GROUND-WATER STUDY 9

by

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

1.0 ABSTRACT

Geology and the Occurrence of Coal

The sedimentary rocks of the Paleocene Fort Union Group consist of sandstone interbedded with siltstone, claystone, and lignite, which dip gently north into the Williston basin. The Bullion Creek and Sentinel Butte Formations of the Fort Union Group contain the only lignite coal reserves suitable for surface mining. The most important lignite seam is the 30-foot Harmon bed, which is separated by underclay from sandstone and siltstone in the lower unit of the Bullion Creek Formation. The rock units are jointed and further fractured by mine operations.

Hydrology

The principal aquifers are the Harmon lignite and the underlying sandstones of the Slope and lower Bullion Creek Formations. The lignite and sandstone aquifers provide base flow to tributaries of Buffalo Creek and are locally important sources of domestic and livestock water. Where present, the Harmon lignite is the surficial aquifer; the sandstone aquifer is confined by the underclay of the Harmon. Where the Harmon lignite is absent, the sandstone aquifer is unconfined. The occurrence and flow of ground water is complex, owing to (l) dendritic channel sands in the strata overlying the Harmon lignite and in the lower unit of the Bullion Creek Formation, and (2) natural fracturing in the lignite beds and additional fracturing caused by mine blasting. The hydraulic conductivity in both aquifers commonly varies by several orders of magnitude within short distances. The mining operations causes additional secondary permeability and porosity.

The hydrologic data-collection network in the 42 square mile area consisted of 546 test holes, 15 core holes, and 44 unsaturated-zone lysimeters; 114 test holes were completed as wells. The wells penetrated both aquifers and were used to determine ground-water flow, hydraulic properties, and water quality. Sodium-adsorption ratios and sulfate and dissolved-solids concentrations proved most useful in detecting water-quality changes caused by mining.

The regional ground-water flow is northeast toward the center of the Williston basin; however, local flow is southwest toward Buffalo Creek. The nature of this flow reversal in the aquifer system is not well understood. The large cones of depression in both aquifers, produced by mine dewatering, have limited shallow ground-water availability. The most important underlying regional aquifer is the Fox Hills-lower Hell Creek aquifer system.

The type of water in the lignite and sandstone aquifers ranges from sodium sulfate to sodium bicarbonate. It is controlled principally by chemical reactions in the unsaturated zone.

Mining Method and Other Stresses on the Aquifer System

Surface mining of lignite from the 30-foot Harmon bed began in 1946 on a small scale. Annual production was increased in 1951 to about 100,000 tons and in 1974 was increased again by a factor of 30.

The aquifer system does not have any significant withdrawals other than those from active coal mines and their dewatering wells. However, domestic and livestock wells yielding small quantities of water are common.

Probable Hydrologic Consequences and Proposed Hydrologic-Monitoring Network

Only aquifers of the Slope-Bullion Creek aquifer system are being directly disrupted by surface-mining activities. In 1981, decline of the potentiometric surface of the sandstone aquifer due to mine dewatering may have been as much as 65 feet and extended as far as 3 miles beyond the mine perimeter. Pumpage to dewater the lignite exceeds 1,000 gallons per minute.

Water levels recover rapidly by lateral flow when dewatering ceases. However, the decreased hydraulic conductivities of mine spoils relative to undisturbed overburden imply long-lasting consequences for water levels in these shallow aquifers.

Oxidation of iron sulfide minerals exposed during mining and the resultant sulfates may significantly degrade post-mining ground waters. Additional sulfate concentrations may result if the replaced overburden is below the water table.

Low-flow water quality in tributaries draining the mine will deteriorate roughly proportional to the amount of basin drainage disturbed by mining. However, the quality deterioration of the principal creek will be smaller than in tributaries because of dilution.

A post-mining hydrologic monitoring network includes (1) about 30 observation wells completed in both major aquifers to monitor the enlarging cone of depression, (2) two streamflow-gaging stations to monitor the effect on stream base flow, and (3) routine water-quality sampling of observation wells and low-flow stream sites.

2.0 GENERAL DESCRIPTION OF AREA

2.1 DESCRIPTION OF GASCOYNE AREA

THE AREA IS IN THE LIGNITE PART OF THE NORTHERN GREAT PLAINS COAL REGION

The climate of the area is semiarid and the lignite seams are important aquifers supplying water for livestock and domestic uses.

The Gascoyne study area (fig. 2.1-1) is in the lignite part of the Northern Great Plains coal region and includes about 45 mi^2 surrounding the Gascoyne Mine in Bowman County. The area lies within the unglaciated part of the Missouri Plateau physiographic province (10). Maximum relief is about 250 feet. The climate is semiarid with mean annual precipitation being about 15 inches (30).

The shallow, flat-lying lignite seams of the Gascoyne area and other surrounding coal areas commonly are important aquifers that supply water for livestock and domestic use. Surface mining of lignite aquifers has prompted concern about the effect of mining on the quantity and quality of shallow ground water in this area. In 1973, the U.S. Geological Survey began hydro-geochemical investigations in the vicinity of the Gascoyne (Peerless) Mine.

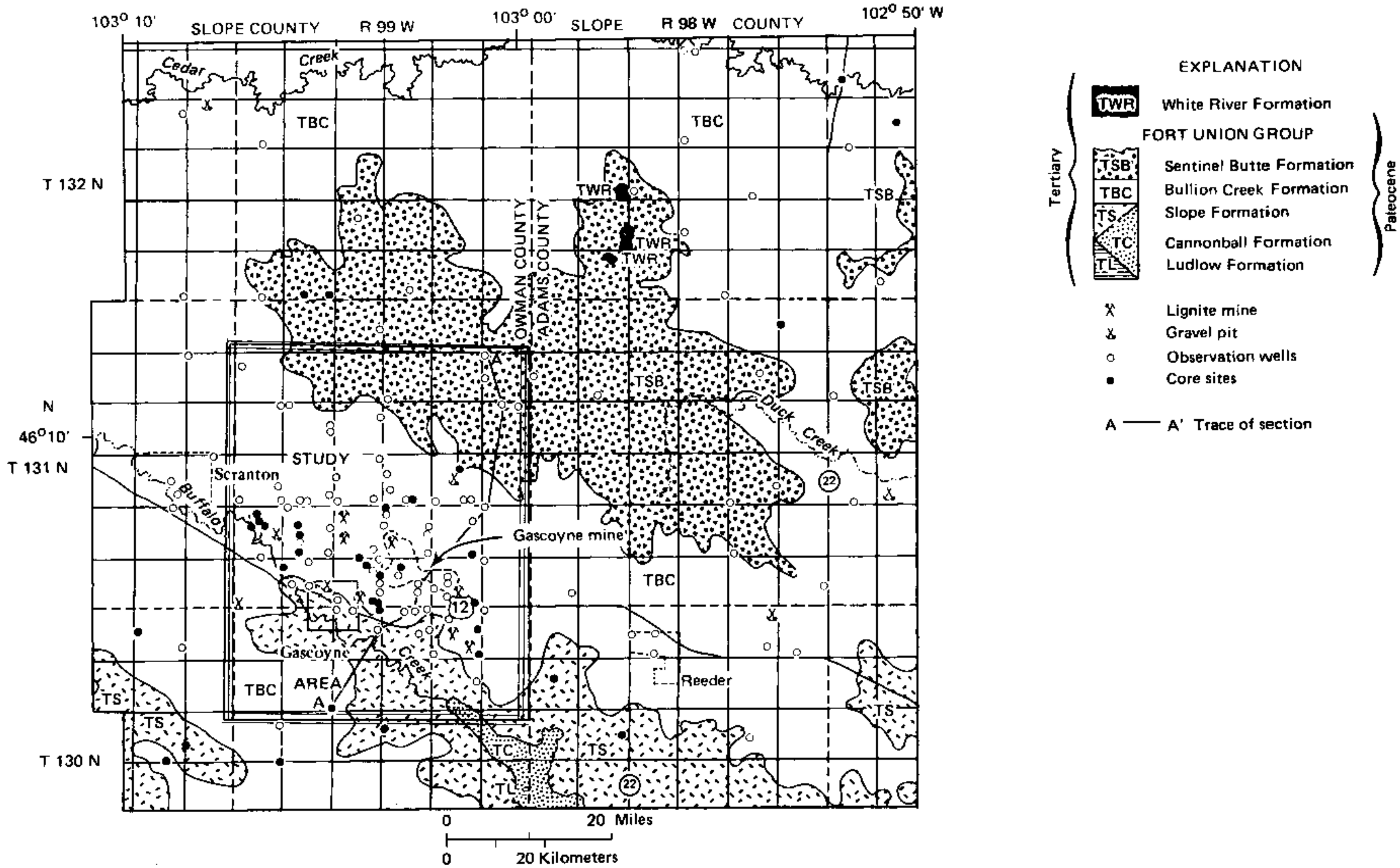

Figure 2.1-1. — Location of the Gascoyne study and the hydrology of the area. (Geology modified from Carlson, 1979.) (From Houghton and others, 1984, fig. 2.)

2.0 GENERAL DESCRIPTION OF AREA

2.2 GEOLOGY, OCCURRENCE, AND MINING OF COAL

THE BULLION CREEK AND SENTINEL BUTTE FORMATIONS CONTAIN THE ONLY LIGNITE RESERVES SUITABLE FOR SURFACE MINING

The geology of sedimentary bedrock containing the lignite beds is complicated due to periods of erosion and of marine and nonmarine deposition causing interfingering of sandstone, siltstones, shales, and lignite beds.

The Fort Union Group is the oldest geologic unit exposed in the area (fig. 2.1-1). The group consists of about 700 feet of sandstone interbedded with siltstone, claystone, and lignite, which dip gently north at about 20 to 30 ft/mi. The Fort Union Group has been divided, in ascending order, into the Ludlow and its lateral marine equivalent the Cannonball, Slope, Bullion Creek, and Sentinel Butte Formations (4). In the general area, the Ludlow, Cannon-ball, and Slope Formations are exposed only in the valley of Buffalo Creek (fig. 2.1-1). The Bullion Creek Formation crops out in most of the Gascoyne area, but is overlain by the Sentinel Butte Formation in the northeastern part.

In the Gascoyne area the stratigraphic sequence is complicated by inter-tonguing of the Ludlow and Cannonball Formations (fig. 2.2-1). In Buffalo Creek valley, carbonaceous sandstones and shales of the Ludlow Formation interfinger with marine shales of the Cannonball Formation. Where the Cannonball is absent, the Ludlow is unconformably overlain by the T-Cross lignite at the base of the Slope Formation. Interfingering of the Ludlow and Slope Formations in parts of Bowman County was considered likely (4), but they cannot be differentiated in the Gascoyne area because their lithologies are similar.

The Bullion Creek and Sentinel Butte Formations contain the only lignite reserves suitable for surface mining in the study area. The weakly consolidated Bullion Creek Formation consists of alternating sequences of sandstone, siltstone, claystone, and lignite beds (fig. 2.2-2). Different lithologies grade laterally into one another within short distances thus reflecting cyclical changes in depositional environment (15, 16, 17). The most important lignite occurs as three seams in the 30-foot Harmon bed (18), about 60 feet above the base of the Bullion Creek Formation and separated from the lower Bullion Creek sandstones and siltstones by underclay as much as 48 feet thick. The silty sandstones of the Sentinel Butte Formation are extensively interbedded with thin beds of lignite, which are only locally thick enough to be economically important.

The Bullion Creek and Sentinel Butte sandstones and siltstones consist principally of grains of quartz and some limestone, dolomite, and metamorphic rock fragments. Expandable sodic smectites and mixed-layer clay minerals compose as much as 60 percent of the clay fraction. Gypsum, mirabilite, and other sulfate minerals are commonly present in the unsaturated zone. In undisturbed rocks, iron sulfide minerals are absent above the water table but constitute as much as 3 percent of the overburden below the water table. Limonite pseudomorphs of pyrite and concentrations of sulfate minerals in the unsaturated overburden indicate the former presence of sulfide throughout both formations.

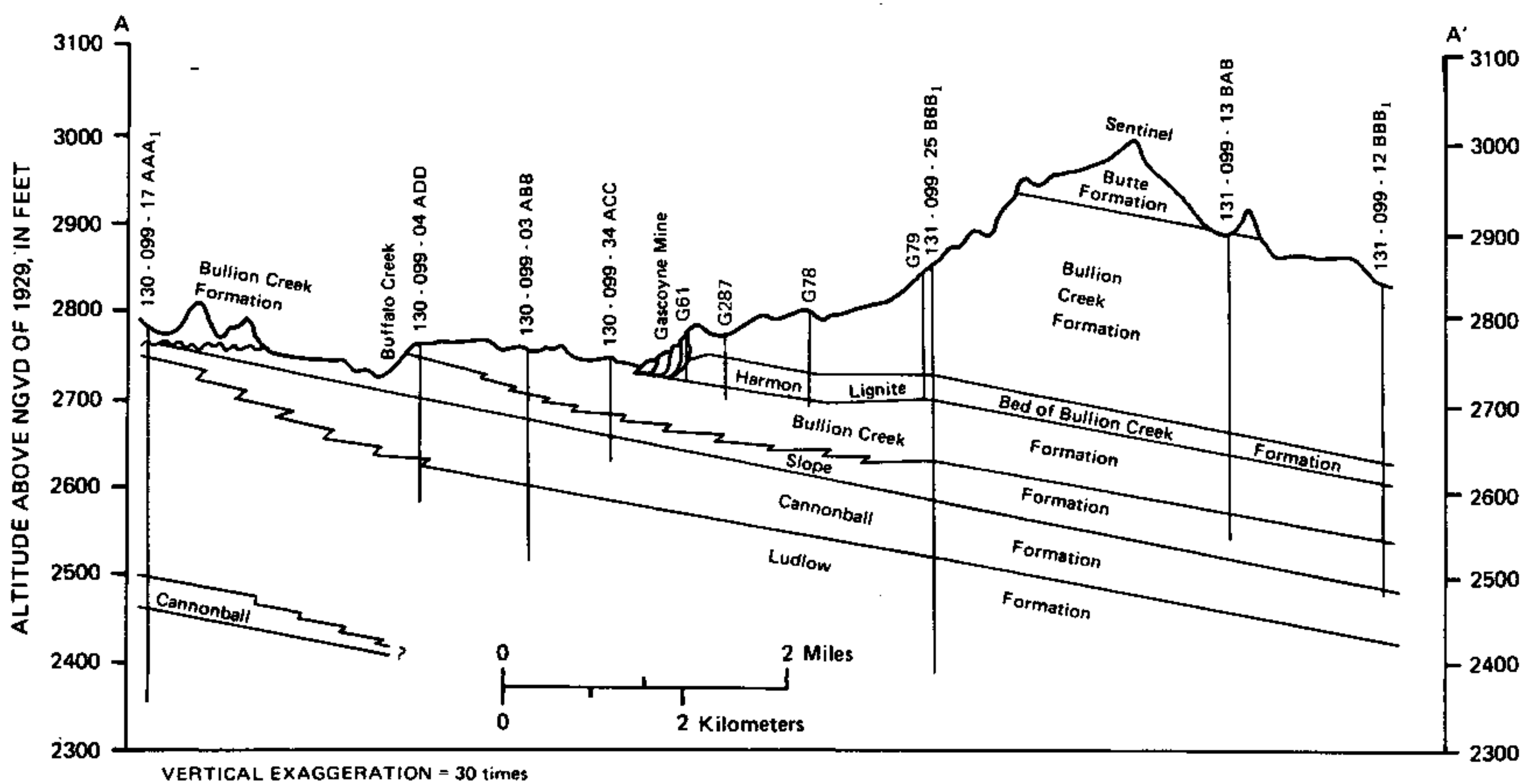

Figure 2.2-1. — Geologic Section A-A′.
(From Houghton and others, 1984, fig. 5.)

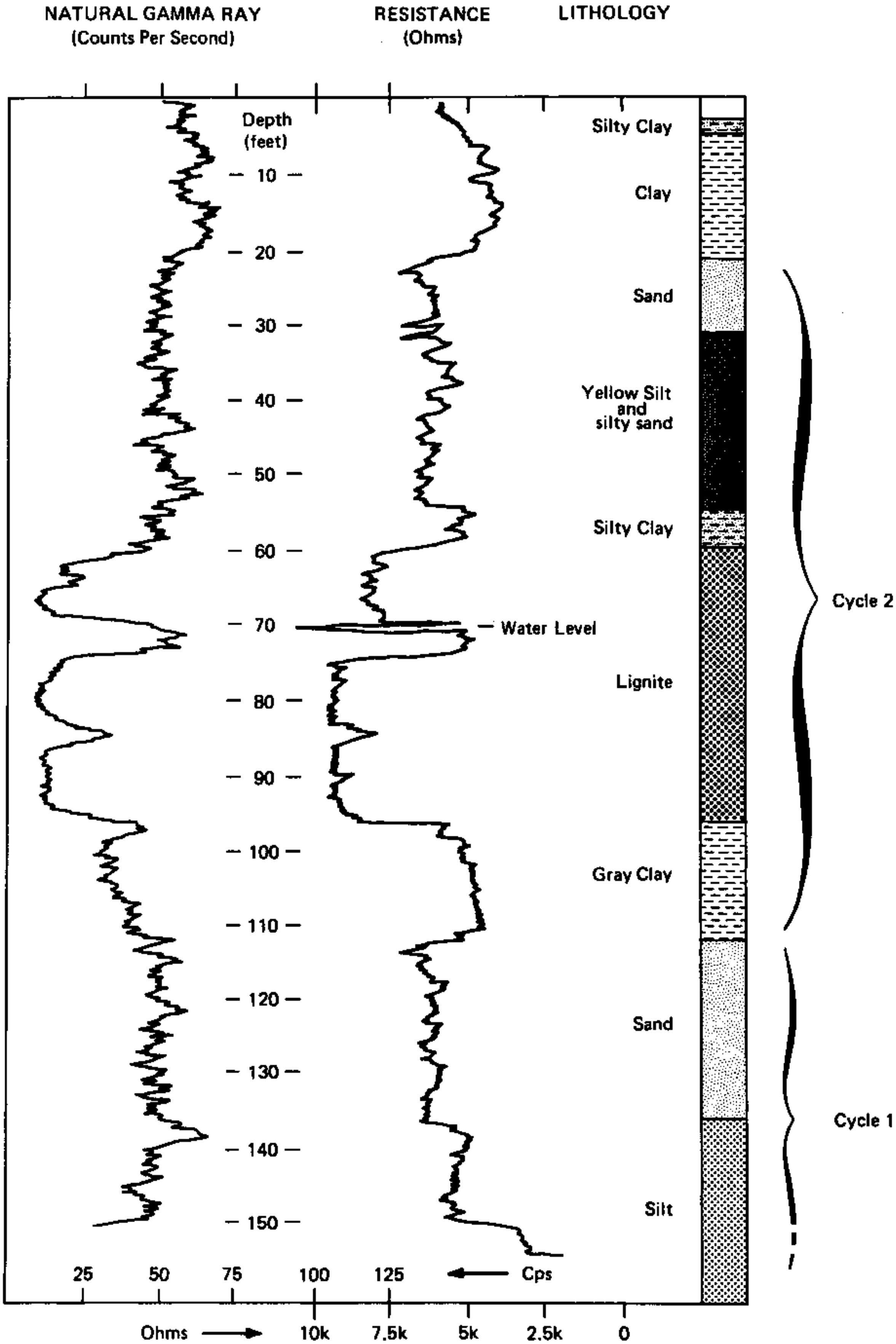

Figure 2.2-2. — Cyclical lithologic sequence of the Bullion Creek Formation in well 131-099-29BBB.
(From Houghton and others, 1984, fig. 12)

2.0 GENERAL DESCRIPTION OF AREA

2.3 THE GASCOYNE MINE

THE GASCOYNE MINE OPENED IN 1946

The definition of overburden by exploratory methods is essential in the determination of reclamation potential and probable hydrologic consequences of mining.

Surface mining of lignite from the 30-foot Harmon bed in the Gascoyne Mine began in 1946. Production was expanded 30-fold in 1975 to its current level of 3 million tons per year. The Gascoyne Mine operates with a surface coal thickness/overburden thickness ratio greater than 0.8. The three lignite seams of the Harmon bed (Alpha, Beta, and Gamma) are mined in four pits. The lignite in each pit has a different sodium content. At the electric power-generating facilities, the lignites are mixed to arrive at an optimum composition for burning. The least sodium content occurs in lignite deposited adjacent to sand channels of the Paleocene fluvial system (fig. 2.3-1). These channels are mappable using geophysical logs and lithologic data collected by the mining company during routine development drilling.

Particle size, chemical characteristics (electrical conductivity, pH, sodium-adsorption ratio, cation-exchange capacity), and hydraulic properties of overburden determined by the mining company from drill cuttings and core material are essential to assessing overburden reclamation potential (11,19) and the probable hydrologic consequences of mine activities. Overburden is removed by standard key cut, cyclical dragline operations (2). Reclamation is proceeding selectively by strike-off grading (8) of individual "reclamation units" as identified in (22) to produce the desired post-mining topographic surface.

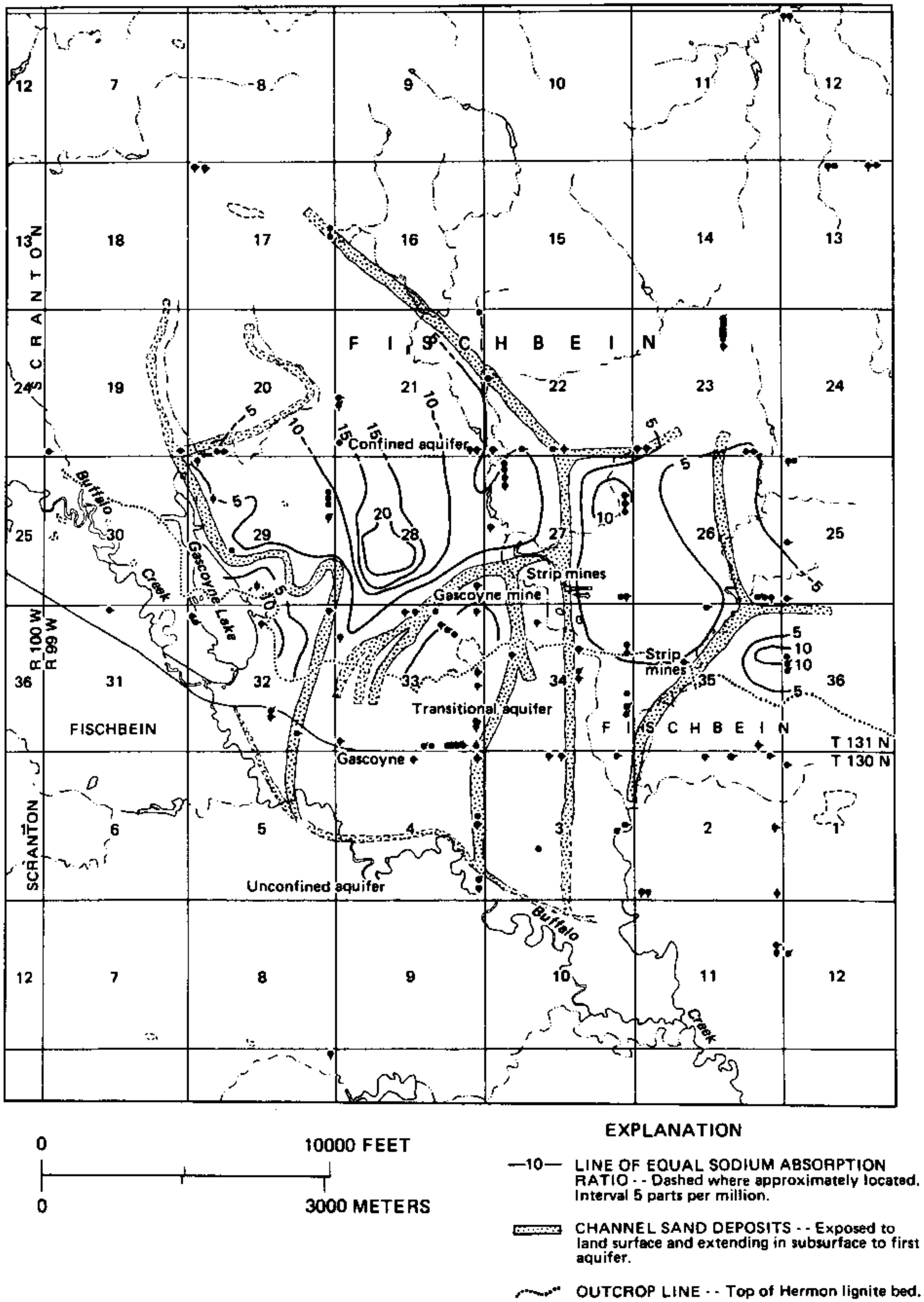

Figure 2.3-1. — Relationship of the sodium adsorption ratio (SAR) of the Harmon lignite to the position of channel sands in the overlying Bullion Creek strata. (From Houghton and others, 1984, fig. 16.)

3.0 GROUND-WATER HYDROLOGY

3.1 HYDROLOGIC REGIME

FIVE REGIONAL AQUIFERS IDENTIFIED

The principal shallow local aquifers in the Gascoyne area are the Harmon lignite and the underlying Slope-lower Bullion Creek sandstone.

Five regional aquifers were identified by (7) in Bowman and Adams Counties. Only aquifers of the Slope-Bullion Creek aquifer system are being directly disrupted by surface-mine activities. Correlation of aquifers to geologic formations is shown in figure 3.1-1. In the Gascoyne area, the Slope-Bullion Creek aquifer system consists of the Harmon lignite aquifer and the underlying Slope-lower Bullion Creek sandstone aquifer. Well data indicate that the claystone below the Harmon lignite is a confining layer over the Slope-lower Bullion Creek sandstone aquifer in the northern one-half of the Gascoyne area. However, the same aquifer is unconfined in the southern one-half of the area (fig. 3.1-1). Along the lignite outcrop line, water levels in wells completed in the Slope-lower Bullion Creek sandstone aquifer are both above and below the claystone confining layer. Both aquifers are locally important sources for domestic and livestock wells yielding small quantities of water. The only large-yield wells in the aquifers in the Gascoyne area were installed by the mine for dewatering purposes.

The lignite aquifer is recharged principally by local precipitation. Potential evaporation demand exceeds precipitation during most of the year and most infiltration from precipitation is lost within the root zone. Only the precipitation from major events percolates below the root zone, and even then percolating water may take 10 to 30 years to reach the water table. Accordingly, most recharge is confined to a few zones with relatively large hydraulic conductivities, such as the sandstones of the Sentinel Butte Formation north of the mine, channel sands within the Bullion Creek Formation that are exposed to the surface, lignite exposed during mining operations, and scoria zones (baked sediment formed by burning of underlying lignite). Outcrops of lignite are commonly encrusted with secondary sulfate minerals generated from the oxidation of iron-sulfide minerals. Recharge through these outcrops is mineralized by dissolution of the salts and is retarded owing to pore closure by the salts. Results from infiltrometer tests, observation-well water-level analysis, and flow modeling indicate that average annual recharge ranges from 0.04 to 0.4 inch. The lignite aquifer discharges through fractures in its underclay mainly to the underlying Slope-lower Bullion Creek sandstone aquifer and to tributaries of Buffalo Creek.

The Slope-lower Bullion Creek sandstone aquifer is about 450 feet thick and includes many lignite and silty clay seams. Where unconfined, the sandstone aquifer is recharged directly by precipitation; where confined, it is recharged by leakage from the overlying lignite. Average annual recharge is estimated to range from 0.15 inches where the aquifer is confined to 2 inches in unconfined zones of large hydraulic conductivity. The base of the sandstone aquifer generally is defined by claystone seams in the upper Slope Formation. Locally, the Slope-lower Bullion Creek sandstone aquifer discharges principally to Buffalo Creek and its tributaries south of the mine according to potentiometric-head data. However, regional discharge is primarily to the northeast by leakage to underlying aquifers.

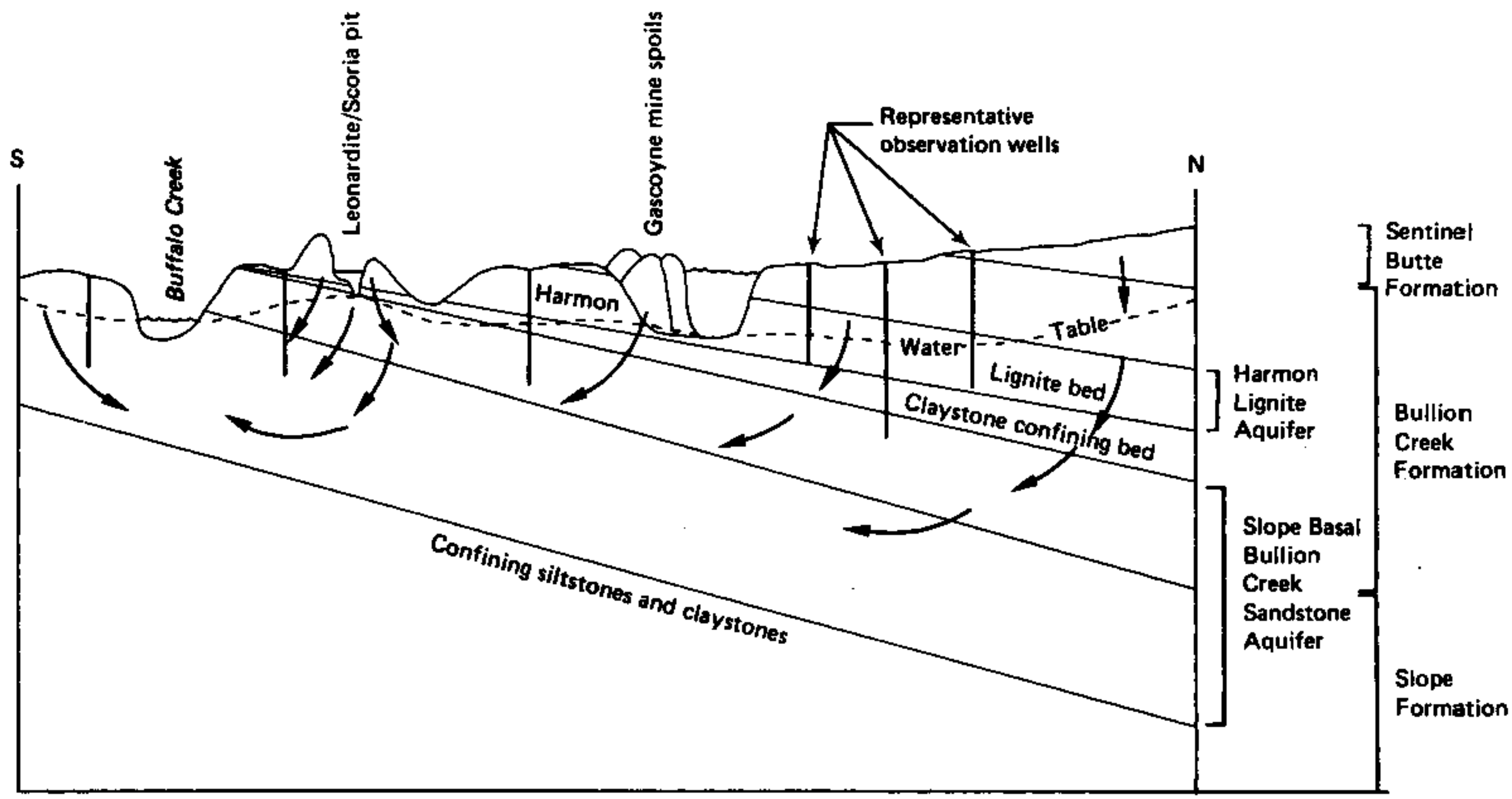

Figure 3.1-1.— Generalized hydrogeologic section showing correlation of aquifers with geologic formations. Arrows show general directions of ground-water flow. (From Houghton and others, 1984, fig. 7.)

3.0 GROUND-WATER HYDROLOGY

3.2 HYDROLOGIC-DATA NETWORK

GROUND WATER OF PRIMARY CONCERN

The hydrologic-data network consisted of wells for water-level measurements and of streamflow-gaging stations for base-flow discharge, and water-quality analyses for both ground water and surface water.

An extensive hydrologic-data network was necessary to permit data collection and development of hydrologic-flow and solute-transport models near the Gascoyne mine. The data network included: 546 test holes and core holes that were geophysically logged to determine lithologic and geochemical variations in overburden and aquifer materials, 44 lysimeters to sample overburden pore waters, and 4 clusters of gas probes to sample free gases in the unsaturated overburden (fig. 3.2-1). Observation wells were completed in 114 of the test and core holes. Only finely screened (less than 0.008-inch slot) wells packed with 9-12 mesh silica sand and sealed at a relatively confining bed with low-sodium cement or plastic packers (fig. 3.2-2) were found to produce water in the finer grained materials and yield relatively unaltered samples for water-quality determinations. All water-quality samples were obtained with teflon or polyethylene air-squeeze or gas-reciprocating pumps to minimize sample contamination and were preserved in the field as prescribed in (3,29) to limit sample alteration prior to analysis.

From this network of wells, the mining company selected about 30 wells in which to measure water levels and to collect semiannual water samples for the life of the mine. Well sites were chosen so that their geographic distribution would permit preparation of reliable potentiometric-surface maps. Most sites have dual wells, one in the lignite aquifer and one in the sandstone aquifer. Wells in the network which were destroyed by mining were reinstalled in or beneath the mine spoils at the same location.

Ground-water contributions to tributaries of Buffalo Creek are measured at two streamflow-gaging stations located upstream and downstream from the mine (fig. 3.2-1). Water quality at these sites is determined every 6 weeks during periods of flow.

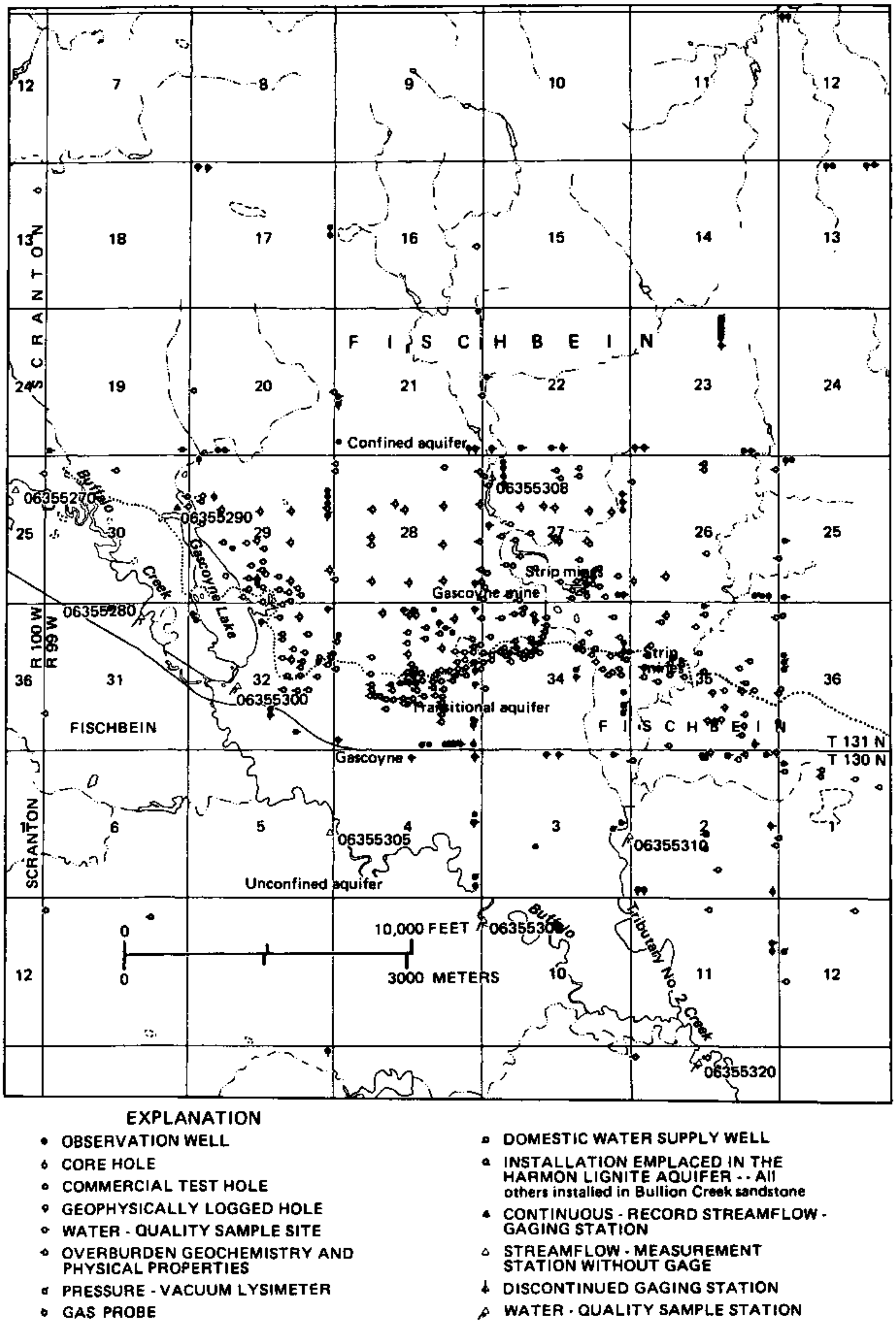

Figure 3.2-1.— Hydrologic data network.
(In part from Boughton and others, 1984, fig. 27.)

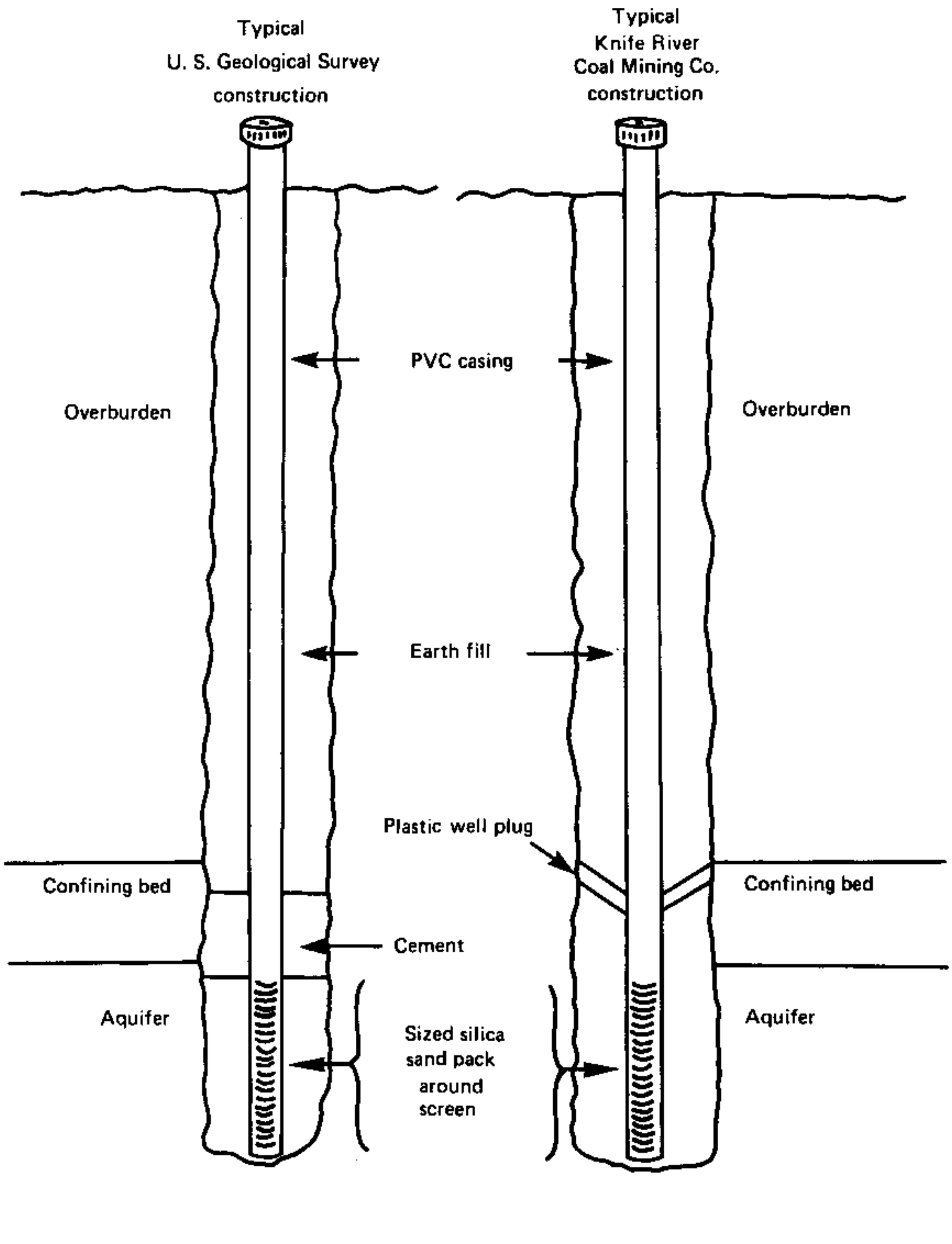

Figure 3.2-2.— Water-quality well designs used in area.

3.0 GROUND-WATER HYDROLOGY

3.3 HYDRAULIC PROPERTIES

HYDRAULIC PROPERTIES NEEDED TO ASSESS PROBABLE HYDROLOGIC CONSEQUENCES OF MINING LIGNITE

The hydraulic properties of each aquifer reflect depositional environment and mine activities.

The hydraulic conductivity, storage coefficient, and transmissivity of the lignite and sandstone aquifers and the confining claystone and siltstone must be known to determine ground-water flow patterns and rates and to evaluate the probable hydrologic consequences of surface mining on ground-water systems. Hydraulic properties for each of these materials in the Northern Great Plains differ widely, because local ground-water flow is controlled by joints and fractures. However, all three hydraulic properties may be determined by specifically designed aquifer tests. Mine production wells and observation wells have usually been adequate for this purpose.

In the Gascoyne area, aquifer tests were conducted at two wells completed in silty sandstones of the Slope-lower Bullion Creek sandstone aquifer. The tests indicated that hydraulic conductivities range from 2.5 to 10 ft/d, storage coefficients are 0.0004 where the aquifer was confined and 0.2 where unconfined, specific capacities range from 0.1 to 0.7 (gal/min)/ft, and computed transmissivities range from 260 to 2,100 gal/d/ft. (35 to 280 ft^2/d). Average hydraulic conductivities of the sandstone aquifer calculated from electric-log curves (6) ranged from 2 to 8 ft/d; these values indicate that geophysical logs collected during mine test drilling may be used to extend the data obtained by other methods and to minimize the necessity for expensive aquifer tests. Results from laboratory tests and field slug tests (5) of hydraulic conductivity, however, indicate that these properties are more variable than determined by the electric-log method. Figure 3.3-1 shows a complex hydraulic conductivity distribution that was used to calibrate a two-dimensional steady-state flow model (31) of the sandstone aquifer. The distribution is based on laboratory determinations. Hydraulic conductivity in the sandstone aquifer ranges from 1.5 to 390 ft/d according to the model results, and the largest hydraulic conductivities form a dendritic pattern corresponding to channel-sand deposits. Smaller hydraulic conductivities characterize levee and overbank siltstones. Hydraulic conductivities calculated from electric logs are in general agreement with this pattern.

Hydraulic-conductivity distributions of the lignite aquifer also indicate a dendritic pattern, which probably reflects fracturing of the lignite beneath saturated sandstones in the overburden. Hydraulic conductivity in the lignite ranges from 1 to about 250 ft/d; an anisotropy is clustered around fracture orientations of about N. 45˚W and N. 58˚E. Additional areas of large conductivity that radiate from active mine pits indicate fracturing of the lignite by mine blasting. The decrease of hydraulic conductivities in both aquifers with depth indicate decreasing fracturing.

Field measurement of the hydraulic conductivity of the claystone confining the sandstone aquifer has not been feasible. Laboratory estimates range from 10^{-6} to 10^{-8} ft/d. Estimates of recharge to the confined sandstone aquifer suggest that larger mean hydraulic-conductivity values for the claystone are the result of fracturing.

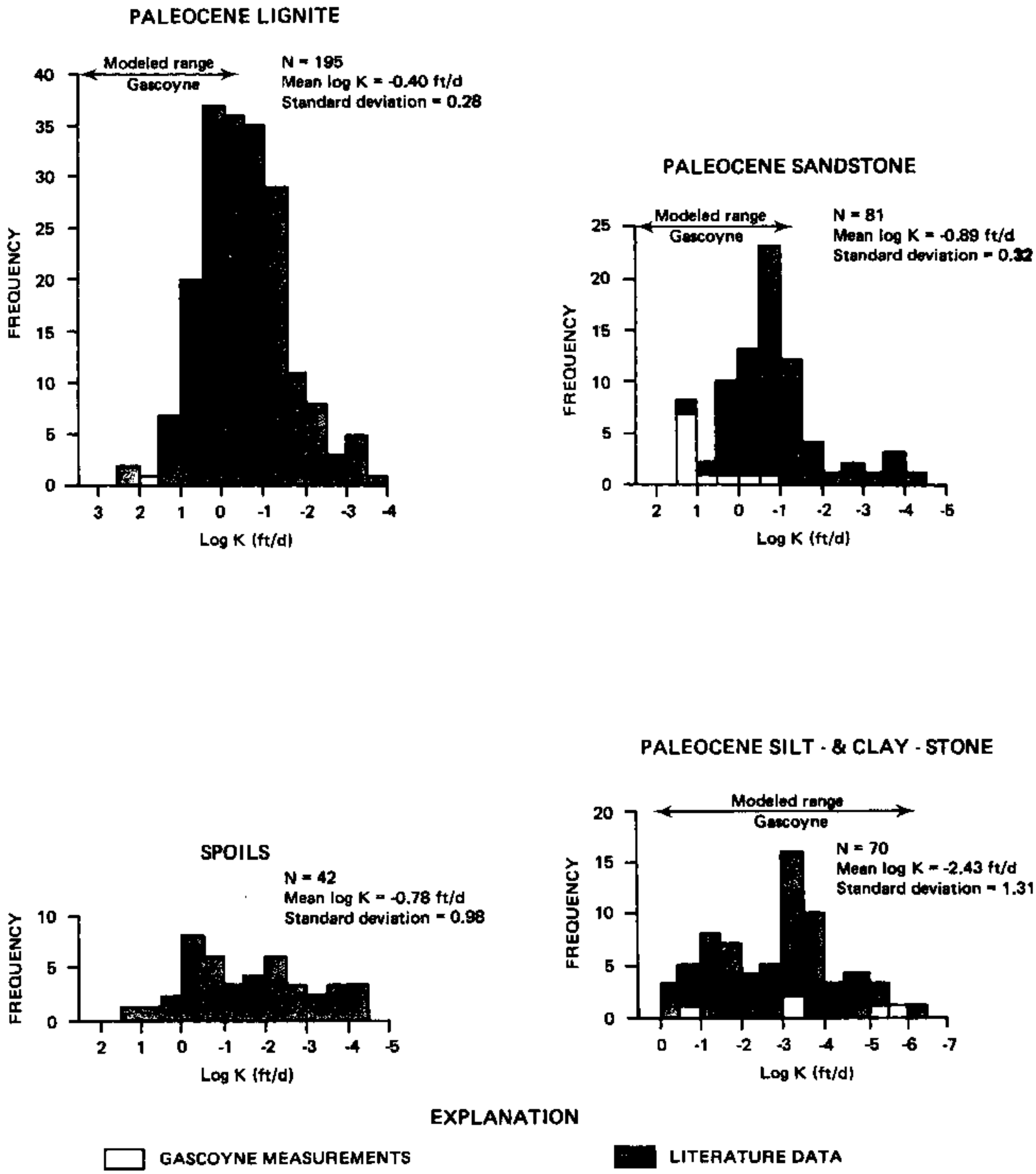

Figure 3.3-1.— Histograms of laboratory determined hydraulic conductivity (K) from the Northern Great Plains.
(Modified after Rehm and others, 1980.)

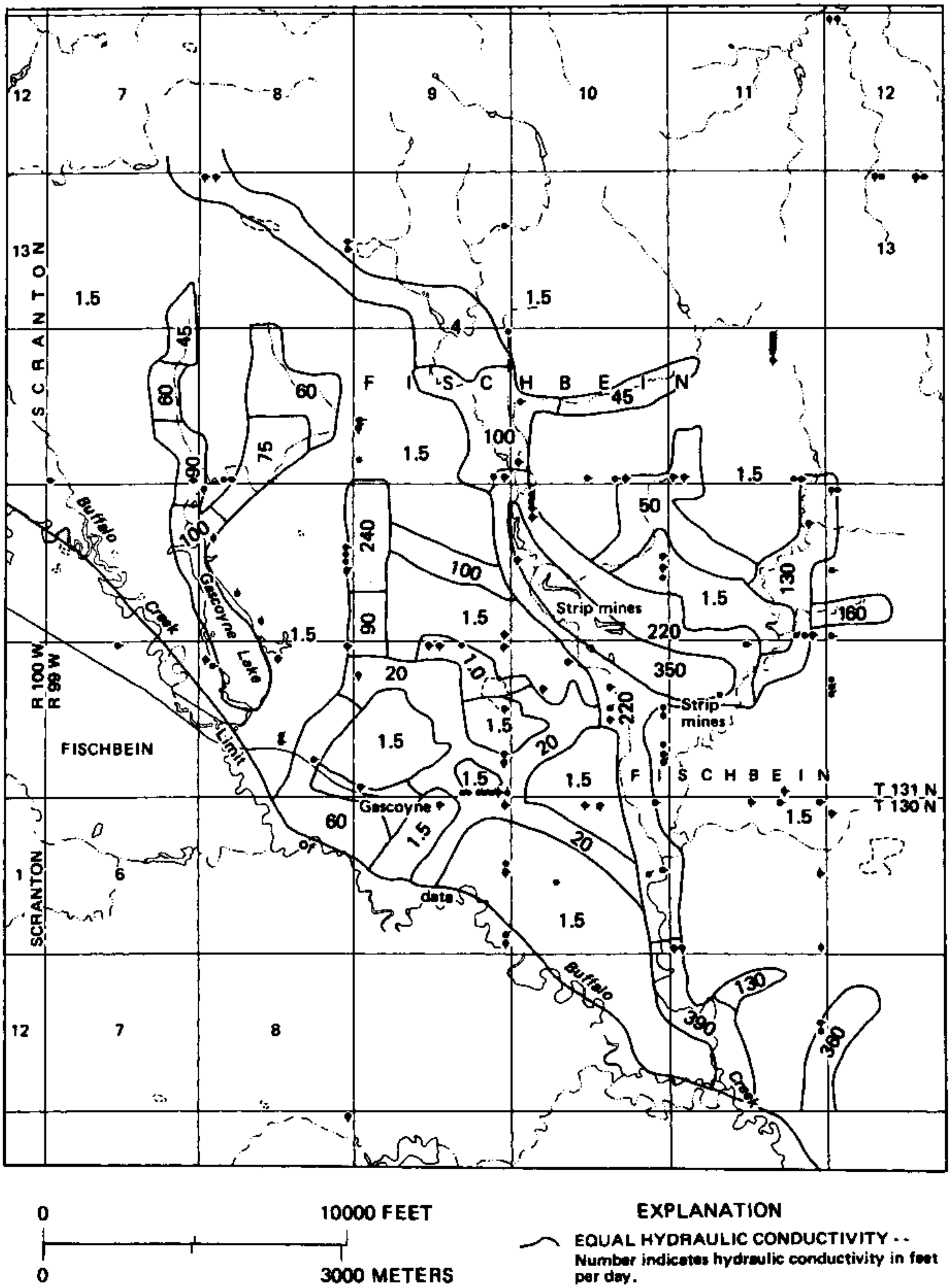

Figure 3.3-2.— Areal distribution of hydraulic conductivity of the basal sandstone of the Bullion Creek Formation.
(From Houghton and others, 1984, fig. 24.)

3.4 POTENTIOMETRIC SURFACES

DEPRESSION OF POTENTIOMETRIC SURFACES BENEATH MINE CAUSED BY DEWATERING.

The potentiometric surfaces of the aquifers reflects variations in lithology and the location of surface-water discharges. Mine dewatering has locally caused ground-water flow reversals where the sandstone aquifer recharges the overlying lignite aquifer in the center of the potentiometric cone of depression.

The potentiometric surface of the Harmon lignite aquifer slopes south toward Buffalo Creek (fig. 3.4-1). Three major southeast-trending lobes persist in the potentiometric surface along the northern border of the mine. Because the potentiometric ridges may be related to sand-channel trends in the overlying Bullion Creek strata, recharge in these areas may be greater. Troughs in the potentiometric surface reflect the generally smaller hydraulic conductivities of interchannel silts and clays as well as seepage from the Harmon to tributaries of Buffalo Creek, The general pattern of the potentiometric surface changed little during the 8 years of the investigation. Water levels fluctuated no more than 3 feet seasonally in response to variations in annual precipitation. The dampened response of water levels to precipitation indicates that infiltrating water may require considerable time to reach the water table.

The potentiometric surface of the Slope-lower Bullion Creek sandstone aquifer is shown in figure 3.4-2. The effects of mine dewatering on recharge of the sandstone aquifer are reflected in a troughlike depression in the potentiometric surface beneath and downgradient from the mine. Deflections of the potentiometric surface from the generally northeasterly regional trend reflect local topography and variations in surface permeabilities that affect the amount of recharge.

In unmined parts of the Gascoyne area, potentiometric heads in the lignite are higher than those in the underlying sandstone aquifer, and the lignite aquifer recharges the sandstone. However, near the mine, the potentiometric head in the sandstone locally may be higher than that in the lignite, reversing the direction of leakage. Two large troughs in the potentiometric surface of the sandstone aquifer have developed beneath the two most active mine pits, where discharge from the sandstone aquifer to the pit is being pumped into surface holding ponds. As pre-mining hydrologic conditions at Gascoyne are not well known, the total effect of mine dewatering activities on the potentiometric surfaces of these aquifers cannot be assessed precisely. However, extension of the regional potentiometric surface for the Slope-lower Bullion Creek Sandstone aquifer through the Gascoyne area indicates that the present cone of depression in the potentiometric surface of the sandstone aquifer due to mine dewatering and aquifer disruption locally may be as much as 65 feet and extend as far as 3 miles beyond the mine perimeter.

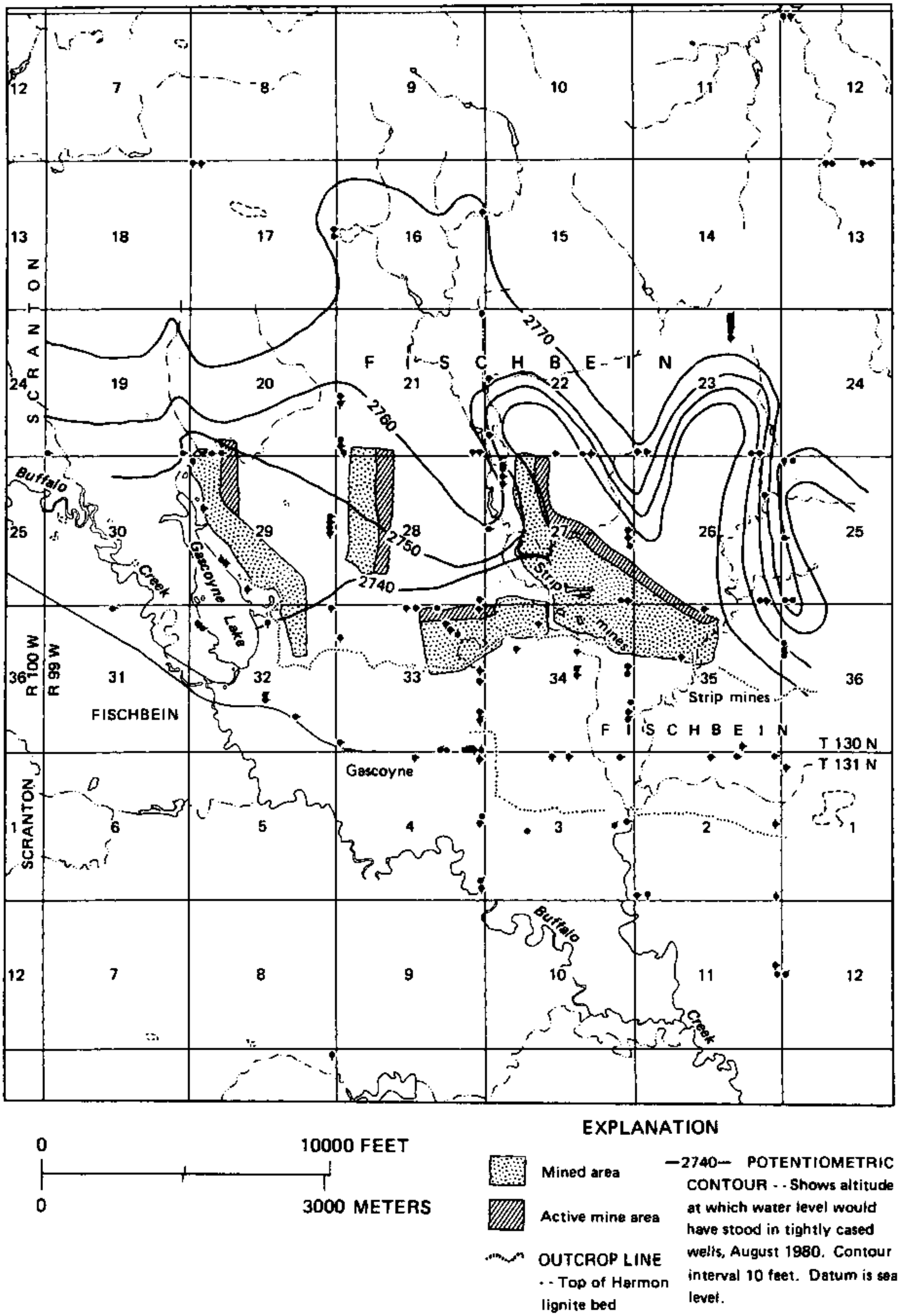

Figure 3.4-1.— Potentiometric map of the Harmon lignite aquifer. (From Houghton and others, 1984, fig. 18.)

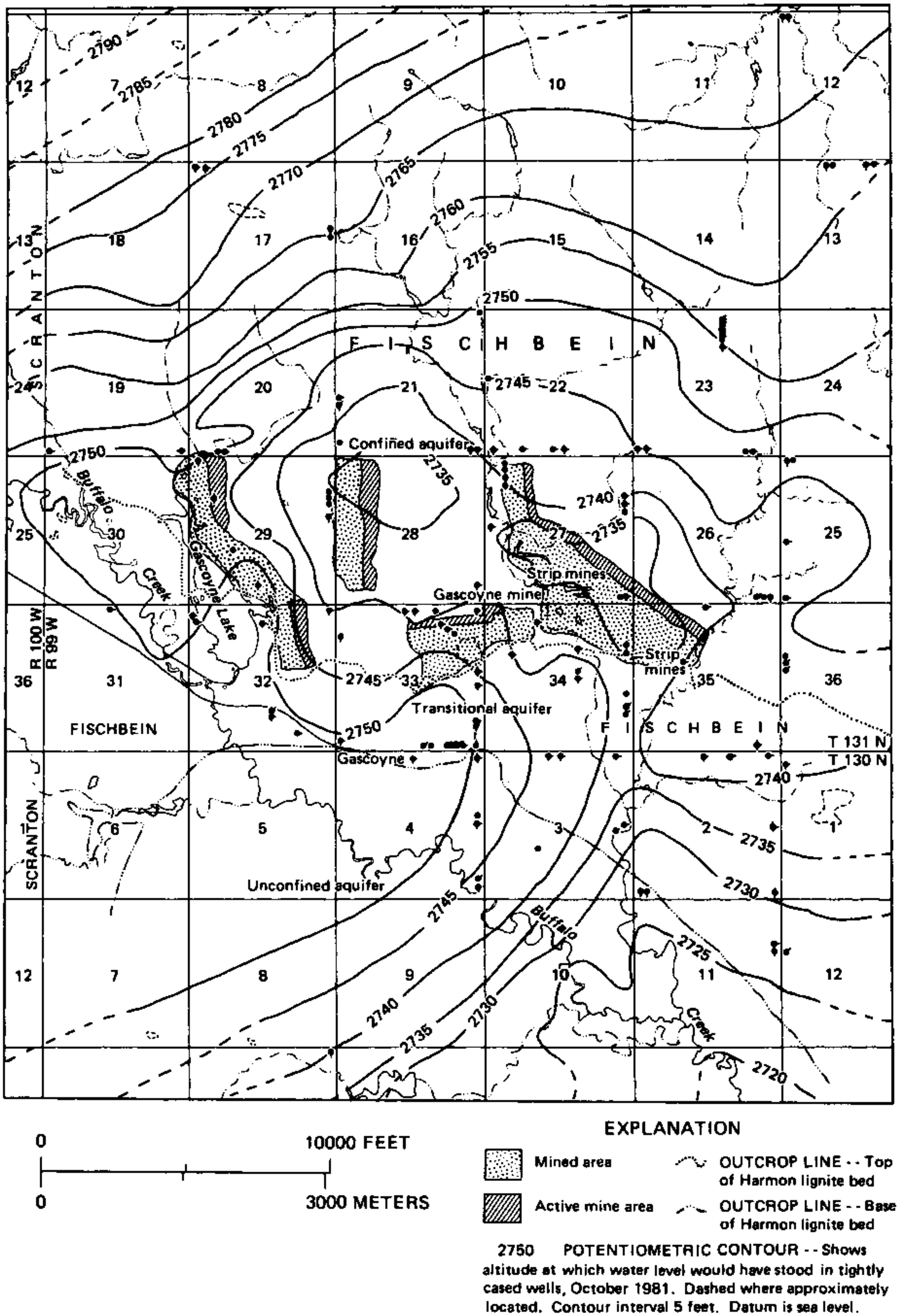

Figure 3.4-2.— Potentiometric map of the Slope-basal Bullion Creek sandstone aquifer. (From Houghton and others, 1984, fig. 25.)

3.0 GROUND-WATER HYDROLOGY

3.5 GROUND-WATER QUALITY

THE LARGEST CHEMICAL CHANGES TO GROUND WATER OCCUR DURING INFILTRATION OF RAIN OR SNOWMELT

Principal ions in water in the lignite and sandstone aquifers are sodium, sulfate, and bicarbonate. Chemical reactions in the unsaturated zone cause the largest changes along the natural ground-water flow path.

Water in the lignite and sandstone aquifers is predominantly a sodium sulfate or sodium sulfate-bicarbonate type (fig. 3.5-1). In general, the sandstone aquifer has larger dissolved-solids concentrations than the lignite aquifer. However, the waters having the largest dissolved solids occur in the lignite aquifer in a narrow band adjacent to its outcrop line. Dissolved-solids concentrations in both aquifers are smallest beneath outcrops of channel sandstones. All the waters analyzed were nontoxic except those within the channel sandstones. Dissolved-sulfide concentrations were small and no methane was detected. Waters in both aquifers generally are slightly saturated with respect to quartz and slightly undersaturated with respect to calcite, dolomite, and gypsum. Waters in the sandstone aquifer are commonly highly colored with organic compounds derived from the lignite. Locally, major seasonal and year-to-year changes in ground-water composition may reflect changes in the quantity and path of percolating water.

As precipitation is the principal source of recharge to the shallow aquifers in the Gascoyne area, the largest chemical changes to ground water occur during infiltration of rain or snowmelt and percolation through the unsaturated zone. Subsequent alteration of water quality within the saturated zone is relatively minor. Laboratory experiments, field observations, and geochemical modeling indicate shallow ground-water quality in the area is controlled mainly by the nine processes detailed in figure 3.5-2. Reaction-path (24) and mass-balance modeling supported by isotopic data indicate organic compounds locally may affect some of the reduction-oxidation reactions. Sulfate concentrations are controlled principally by dissolution of gypsum. In equilibrium, gypsum dissolution should generate sulfate concentrations of no more than about 1,240 mg/L. However, if a sink for calcium is present, such as clay minerals or organic materials having large cation exchange/adsorption capacity, larger sulfate concentrations may occur. Exposure of lignitic compounds, clay minerals, and gypsum, produced by oxidation of iron sulfide minerals, to infiltrating solutions along the lignite outcrop line permits sulfate concentrations in the shallow aquifers to approach 8,000 mg/L locally. Exchange of calcium and magnesium for sodium on sodic clay minerals and lignites generates the observed sodium-sulfate type water. The amount of gypsum present in and just below the root zone exceeds that which would be generated from the available sulfur sources in the Bullion Creek strata. This gypsum accumulated over geologic time as erosion of overlying strata exposed sulfur sources, such as iron sulfide minerals, to the oxidizing environment.

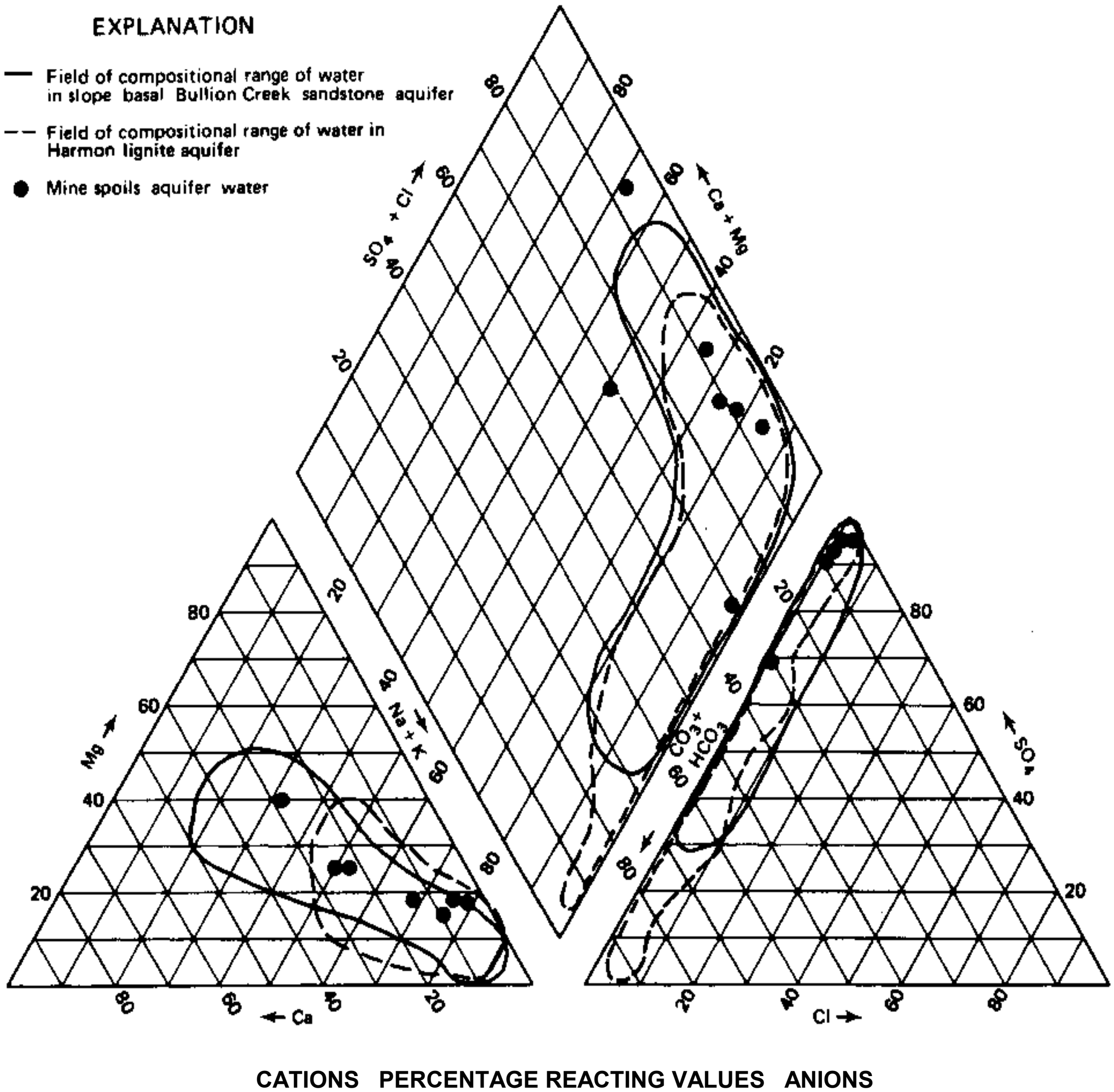

Figure 3.5-1.— Piper diagram of the relationship of major constituents in the mine spoils to the shallow aquifers of the Gascoyne area. (From Houghton and others, 1984, fig. 45.)

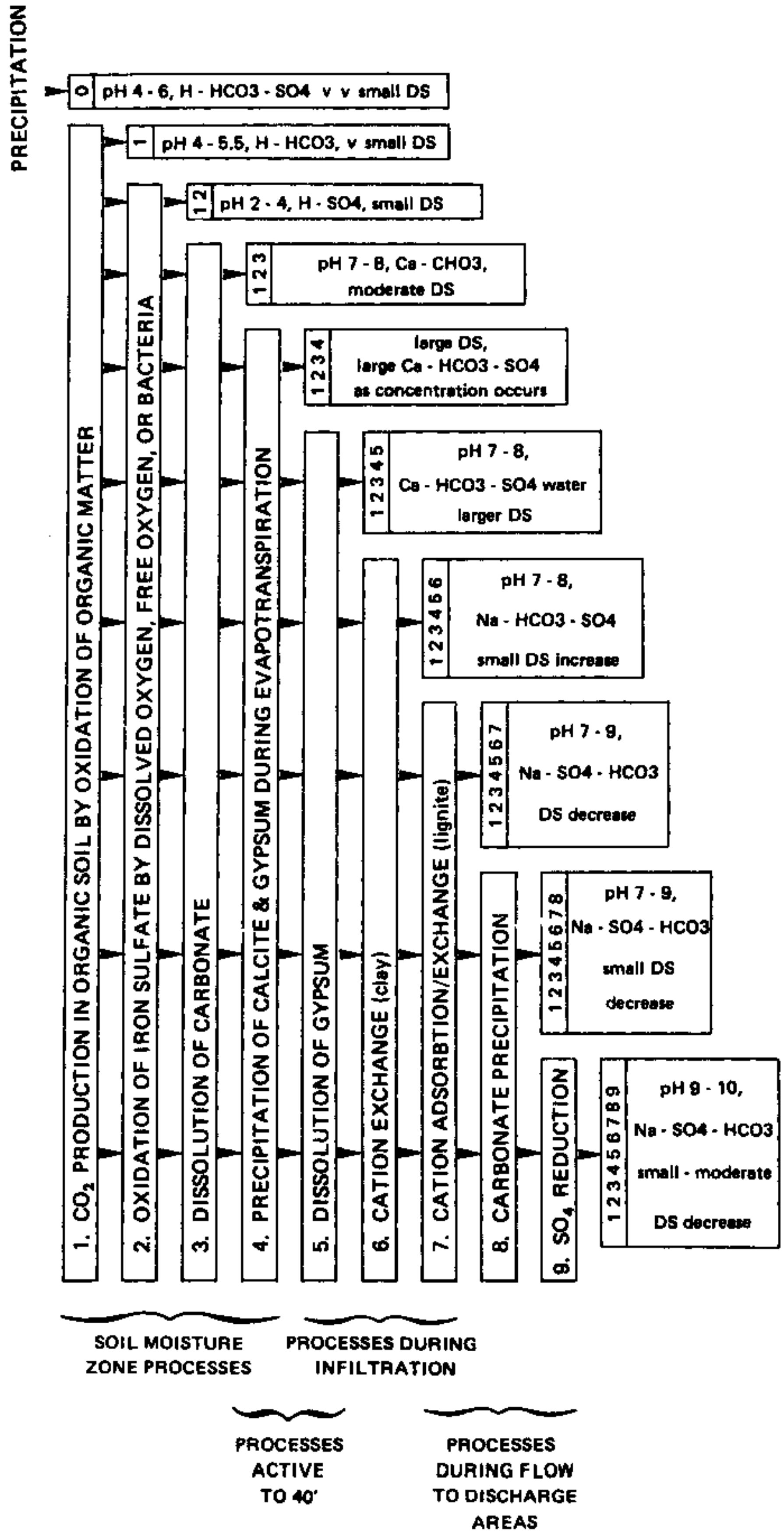

Figure 3.5-2.— Relationships between major geochemical processes and water chemistry in the Gascoyne area.
(Modified from Moran, Groenewold, and Cherry, 1978.)

4.0 HYDROLOGIC CONSEQUENCES

4.1 QUANTITY AND AVAILABILITY OF POST-MINING SHALLOW GROUND WATER

MINE DEWATERING HAS PRODUCED A LARGE CONE OF DEPRESSION WHICH WILL PROBABLY RECOVER 1 TO 3 YEARS AFTER RECLAMATION

As mining in the Gascoyne area disrupts the aquifer recharge area, a decrease in the infiltration potential of surficial materials may be expected to cause post-mining water levels to decline both locally and farther downgradient.

Mine dewatering has lowered water levels continuously in the lignite and sandstone aquifers, thereby producing large potentiometric cones of depression below the mine. Although water levels rebound rapidly when dewatering ceases, the decreased hydraulic conductivities of mine spoils relative to undisturbed overburden imply that mining of this recharge zone may have long-lasting consequences for water levels in these shallow aquifers.

Between 1976 and 1980, water levels in the Harmon lignite in the vicinity of the mine (such as that in well 131-099-19DDD) declined about 2 ft/yr (fig. 4.1-1); however, since 1980 water levels in the lignite appear to have stabilized. Water levels in wells more than 3 miles from active mine pits seemed to be nearly unchanged between 1976 and 1980. Pumping to dewater the lignite at the mine currently exceeds 1,000 gal/min and is believed to be the principal cause of observed water-level decline. Temporary cessation of pumping by mine sumps (point A, fig. 4.1-1) locally resulted in a 1-month 25-foot rise in the water level in the lignite. Water levels in the Slope-lower Bullion Creek sandstone aquifer (such as in wells 131-099-22CCB and 131-099-29BBB) have declined about 1.5 ft/yr since 1978, a rate which may continue for the life of the mine.

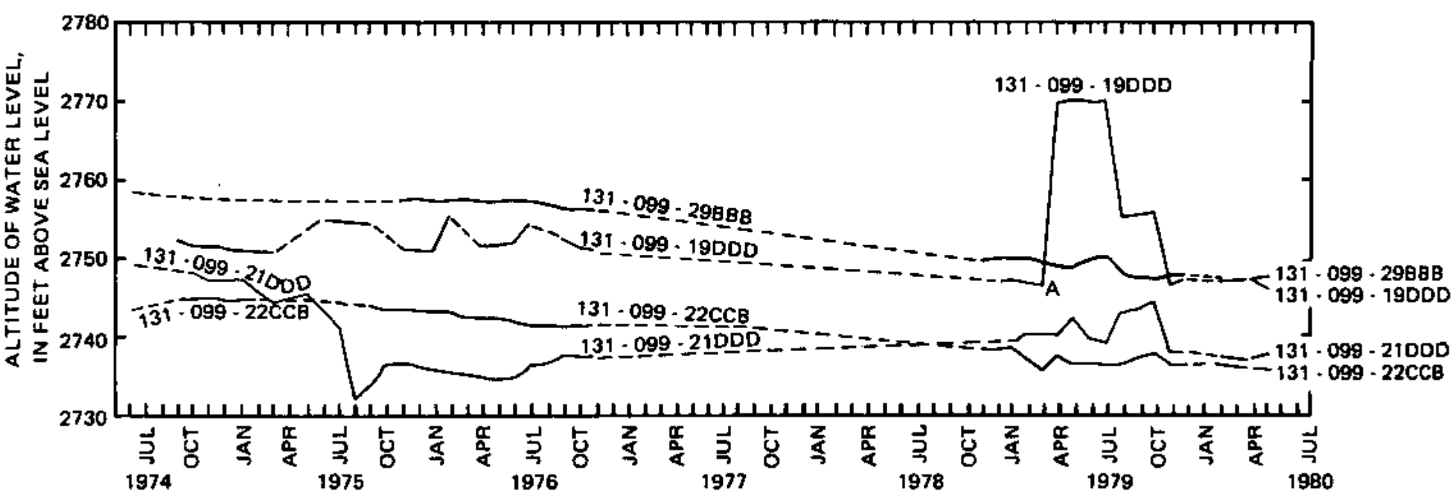

Figure 4.1-1.— Historical water levels in selected wells. (From Houghton and others, 1984, fig. 21.)

Rubble zones at the base of the recontoured spoils are resaturated by lateral flow from the unmined lignite aquifer. Within 3 years, water levels probably will return to pre-mining levels. However, gradual compaction of the spoils may reduce its water-bearing capacity with time (13). The mining process by homogenizing much of the stripped overburden eliminates former zones of larger higher hydraulic conductivity, such as channel sandstones, by mixing them with sediments of lesser hydraulic conductivity, such as overbank siltstones. Young mine spoils from a single site generally have hydraulic conductivities ranging about one order of magnitude. Compaction of the spoils with time may reduce this range even further. Infiltrometer measurements in spoils replacing channel fill differ little from those in spoils replacing overbank silts (fig. 4.1-2). Infiltration rates change rapidly during the first year after reclamation owing to

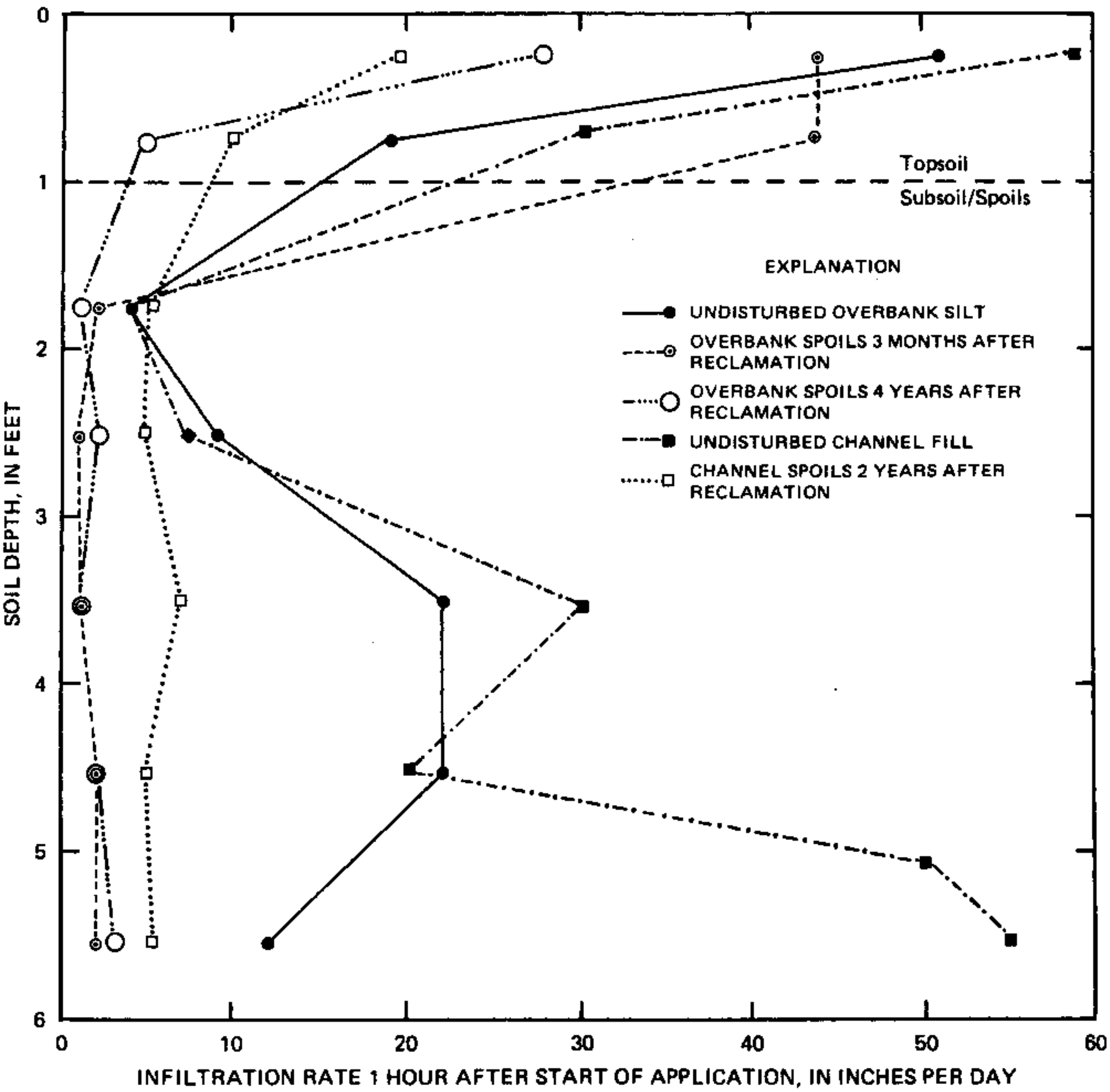

Figure 4.1-2.— Infiltration rate measured by infiltrometer on soil and mine spoils in relation to depth in soil system.

compaction, but the change is slower thereafter. As mining in the Gascoyne area disrupts the aquifer recharge area, reduction in the infiltration potential of surficial materials may be expected to cause post-mining water levels to decline both locally and farther downgradient.

As the spoils aquifer will have significantly less storage and permeability than the lignite aquifer it replaces, alternative water supplies may have to be developed for local domestic and livestock use. The Slope-lower Bullion Creek aquifer generally will be adequate for a limited need, but wells will cost more because this aquifer is deeper than the lignite aquifer. If larger volumes of water are required, the Fox Hills-lower Hell Creek aquifer contains abundant water below the Fort Union strata. However, this deep water commonly contains fluoride concentrations in excess of the drinking-water standard established by the U.S. Environmental Protection Agency (32).

Because water is used to replenish ground-water levels, base flow to Buffalo Creek tributaries has slightly decreased. However, these tributaries have no current use downstream from the mine, so this impact is considered noncritical.

4.0 HYDROLOGIC CONSEQUENCES

4.2 QUALITY OF POST-MINING SHALLOW GROUND WATER

SELECTIVE PLACEMENT OF SPOILS MATERIAL CRITICAL TO MINIMIZING POTENTIAL WATER-QUALITY PROBLEMS

Selective placement of organic- and clay-rich material below the water table and mineral rich, near-surface overburden above the water table may limit significant degradation of post-mining shallow ground-water quality.

Oxidation of iron sulfide minerals exposed during mining and dissolution of resultant sulfate minerals may significantly degrade post-mining ground water. Additional sulfate concentrations may result if near-surface, mineral rich overburden is placed below the water table. Dissolved-solids concentrations in the Harmon lignite aquifer re-established in the rubble zone at the base of the spoils may increase if any of the geochemical processes outlined in figure 3.5-2 are accelerated during mining or reclamation activities. Oxidation of iron sulfide minerals (usually framboidal and micro-crystalline forms of pyrite and marcasite) to sulfate minerals or compounds proceeds to completion during overburden removal and before reclamation begins. Dissolution of these sulfide minerals is the principal source of solutes to the spoils aquifer and significantly enriches the sulfate content adjacent to some mine pits (fig. 4.2-1). However, as natural waters percolating below the root zone are already near saturation with respect to gypsum, increased ground-water solute concentrations in mine waters can result only where sulfate solubilities are increased by complementary reactions removing calcium. Where spoils material is devoid of relict lignite or carbonaceous clays, which remove calcium by cation exchange and adsorption, sulfate concentrations in mine ground waters are not significantly enriched. Larger solute concentrations can result if near-surface overburden enriched in sulfate minerals through geologic time is emplaced below the water table during mining.

Leakage from the spoils/lignite aquifer through the remaining underclay to the sandstone aquifer results in deterioration of water quality in the sandstone aquifer. Selective placement of organic- and clay-rich materials below the water table and mineral-rich, near-surface overburden above the water table may limit significant degradation of post-mining shallow ground-water quality. Increased overburden handling could be accomplished with minimal delays for about 1.1 to 1.5 times normal operating costs (9). If organic-rich material is emplaced in the oxidizing zone (generally the upper 2 to 5 feet at Gascoyne), infiltrating waters are also enriched in trace metals like boron, lithium, lead, and zinc, similar to waters along the lignite outcrop line.

Cation-exchange reactions have depleted sodium in near-surface overburden relative to the rocks at depth. Surface spoils tend to be enriched in sodium by a factor of 2 to 3 over undisturbed rocks, indicating an increased exchange potential. Waters infiltrating surficial spoils are enriched in sodium by exchange. Cycling of the unsaturated spoils waters through the overlying top-soils by evapotranspiration and capillary attraction increases the sodium-adsorption ratio of mine soil waters (fig.4.2-2), which would significantly limit use of the land for some

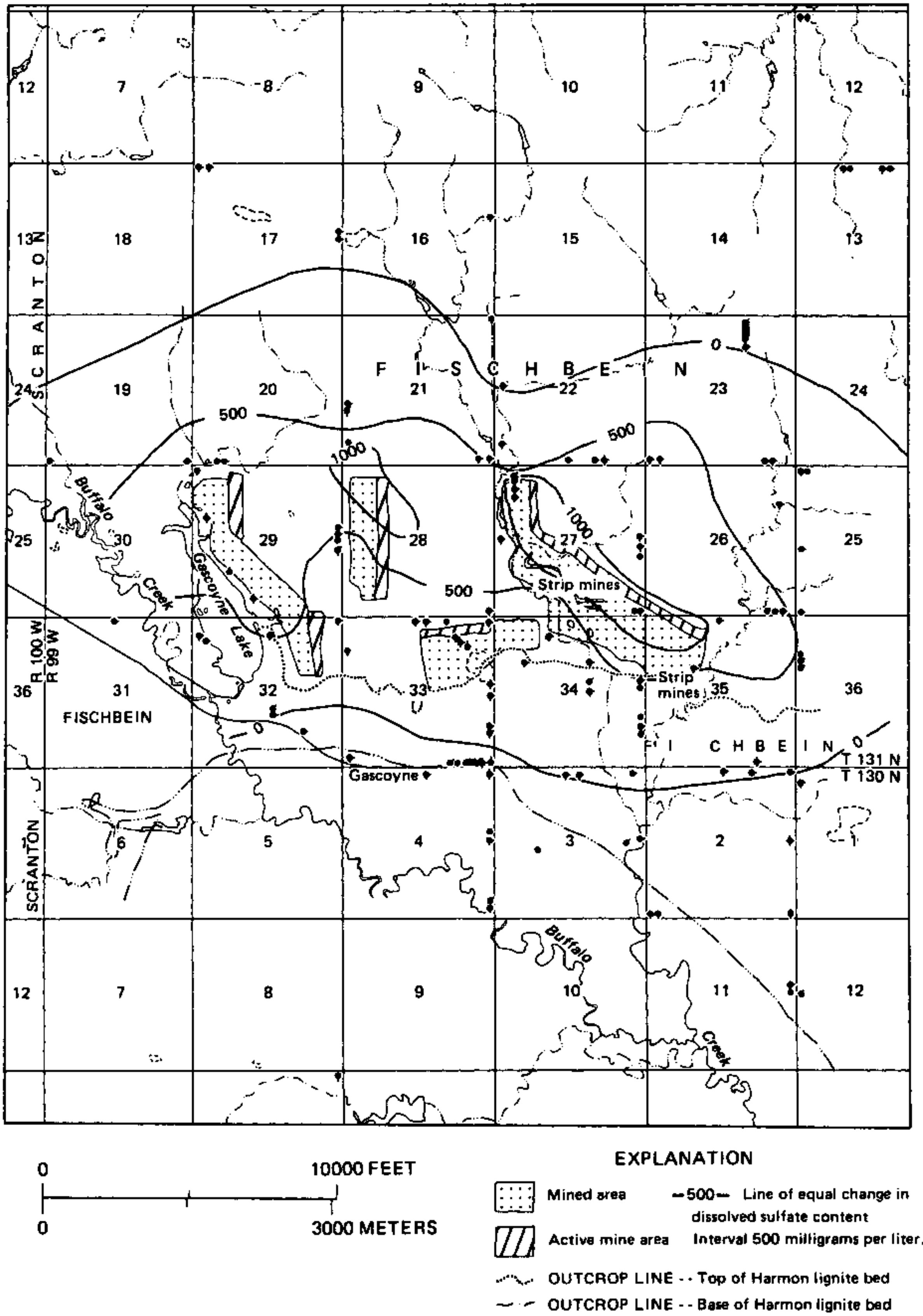

Figure 4.2-1.— Change in dissolved-sulfate concentrations in the Harmon lignite/spoils aquifer, 1976-81.
(Modified from Houghton and others, 1984, fig. 41.)

types of agriculture (19). Standard reclamation methods to reduce the sodium-adsorption ratio in soil water involve application of calcic salts. However, this application only enriches the total sodium-adsorption ratio of water percolating to the water table by making more divalent cations available for exchange with sodium adsorbed on clay minerals and organic materials.

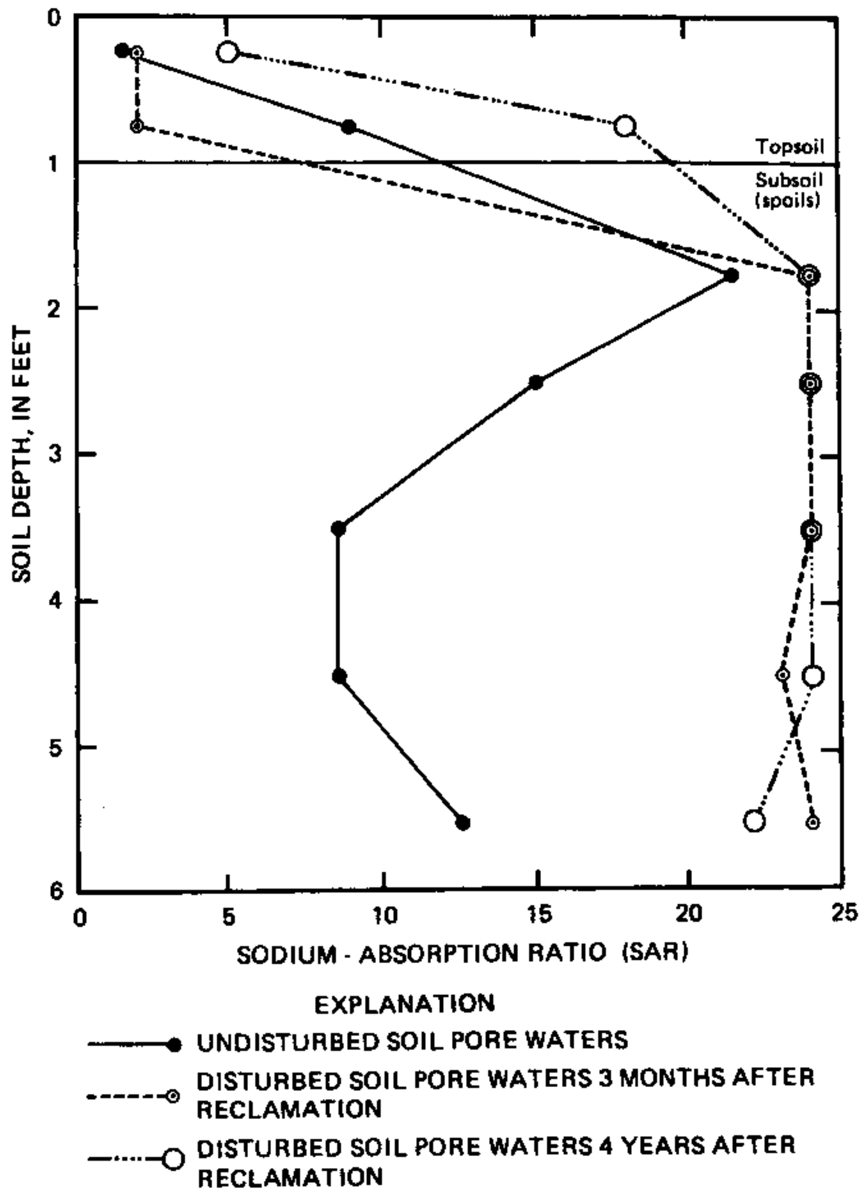

Figure 4.2-2.— Sodium-adsorption ratio of soil waters before and after mine disturbance.

4.0 HYDROLOGIC CONSEQUENCES

4.3 QUALITY OF POST-MINING SURFACE-WATER BASE FLOW

MINE INDUCED DEGRADATION OF GROUND-WATER QUALITY MAY BE REFLECTED IN STREAMS DURING PERIODS OF LOW FLOW.

The chemical quality of low flows in tributaries draining the mine will deteriorate roughly proportional to the amount of basin drainage disturbed by mining, but the chemical quality of Buffalo Creek will be essentially unaffected.

Water in the lignite and sandstone aquifers discharges to Buffalo Creek and its tributaries; therefore, any mine-induced degradation in ground-water quality should be reflected in surface-water quality during periods of low flow. In the Gascoyne area, the dissolved-solids concentrations of natural ground water average about 1,605 mg/L, whereas for mine waters the average is 6,330 mg/L. A plot of dissolved-solids concentrations of base flow of a tributary to Buffalo Creek downstream from the mine (station 06355310 in fig. 3.2-1) versus the fraction of drainage basin occupied by mine spoils from 1974 to 1981 closely approximates the line drawn between natural ground water and mine spoils water in figure 4.3-1. This linear relationship is based on data analyzed for a broad range of areas disturbed by mining in nearby basins (21). Assuming all leased land is mined, 32 percent of the basin of Buffalo Creek would be disturbed and the dissolved-solids concentration of base-flow discharge to the tributary can be expected to increase to about 3,000 mg/L. However, any direct discharge of mine waters to the main stem of Buffalo Creek will be diluted substantially.

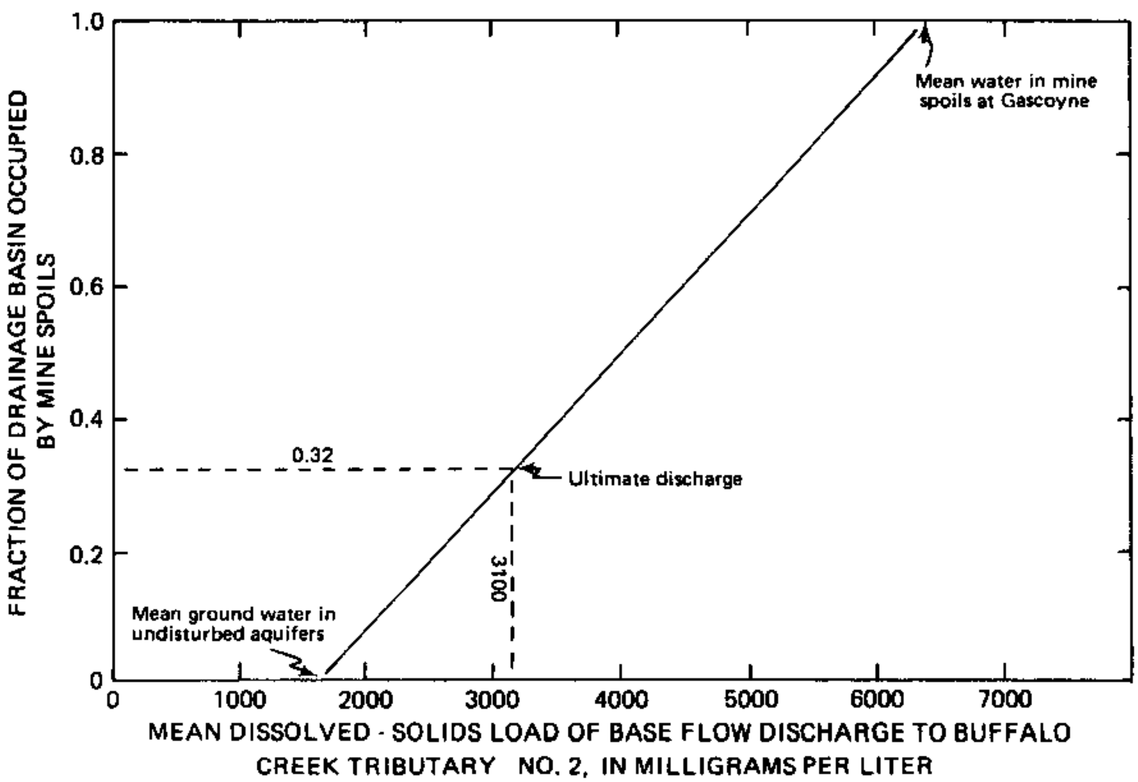

Figure 4.3-1.— Nomograph for determining dissolved solids concentrations of the base flow component of streamflow given the proportion of the drainage basin occupied by mine spoils and the dissolved-solids loads of natural ground water and water in spoils.

5.0 ADDITIONAL LITERATURE RESOURCES

> NUMEROUS STUDIES HAVE BEEN MADE OF IMPACTS OF MINING LIGNITE
>
> Procedures employed during this investigation are detailed in technical manuals and are recommended as a means of acquiring the hydrologic data required to meet mining and reclamation regulations.

Details of hydrogeochemical investigations at Gascoyne summarized here are presented in (15). Similar investigations (12, 22, 23) were made around nearby mines in the Sentinel Butte Formation. Procedures utilized for hydrologic aspects of the investigation are summarized in (1). Procedures for geochemical characterization of overburden, spoils, and their waters are described in (28). Methods for successful reclamation of mined land in the Northern Great Plains are summarized in (25, 27). The methods detailed in these technical reports and utilized in this investigation are judged to be appropriate for the acquisition of data to meet mining and reclamation regulations currently established by State and Federal regulatory authorities.

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