Belmont aquifer is a confined body of sand and gravel that underlies about 7 square miles in northeastern Traill County. It consists of fine to coarse gravel and sand with a maximum known thickness of 161 feet and is overlain by about 150 feet of lake deposits and till. Water from the Belmont aquifer is a sodium chloride type; it is very hard and the dissolved-solids content in 8 samples averages 2,630 ppm. Chloride averages slightly less than 1,000 ppm and sulfate averages 573 ppm.

Numerous small aquifers are found in the till and beach deposits. The sand and gravel bodies comprising the aquifers are generally only a few feet thick, but may be as much as 50 feet thick. The sand and gravel bodies are distributed randomly throughout the drift and are the chief source of water for many farm wells. Locally, these small aquifers will yield adequate water for small public supply use.

The quality of water from the small aquifers differs considerably from place to place. Water from the small aquifers in the beach deposits is generally of better quality than that from aquifers in the till. The dissolved-solids content in 8 samples of water from the beach aquifers averages 822 ppm and sulfate averages 204 ppm. The predominant water type is calcium bicarbonate.

Water in the small aquifers in the till differs greatly in quality. The dissolved-solids content in 39 samples averages 1,880 ppm. The water types in order of abundance are: sodium chloride, sodium bicarbonate, sodium sulfate, calcium bicarbonate, and calcium sulfate.

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APPENDIX

Chemical analyses of ground water in Traill County

(Analytical results in parts per million except as indicated)

Location	Depth	Date of collection	Temperature (°F)	Silica (SiO_2)	Total iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids: Residue on evaporation at 180°C	Dissolved solids: Sum	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Percent sodium	Specific conductance (micromhos at 25°C)	pH	Sodium-adsorption ratio
Dakota aquifer																								
144-50-13add	320	3-28-59	39	20	1.4	77	36	1,000	10	232	0	928	982	0.8	1.7	2.5	3,200	3,170	342	152	86	5,050	6.9	24
144-51-28dda	420	3-28-59	39	6.6	1.2	24	10	1,310	12	276	0	1,350	931	3.6	2.7	3.6	3,780	3,790	102	0	96	5,750	7.3	56
144-51-33bab	315	9-30-65	44	8.8	1.1	34	12	1,140	14	124	61	1,220	846	1.8	12	2.5	3,400	3,350	134	32	94	5,190	7.0	43
144-52-17aa	665	7-16-58	..	....	1.2	38	17	1,380	28	300	0	1,420	964	3.8	3.4	4.3	3,970	4,010	162	0	94	.....	8.0	47
145-49-20daa	340	6-21-66	..	10	5.6	62	33	1,020	10	335	0	614	1,140	.6	1.2	2.3	3,060	3,180	290	16	88	4,950	7.4	26
145-51- 6bbd	351	3-28-59	45	9.2	3.9	106	30	1,080	38	282	0	1,390	799	.5	2.6	3.1	3,630	3,600	388	157	84	5,370	7.6	24
145-51-24ccb	625	3-28-59	44	7.7	.19	54	19	1,330	24	286	0	1,310	1,090	3.2	.7	4.1	4,000	3,980	212	0	92	6,130	7.7	....
145-51-29bbb	360	10-5-65	45	22	.49	76	16	1,040	33	288	142	1,180	727	3.0	.3	2.8	3,250	3,240	256	20	88	4,900	8.0	28
145-53- 2aad	415	3-28-59	45	10	5.0	135	44	818	34	247	0	1,230	657	2.1	1.0	2.3	3,080	3,060	516	313	76	4,520	7.3	16
145-53-23dcc	480	3-28-59	48	7.2	2.5	96	24	1,130	36	266	0	1,400	804	3.2	.8	3.4	3,660	3,640	338	120	86	5,530	7.2	27
145-53-27ada	520	10-5-65	46	14	1.3	181	50	1,070	260	367	179	1,800	745	2.5	14	2.6	4,340	4,330	673	375	70	6,080	7.7	18
146-50- 5bbb	420	6-30-58	..	....	1.0	171	69	1,240	40	307	0	1,260	1,240	1.4	2.4	3.0	4,290	4,180	711	459	78	.....	8.0	20
146-50-25bda	398	10-6-65	48	7.4	1.5	39	22	1,250	14	312	153	960	1,110	1.4	1.2	3.3	3,560	3,570	189	0	93	5,700	7.8	40
146-52- 6a	365	1927	..	....	2.2	177	70	867	.....	254	0	1,230	790	...	15	...	3,370	.....	730	.....	..	.....	...	....
146-53- 1aaa	427	7-13-36	..	....	6.0	246	71	875	.....	224	...	1,410	822	...	11	...	3,700	.....	918	.....	..	.....	...	....
146-53- 2aab	437	9-17-48	..	....	2.1	202	80	876	.....	222	...	1,380	870	...	104	...	3,660	.....	830	.....	..	.....	...	....
146-53- 5aaa2	530	10-7-65	48	7.7	2.6	309	109	303	39	220	108	1,460	940	2.2	.2	1.7	4,030	3,780	1,220	1,040	58	5,480	7.8	10
147-49-14bba	380	6-18-58	..	....	.6	24	15	710	11	317	17	355	680	.9	2.3	2.7	1,990	.....	66	0	95	.....	8.3	38
147-51-11bab	440	10-8-46	..	....	4.4	140	23	1,210	.....	200	7	1,360	1,630	...	.....	...	5,380	.....	445	.....	..	.....	...	....
147-52-31dad	393	3-30-49	..	....	1.4	160	87	830	.....	242	0	1,250	755	...	4.3	...	3,330	.....	758	.....	..	.....	...	....
147-52-36dcc	350	6-21-66	54	16	1.7	152	49	924	37	240	0	1,390	731	1.0	.4	3.1	3,420	3,660	581	384	76	5,070	7.6	17
147-53-14abb	412	7-15-48	..	....	1.0	237	123	804	.....	198	0	1,260	970	...	10	...	3,940	.....	1,100	.....	..	.....	...	....
147-53-35ddc1	450	8-17-48	..	....	1.2	192	70	872	.....	222	...	1,330	797	...	104	...	3,580	.....	856	.....	..	.....	...	....
147-53-35ddc4	300	8-6-41	..	....	4.5	135	61	1,570	.....	646	...	3,220	84	...	.....	...	5,710	.....	581	.....	..	.....	...	....
148-50-30abb	372	10-15-46	..	....	.3	63	13	966	.....	212	31	1,290	816	...	.....	...	3,590	.....	213	.....	..	.....	...	....
148-51- 4baa	487	8-15-58	..	....	.6	487	339	1,040	44	204	30	1,430	1,010	1.8	1.8	2.4	4,060	.....	826	.....	..	.....	8.3	....
148-51-25dac	374	10-15-46	..	....	1.0	126	23	1,280	.....	146	26	1,330	1,720	...	.....	...	5,140	.....	410	.....	..	.....	...	....
148-51-28aad	320	10-2-46	..	....	1.0	236	55	968	.....	249	...	1,360	765	...	.....	...	3,690	.....	825	.....	..	.....	...	....
148-52-17ccc	425	8-30-56	..	....	1.4	566	406	770	54	102	0	1,290	1,130	1.5	.3	2.3	4,160	3,630	972	.....	58	.....	7.8	....
Hillsboro aquifer																								
144-51-12abb	75	3-28-59	47	29	1.8	107	40	16	4.3	394	0	131	4.9	.6	3.3	.13	539	.....	430	107	7	813	7.3	.3
144-51-12dcc	120	7-27-65	..	17	4.5	440	142	150	13	413	0	1,410	181	0	.8	.36	2,750	2,560	1,680	1,340	16	3,070	7.5	1.6
145-51- 1aba	Spring	10-25-65	46	27	.64	132	47	304	12	381	0	498	275	.6	2.4	.80	1,520	1,490	524	212	55	2,250	7.5	5.8
145-51- 1adc3	115	10-26-65	46	29	1.5	103	41	58	5.6	322	0	229	30	.4	5.9	.17	691	602	424	160	22	997	7.9	1.2
145-51- 1dab	115	3-28-59	45	28	2.3	131	45	175	8.2	354	0	382	155	.5	2.6	.45	1,150	1,100	514	224	42	1,670	7.2	....
145-51- 1ddc	90	8-3-65	..	16	.84	333	104	150	10	358	0	1,010	158	0	2.7	.40	1,160	1,960	1,260	967	20	2,470	7.7	1.8
146-51-24cdd1	55	6-21-66	46	26	.40	78	36	2.4	2.0	312	0	61	15	.2	.3	0	375	425	343	87	1	645	7.6	.1
146-51-24dcc	28	6-21-66	46	27	.10	65	33	1.9	2.0	346	0	11	4.8	.2	1.0	1.1	100	366	298	14	1	541	7.6	0
147-51- 5aaa	220	5-7-68	..	27	2.2	111	44	170	16	480	0	299	102	.9	1.0	.73	990	1,010	460	66	44	1,500	8.2	3.5
147-51- 9baa2	200	5-3-68	..	28	.10	32	6.1	241	11	416	0	229	44	.6	1.0	.44	814	798	105	0	81	1,210	8.2	10
147-51- 9ddd	120	5-3-68	..	27	1.2	84	23	35	5.3	357	0	36	42	.3	0	.20	426	430	306	13	20	713	8.2	.9
147-51-16bab2	100	10-18-65	46	27	5.2	128	65	60	6.4	356	0	285	81	.3	.1	.18	878	833	585	293	18	1,270	7.6	1.1
147-51-16cdd	130	5-2-68	..	24	.92	195	53	205	13	368	0	506	254	.3	0	.83	1,540	1,430	705	403	38	2,130	8.0	3.4
147-51-22bbb	100	8-9-65	..	17	.36	101	38	582	20	314	0	800	458	2.2	2.2	1.9	2,160	2,180	408	151	74	3,280	8.0	13
147-51-34ada2	125	7-11-58	48	....	.8	95	40	61	6.5	282	0	149	130	.2	1.6	.1	694	.....	400	169	24	.....	7.6	1.3
147-51-34ddd1	120	8-2-65	..	16	.98	196	63	712	22	283	0	1,130	667	1.0	2.1	2.1	3,120	2,950	750	519	67	4,200	7.6	11
Galesburg aquifer																								
145-53- 8aad	20	7-22-58	..	....	.38	162	60	8.0	10	281	32	352	54	.4	2.4	.3	1,060	819	650	366	3	.....	8.5	.1
146-53- 5aaa1	26	10-7-65	46	26	.03	165	73	86	9	520	256	361	52	.2	28	.32	1,100	1,060	712	286	21	1,510	8.1	1.4
146-53-29bbb	12	3-28-59	..	24	.34	170	66	35	33	518	0	153	139	.2	36	.12	1,060	912	694	269	9	1,500	7.0	.6
Elk Valley aquifer																								
148-53- 7aab	38	8-18-65	..	17	1.0	83	36	50	6.3	429	0	80	22	1.2	.9	.25	500	.....	354	3	23	842	7.8	1.2
148-53-12dcc	10	3-26-59	..	....	.22	105	32	5.4	1.2	374	0	65	7.7	.4	24	.12	459	450	392	.....	3	.....	7.2	.....
148-53-18acb	40	8-13-65	..	18	.04	230	106	31	4.6	488	0	543	64	.6	19	0	1,250	.....	1,010	610	6	1,630	7.7	.4

Location	Depth	Date of collection	Temperature (°F)	Silica (SiO_2)	Total iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids: Residue on evaporation at 180°C	Dissolved solids: Sum	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Percent sodium	Specific conductance (micromhos at 25°C)	pH	Sodium-adsorption ratio
Belmont aquifer																								
148-49-17cdd	175	11-3-67	..	27	1.8	106	33	419	14	308	0	340	522	1.1	3.5	1.1	1,620	1,620	403	149	69	2,680	7.6	9.1
148-49-18aab	180	11-3-67	..	26	.74	115	41	500	10	239	0	364	727	1.2	0	.81	1,910	1,900	455	259	70	3,220	7.7	10
148-49-18bbb	230	6-11-58	..	....	.48	83	39	245	11	282	22	179	309	.4	2.7	1.1	1,120	.....	370	102	58	.....	8.3	5.5
148-49-18ddd	255	8-20-67	46	24	.40	117	30	795	19	258	0	628	942	1.0	0	1.5	2,700	2,680	414	203	80	4,360	7.6	17
148-50- 1cdc	230+	6-21-66	..	1.0	6.3	78	41	1,140	21	68	0	612	1,600	.2	2.4	2.0	3,540	3,430	363	308	86	5,770	8.2	26
148-50-13add1	270	8-19-67	46	25	2.2	251	85	1,130	25	270	0	1,080	1,520	.7	0	1.9	4,420	4,250	975	754	71	6,490	7.6	16
148-50-13add2	230	8-19-67	47	25	.76	172	37	303	16	336	0	248	524	.2	0	.55	1,500	1,490	581	306	52	2,510	7.3	5.5
148-50-13dcd	184	11-3-67	..	25	3.1	268	76	1,110	28	280	0	1,130	1,440	2.3	0	1.7	4,210	4,220	983	754	70	6,550	7.6	15
Aquifers in the Lake Agassiz beach deposits																								
144-52-30baa2	34	3-28-59	42	24	.18	258	111	58	41	474	0	576	116	.2	141	.47	1,630	1,560	1,100	711	10	2,120	7.2	.8
145-50-24bcb	16	7-2-58	46	....	1.8	159	149	110	9.8	617	0	645	81	.4	.4	.2	1,740	1,460	1,010	504	19	.....	7.8	1.5
147-50-18dcd	12	10-6-65	46	28	.6	75	42	8.2	28	452	222	22	12	.2	.1	.06	439	438	358	0	4	726	8.0	.2
148-50-22adb	19	6-17-58	45	....	.6	62	31	4.0	3.0	324	0	37	0	.3	4.3	.2	372	.....	280	14	3	.....	7.7	.1
148-51-25ccc1	17	6-24-21	..	....	Trace	56	18	6.9	....	232	0	24	2	...	.....	....	250	.....	214	.....	..	.....	...	.....
148-51-25ccc3	30	10-2-46	..	....	.08	230	46	90	....	402	...	108	375	...	.....	....	1,200	.....	764	.....	..	.....	...	.....
148-51-36bbb1	16	10-2-46	..	....	0	80	34	0.1	....	249	...	76	20	...	.....	.....	354	.....	340	.....	..	.....	...	.....
148-52-13bcd2	13.2	3-26-59	38	23	.02	102	33	12	24	272	0	143	24	.1	70	.47	596	.....	392	169	6	839	7.6	.3
Small sand and gravel aquifers in the till																								
144-49-16cdc	140	3-27-59	41	27	.53	82	31	275	8.6	236	0	225	390	.4	3.7	7.6	1,200	1,160	334	140	63	2,010	7.4	6.5
144-50-12cca	180	3-28-59	..	27	.07	87	30	1,050	16	240	0	976	1,010	.8	.9	2.3	3,360	3,360	340	143	86	5,220	7.3	25
144-50-21cdc	168	9-30-65	46	29	1.9	128	53	1,020	37	296	146	1,020	1,040	.9	1.0	2.1	3,530	3,480	538	295	79	5,380	7.5	19
144-50-26ccb1	136	9-21-65	48	15	.62	166	49	659	16	210	0	576	939	.3	0	1.8	2,570	2,520	615	451	69	4,250	8.1	12
145-49-13bdc	177	10-1-65	52	28	.35	33	14	276	4.7	346	170	118	231	.4	3.4	.85	883	880	141	0	80	1,510	7.6	10
145-49-31abc	135	7-1-58	..	....	1.8	42	36	575	15	292	0	348	626	.4	1.6	1.9	1,800	.....	254	15	82	.....	8.2	16
145-50- 6bac	254	7-7-58	..	....	.7	119	49	1,130	39	322	0	1,320	855	2.0	2.6	2.9	3,710	.....	499	235	82	.....	...	.....
145-51-16cbb1	150	10-5-65	44	29	.96	67	15	1,050	27	278	137	1,180	748	2.9	.4	2.8	3,300	3,260	227	0	90	4,990	7.9	30
145-52-10ccc	100	10-5-65	50	26	.79	72	19	382	15	342	168	391	294	.7	2.7	1.5	1,390	1,370	257	0	75	2,230	7.9	10
145-52-27bbb2	120	10-5-65	46	9	.59	69	22	150	8.8	392	193	134	104	.3	1.5	.83	715	693	261	0	55	1,160	8.1	4.0
145-53-10ccc1	165	10-5-65	54	30	4.2	91	23	158	10	468	230	114	127	.2	1.3	.99	783	790	321	0	51	1,300	7.9	3.8
146-49- 4cdc	83	3-27-59	41	27	2.1	54	24	405	9.2	322	0	210	477	.4	8.4	1.3	1,390	1,380	235	0	78	2,370	7.3	12
146-49-20aaa	130	3-27-59	..	9.8	3.8	63	32	375	11	310	0	173	485	.4	13	1.2	1,340	1,320	288	34	73	2,330	7.2	9.6
146-50-10ddd	185	7-1-58	..	....	.8	116	60	1,050	24	337	0	1,220	933	.7	.4	3.1	3,640	3,580	540	264	80	.....	7.7	20
146-51-11adb	90	3-28-59	43	15	.9	208	60	283	14	244	0	591	425	.1	3.0	.75	1,810	1,720	766	566	44	2,650	7.2	4.5
146-51-13cbb1	90	10-12-65	45	....	3.1	185	54	665	18	286	0	1,080	578	1.1	3.4	2.3	2,860	2,730	682	447	67	4,060	7.6	11
146-51-35ccc3	Spring	3-28-59	45	31	2.7	123	42	26	8	602	0	17	13	.1	14	.4	569	.....	478	0	10	931	7.0	.....
147-49-35aaa	172	6-26-58	..	....	.38	34	24	438	6	337	0	197	486	.6	2.1	1.3	1,360	1,360	186	0	83	.....	8.2	14
147-50-12aad	180	3-27-59	41	27	1.6	178	73	895	21	256	0	1,080	984	.5	8.6	2.3	3,470	3,400	744	534	72	5,170	7.0	14
147-51- 2adc	174	10-8-46	..	....	3.6	27	7	423	34	405	...	283	376	...	.....	...	1,550	.....	96	.....	..	.....	...	.....
147-51-34ddd2	205	8-2-65	..	18	1.7	129	40	996	16	349	0	1,240	818	.7	1.1	3.5	3,700	3,440	485	199	81	5,140	7.7	20
147-53-35aaa	147	11-10-48	..	....	4.0	47	60	209	....	428	0	294	120	...	4.3	...	932	.....	240	.....	..	.....	...	.....
147-53-35dbb1	135	8-16-41	..	....	0	157	58	183	....	628	.3	377	86	...	.....	...	1,490	.....	631	.....	..	.....	...	.....
148-49- 3bbd1	226	3-27-59	44	26	.93	44	20	523	7.5	330	0	205	605	.8	4.6	1.7	1,610	1,600	192	0	85	2,770	7.3	16
148-49- 7ccd	159	10-6-65	44	19	2.6	80	33	174	9.6	289	142	70	293	.4	2.8	.77	855	827	336	99	52	1,510	7.9	4.1
148-49-28bab	168	6-21-66	..	28	2.2	77	31	110	7.5	545	0	62	32	.3	2.7	.94	100	650	318	0	42	1,060	7.4	2.7
148-49-30aba	170	11-3-67	..	27	3.7	110	35	255	8.9	329	0	228	348	.8	3.9	.55	1,200	1,180	419	150	56	1,970	7.6	5.4
148-50- 9ddd	240	8-21-67	45	26	3.4	295	98	892	16	232	0	875	1,460	.2	0	1.1	3,740	3,780	1,140	951	63	5,850	7.6	12
148-50-23dcc	271	6-21-66	..	9.1	7.5	197	94	652	18	152	0	667	1,090	.3	12	1.2	2,820	3,100	878	754	61	4,590	7.1	9.6
148-51-21daa	293	10-2-46	..	....	1.0	264	124	862	....	244	...	1,470	930	...	.....	...	4,000	.....	1,100	.....	..	.....	...	.....
148-51-26cdd	275	10-8-46	..	....	8.4	50	10	491	....	344	38	525	472	...	.....	...	2,110	.....	164	.....	..	.....	...	.....
148-51-30ddd1	115	10-15-46	..	....	1.4	30	5	226	....	134	22	86	376	...	.....	...	978	.....	96	.....	..	.....	...	.....
148-51-32aaa	140	5-7-68	..	25	4.0	232	72	914	31	249	0	1,360	908	1.8	0	2.6	3,850	3,670	877	673	68	5,240	8.1	13
148-52-20bcc	162	8-30-56	..	....	1.8	30	78	235	10	396	0	144	86	.7	1.0	2.0	846	707	108	.....	84	.....	7.9	.....
148-53- 8dbb	196	5-5-65	..	31	.22	32	10	266	11	598	0	12	155	.7	4.9	1.4	818	.....	121	0	81	1,340	7.9	11
148-53-15dcc	128	5-6-65	..	25	.27	95	21	126	10	514	0	150	27	.3	0	1.1	696	709	324	0	45	1,340	7.9	3
148-53-18a	240	9-19-56	..	....	.8	15	18	220	8.0	494	0	48	94	.5	.4	1.3	807	628	110	.....	80	.....	8.0	.....
148-53-18abd2	239	6-8-65	..	28	.59	27	7	250	9.7	616	0	12	99	.6	1.1	1.6	732	740	96	0	83	1,200	8.1	11
148-53-20abd3	277	5-27-65	..	26	.06	20	2.7	276	9.2	621	0	29	106	.7	.9	2.1	850	779	61	0	89	1,250	7.9	13