WATER RESOURCES RESEARCH INSTITUTE

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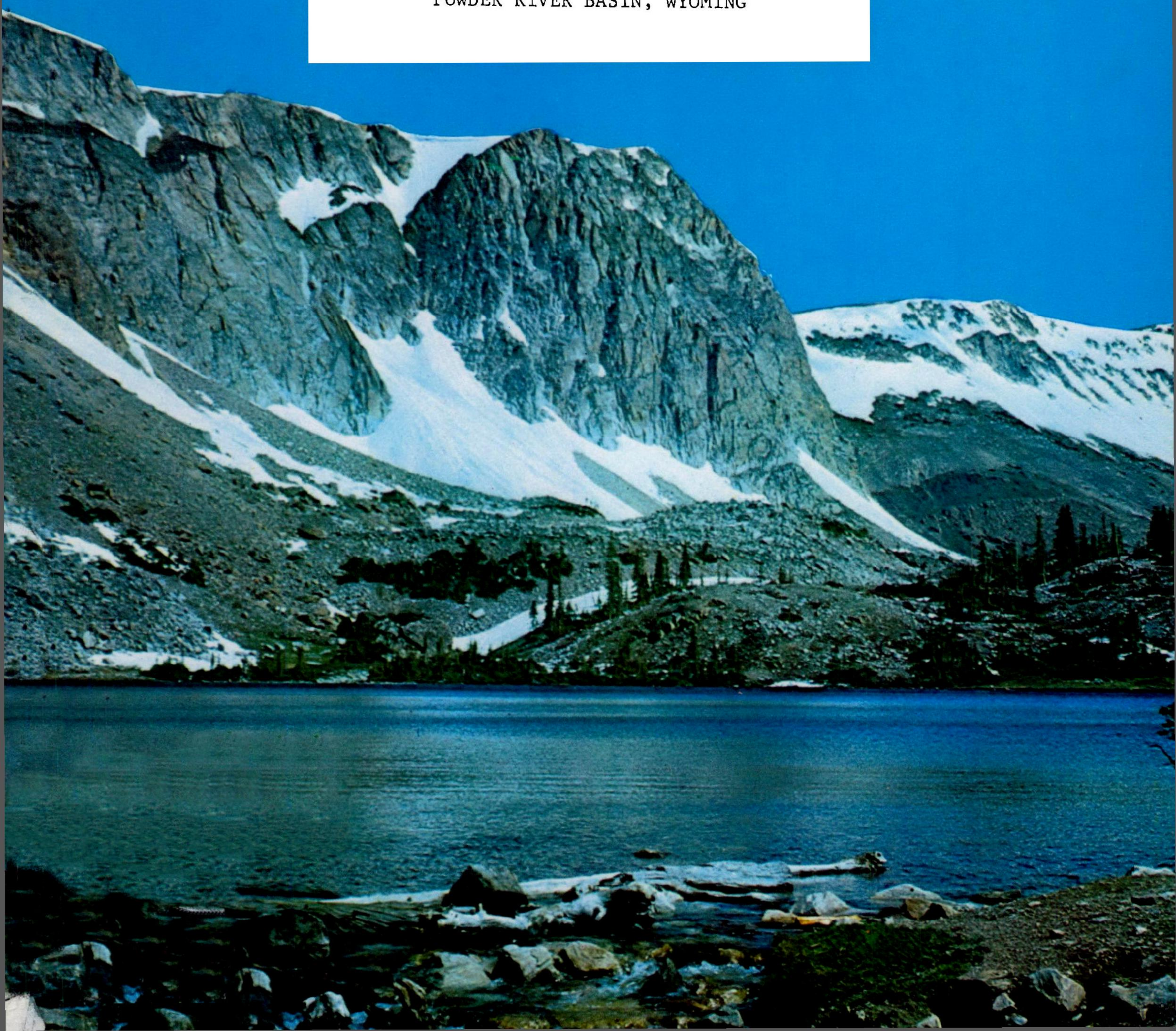
VOLUME I-A

OCCURRENCE AND CHARACTERISTICS OF
GROUND WATER IN THE
POWDER RIVER BASIN, WYOMING



VOLUME I-A

OCCURRENCE AND CHARACTERISTICS OF GROUND WATER IN THE POWDER RIVER BASIN, WYOMING

by

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Report to

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Project Officer
Paul Osborne

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INTRODUCTION

This report is the first of a series of hydrogeologic basin reports that define the occurrence and chemical quality of ground water within Wyoming. Information presented in this report has been obtained from several sources including available U.S. Geological Survey publications, the Wyoming State Engineer's Office, the Wyoming Oil and Gas Commission, the Wyoming State Department of Enviromental Quality, and the Wyoming Geological Survey.

This study was funded by the U.S. Environmental Protection Agency under Contract no. G-008269-79, to provide background information for implementation of the Underground Injection Control Program (UIC). The UIC program, authorized by the Safe Drinking Water Act (P.L. 93-523), is designed to improve the protection of ground-water resources from possible contamination cauded by injection of waste brines, sewage, and other fluids. This report identifies the stratigraphic limits, hydraulic properties, chemical quality, and use of the major water-bearing units within the Powder River basin, and can therefore be used to assist identification of the aquifers in need of protection. This report will also help identify the current extent of knowledge and where future research emphasis is needed within the Powder River basin.

ACKNOWLEDGMENTS

We wish to thank several individuals who greatly aided the completion of this report series. The staffs of the Wyoming State Engineer's Office, the Oil and Gas Commission, the Wyoming Geological Survey, and the U.S. Geological Survey were especially helpful during the data acquisition phases of the project. Marlin Lowry, of the U.S. Geological Survey, reviewed the first report in the series; his comments and criticisms were greatly appreciated. WRRI technical editor Jane Reverand reviewed all manuscripts, and contributed many useful comments concerning report organization and format. JoAnn Foster typed the report series; we are grateful for her diligence, and especially her patience.

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I. SUMMARY OF FINDINGS

I. SUMMARY OF FINDINGS

1. Four major bedrock aquifer systems have been identified within the Powder River basin. These are the Paleozoic Madison, Lower Cretaceous Dakota, Upper Cretaceous Fox Hills/Lance, and Lower Tertiary Wasatch/Fort Union aquifer systems. Additionally, several minor or local aquifers have been identified, including Permo-Triassic aquifers and the Jurassic Sundance aquifer in the northeastern part, Upper Cretaceous aquifers in the western part, Middle Tertiary aquifers in the southeastern part and unconsolidated Quaternary alluvial aquifers throughout the basin. Aquifer recharge rates, ground-water flow paths, and the extent of interformational mixing are poorly known. Data concerning hydrologic and hydrochemical properties are sparse, especially for pre-Tertiary strata in the central basin.

2. The Paleozoic Madison aquifer system has excellent potential for producing large quantities of good quality water, and has been extensively investigated as a result of pending additional developments. The Madison Limestone is the most extensively exploited aquifer of the system, although the Minnelusa/Tensleep and Bighorn/Red River formations also have good development potential. Water from the aquifer system is currently utilized mainly for municipal supply and secondary oil recovery, but proposed future uses also include slurry transport of coal and the synthetic fuels industry. The upper Minnelusa is extensively developed for production of oil and gas through primary and secondary recovery methods.

Aquifer properties are highly variable, are dependent upon secondary permeability, and, with the exception of the Madison aquifer, are very poorly known. Madison Formation transmissivities generally vary from 1,000 to 60,000 gpd/ft, but may exceed 300,000 gpd/ft locally. Specific capacities range from 0.5 to over 50 gpm/ft of drawdown, and are highly yield dependent. Yields generally vary from 600 to 1,200 gallons per minute, but may locally be higher. High-yield wells are often accompanied by several hundred feet of drawdown.

The principal recharge mechanism is outcrop infiltration, and recharge rate estimates for the Madison aquifer of the system range from 8,000 to over 100,000 acre-feet/yr. Although the basal Minnelusa and Madison aquifers are hydraulically connected, little interformational mixing occurs between other aquifers comprising the system, except along structurally disturbed zones.

Near outcrop Madison aquifer waters contain less than 600 mg/l total dissolved solids (TDS) and are primarily calcium-magnesium bicarbonate. Basinward, TDS increases to over 3,000 mg/l with sodium sulfate-chloride predominating. Near outcrop Minnelusa aquifer waters are generally similar to Madison aquifer waters, although some waters in the east part of the basin show higher (up to 3,000 mg/l) TDS and calcium sulfate enrichment. Deep basin Minnelusa waters contain greater than 10,000 mg/l TDS and are primarily sodium chloride. Objectionably high concentrations of fluoride are often present. Chemical data for other aquifers of the system are sparse, but indicate somewhat similar chemistry.

3. The Lower Cretaceous Dakota aquifer system is a potentially important shallow water source in the northeastern part of the basin.

The thick sedimentary sequence can produce large amounts of water at the expense of hundreds of feet of drawdown. Current interest in the aquifer system is limited because in the same area the Madison system is at an economically attractive drilling depth.

The Fall River and Newcastle ("Muddy") formations of the system are significant oil producers through primary and secondary recovery methods. The Lakota and Fall River formations contain important uranium deposits in the Black Hills region.

The lenticular nature of sandstone bodies results in spatially variable aquifer properties. Transmissivity values are poorly known, but are typically estimated between several hundred and several thousand gpd/ft. Specific capacities generally range from 0.1 to 1 gpm/ft. Existing yields are generally under 50 gpm. Higher yields are associated with large drawdowns.

Recharge is primarily through infiltration in outcrop areas. Upper Cretaceous shales (e.g., Pierre) effectively isolate the system from shallow aquifers.

Outcrop waters contain from 277 to 3,300 mg/l TDS. Major ion composition changes basinward from calcium-magnesium sulfate at the outcrop to sodium sulfate to sodium bicarbonate. Deep basin waters contain greater than 10,000 mg/l TDS and are enriched in sodium chloride.

4. The uppermost Cretaceous Fox Hills/Lance aquifer system is utilized for industrial applications in the northeast part of the basin and for municipal supplies in the southwest and northeast.

Aquifer properties are poorly known. Transmissivities vary from about 100 to 2,000 gpd/ft. Specific capacities are generally between

0.05 and 2 gpm/ft. Well yields up to 350 gpm occur, but are associated with long perforated intervals and large drawdowns.

Recharge occurs principally through downward leakage from overlying aquifers, supplemented locally by outcrop infiltration. Discharge is through subsurface flow to the north, and also to some principal stream valleys.

Outcrop waters contain from 350 to 3,500 mg/l TDS, and show a variable major ion composition. Central basin waters contain 1,000 to 3,500 mg/l TDS, and are sodium bicarbonate-sulfate in character. East basin waters often contain objectionable amounts of fluoride.

5. In the central part of the basin the Tertiary Wasatch/Fort Union aquifer system is the most important source of ground water. It is developed extensively by shallow domestic and stock wells and also serves as a water source for several municipalities. The Fort Union Formation contains most of the Powder River basin coal reserves and the Wasatch Formation includes extensive uranium deposits.

Aquifer properties are locally unpredictable due to the widely varying lithologies. Transmissivities vary from 1 to 5,000 gpd/ft but locally clinker values are much higher, ranging up to 3,000,000 gpd/ft. Coal and clinker beds generally have higher transmissivities than sandstones. Specific capacities vary from less than 0.1 to 2 gpm/ft, although clinker wells with over 2,000 gpm/ft are reported. Yields of up to 250 gpm have been attained, but are associated with several hundred feet of drawdown or local recharge. Clinker wells may yield several thousand gpm.

Recharge occurs principally through outcrop infiltration but downward water leakage may also occur. Topographic valleys are important discharge points. Although shallow water circulation is under topographically controlled water table conditions, deeper strata have dominantly stratigraphically controlled horizontal flow. Hydrologic conditions vary from water table to fully confined between and within individual water-bearing zones.

TDS content shows some apparent spatial distribution, ranging from 250 to 6,500 mg/l. Major ion composition varies widely, but deeper zones generally produce waters relatively enriched in sodium bicarbonate. Good quality water is obtainable from water-bearing zones associated with recharge zones.

6. Minor aquifers (Permo-Triassic, Sundance, and Upper Cretaceous aquifers) produce adequate amounts of water for many purposes, but water is of marginal to poor quality for domestic use. The aquifers are only locally exploited, with the Permo-Triassic and Sundance aquifers important in the northeastern part of the basin, and the Upper Cretaceous aquifers important in the southwest. The Sundance and Upper Cretaceous formations are significant oil producers through primary and secondary recovery methods.

Little hydrologic data for these aquifers are available, with the exception of oil field data. Reported water yields are generally small. Recharge is through outcrop infiltration of precipitation, but water circulation through the central part of the basin is likely restricted.

Total dissolved solids often exceed 1,000 mg/l; dissolved sodium sulfate or bicarbonate predominate near the outcrops, and sodium chloride brines in the central part of the basin. Objectionable levels of selenium and fluoride are often present in water from the Upper Cretaceous aquifers.

7. Middle Tertiary aquifers and Quaternary alluvial aquifers are locally important water sources where present in the southeast and in the west and south parts of the basin, respectively, where they provide municipal water supplies.

Reported yields of wells in the Middle Tertiary aquifers exceed 1,000 gpm southeast of the study area; within the area investigated, specific capacities typically range from 0.2 to 4 gpm/ft but can exceed 200 gpm/ft. Precipitation infiltration through outcrops is the principal recharge mechanism.

Wells completed in the Quaternary alluvial aquifers can yield over 1,000 gpm, although much of the yield may be induced recharge from adjacent rivers. Transmissivity of alluvial aquifers is dependent on saturated thickness and sediment size; reported values range from 15 to 64,000 gpd/ft.

Water from the Middle Tertiary aquifers generally has less than 500 mg/l TDS, with dissolved sodium bicarbonate dominant.

Alluvial aquifers often contain water with over 1,000 mg/l TDS, but in places adjacent to the North Platte River TDS concentrations are lower, reflecting the influence of surface water. Alluvial aquifer waters vary in composition, containing sodium, calcium, bicarbonate, and sulfate.

8. Within the Powder River basin, concentrations of water quality parameters that exceed U.S. Environmental Protection Agency primary drinking water standards include selenium, fluoride, radium-226, gross alpha radiation, and occasionally nitrate, mercury, and lead.

Selenium concentrations in excess of 0.01 mg/l Se are geographically confined to the far southwestern part of the basin, and are produced from wells completed in isolated Upper Cretaceous aquifers or associated alluvial aquifers. Fluoride concentrations in excess of 2.4 mg/l F were measured in ground water from a number of geologic formations and many geographic areas within the basin. The Madison system throughout much of the basin, the Fox Hills/Lance in the eastern basin, and isolated Upper Cretaceous aquifers in the southwestern part of the basin typically produce waters with high concentrations of fluoride.

Concentrations of radium-226 greater than the drinking water standard (5 pCi/l) were measured at two Madison aquifer wells, as well as numerous Wasatch/Fort Union wells located near uranium ore zones. Gross alpha radiation in excess of the drinking water standard (15 pCi/l) was measured in two wells from each major pre-Tertiary aquifer system as well as numerous Wasatch/Fort Union wells in uranium ore zones.

Mercury and lead concentrations greater than drinking water standards (0.002 mg/l Hg and 0.05 mg/l Pb) were measured at one mine site in the southwestern portion of the basin in Wasatch Formation ground water. Nitrate levels which exceed the drinking water standard (10.0 mg/l N) are found sporadically in water from shallow wells in several aquifers.

The secondary standards for sulfate (250 mg/l $SO_4^{=}$) and TDS concentrations (500 mg/l) are exceeded throughout much of the basin in all water-bearing units. Waters with less than 500 mg/l TDS concentration are generally restricted to the Madison aquifer system near the basin flanks, to parts of the Wasatch/Fort Union system, and to the Middle Tertiary aquifers and Quaternary alluvial aquifers. Although recommended standards are exceeded, the sulfate-rich shallow ground waters of the basin are used by many of its residents.

9. A precise tabulation of ground-water use by economic sector and source aquifer is impossible until more actual withdrawal data are available. Approximately 128,000 to 148,000 acre-feet of ground water are used each year in the Powder River basin, accounting for roughly one-third of all water used within the basin. Estimates identify the petroleum industry as withdrawing the greatest amounts of ground water, followed by irrigation users and public and private domestic drinking water supplies.

Industry uses roughly 66,000 to 73,000 acre-feet of water within the Powder River basin. Most is ground water withdrawn by the petroleum industry during oil production.

Overall agricultural water use in the Powder River basin is roughly 250,000 to 300,000 acre-feet/yr, of which about 33,000 to 45,000 or more acre-feet/yr is ground water. Irrigation of 37,272 acres accounts for 66 to 76 percent or more (22,000 to 34,000+ acre-feet/yr) of the estimated amount of agricultural ground water used. Stock watering uses about 11,000 acre-feet/yr, derived from the shallowest aquifers in any given area through low-yield intermittent production wells.

Public and private domestic drinking water use totals about 33,200 acre-feet/yr and ground water represents slightly more than three-quarters of the total (25,500 acre-feet/yr). Community supply systems account for 79 percent of the total domestic use. They use 71 percent ground water (18,455 acre-feet/yr), principally from the Madison and Wasatch/Fort Union aquifer systems in the east and central parts of the basin, respectively, and Quaternary alluvial aquifers in the southwest part of the basin. Municipalities in the northwest part of the basin use surface water, while other community systems nearby tap the Wasatch/Fort Union aquifer system. Noncommunity public and private domestic water needs are met by numerous shallow, low-yield, intermittently producing wells at the point of use, and aggregate water use is about 7,000 acre-feet/yr.

II. GEOGRAPHIC AND GEOLOGIC SETTING

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The Powder River basin of Wyoming, sparsely populated and lying far from any large metropolitan areas, is fast becoming a region of major importance, not only to the state of Wyoming but to the nation as well. The cause of this rising interest may be summarized in three words: coal, petroleum, and uranium. With low-sulfur coal reserves in excess of 90 billion tons, annual oil production in excess of 35 million barrels, and one of the nation's largest and most easily exploitable reserves of uranium, the Powder River basin represents one of the greatest energy sources in the United States. Development, utilization, and transport of these resources will require large volumes of water, and place further demands on potable water supplies from the population boom associated with resource exploitation. Projected water needs exceed available surface supplies, indicating increased demands will be placed on ground-water resources.

Within the state of Wyoming the Powder River structural basin (Figure II-1) extends from T. 58 N., at the Wyoming-Montana state boundary southward to roughly T. 27 W., a distance of about 190 miles, and from R. 60 W. at the Wyoming-South Dakota state boundary westward as far as R. 89 W., a distance of about 180 miles. The basin is bounded on the west by the Bighorn Mountains, on the southwest by the Casper arch, on the south by the Laramie Mountains, and on the southeast by the Hartville uplift. For purposes of this study the northern and eastern boundaries of the area are taken to be the Wyoming-Montana

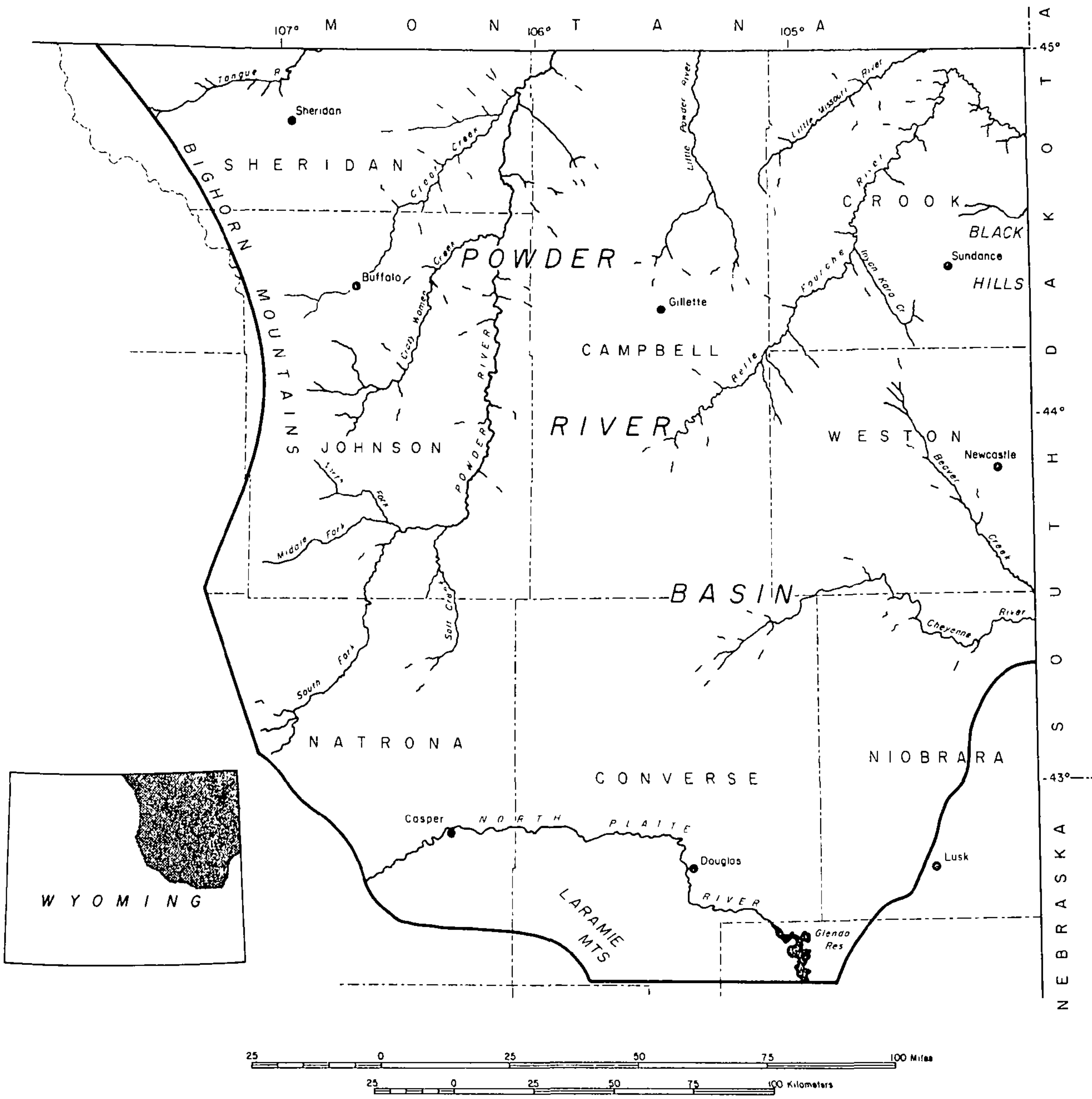


Figure II-1. Geography of the Powder River structural basin, Wyoming.

and the Wyoming-South Dakota state boundaries, respectively. As thus defined and outlined on Figure II-1, the Powder River structural basin has an areal extent of about 25,000 square miles, and includes all of Crook, Weston, and Campbell counties; most of Sheridan, Johnson, and Converse counties; and significant parts of Natrona and Niobrara counties.

PHYSIOGRAPHY

Topography

The topographic basin is typically hilly to rugged upland plains into which meandering streams have incised broad terrace-flanked valleys. Elevation of the basin surface varies from roughly 5,000 feet near the western margin to about 3,100 feet in the east, where the Belle Fourche River crosses the state boundary; locally relief may exceed 400 feet where badlands have formed.

The western margin of the study area lies in the Bighorn Mountains and has a fairly uniform regional elevation of 8,000 to 9,000 feet. West of the area the higher peaks of the Bighorns rise several thousand feet above this level, reaching a maximum elevation of 13,165 feet at the summit of Cloud Peak. The east front of the Bighorns rises abruptly from a narrow band of foothills, which in turn stand 1,000 to 2,000 feet above the adjacent basin.

A part of the Black Hills lies within the study area and forms the eastern margin of the Powder River topographic basin. The Black Hills area is characterized by tree- and grass-covered crests and dissected plateaus with local relief up to 1,650 feet. Elevations in the Wyoming part of the Hills, up to 6,500 feet, generally decrease to the west, where a band of hogback ridges marks the Hills/basin boundary.

The northern Laramie Mountains occupy the southern margin of the area. Crestal elevations are commonly about 9,000 feet but rise to a high of 10,272 feet at Laramie Peak.

Surface Drainage

The Powder River structural basin lies within the Missouri River drainage system. The western part of the basin is drained by tributaries of the Yellowstone River, including the Powder and Tongue rivers. The eastern part is drained by the Belle Fourche, Little Missouri, and Cheyenne rivers. The southern edge of the basin is drained by the North Platte River. The area of each drainage basin, within the limits of the present study, is given in Table II-1.

Climate

The climate of the Powder River basin is semi-arid continental, marked by extreme and abrupt variations in temperature and precipitation. Elevation and topography have a strong influence on local climatic conditions. Annual precipitation averages 12 to 16 inches over most of the lowlands, decreasing to as little as 7 inches per year in the southwest part. Over half of the basin precipitation occurs between April and June. Precipitation is greater at higher elevations, reaching 20 inches per year over the Black Hills and as much as 40 inches per year in portions of the Bighorn Mountains. A significant part of the mountain precipitation is snowfall which contributes to spring runoff.

Table II-1. Selected Missouri River system tributaries present in the report area, listed by tributary rank (shown by indentation), giving selected drainage basin areas included in the study area.

Tributary	Approximate Area (sq. mi.)		Percent of Total Area
(Yellowstone River drainage)	10,420		41
(Bighorn River drainage)		140	
Little Bighorn River[a]			
Tongue River		1,440	
Goose Creek			
Prairie Dog Creek			
Powder River		8,840	
Middle Fork			
North Fork			
South Fork			
Salt Creek			
Dry Fork			
Crazy Woman Creek			
Clear Creek			
Little Powder River[b]			
Little Missouri River	720		3
Cheyenne River	10,810		43
Antelope Creek		1,054	
Dry Fork		473	
Black Thunder Creek		535	
Lodgepole Creek		534	
Lance Creek		2,070	
Lightning Creek			
Beaver Creek[c]		1,330	
Stockade Beaver Creek			
Belle Fourche River[c]		3,740	
Caballo Creek			
Buffalo Creek			
Donkey Creek			
Inyan Kara Creek			
Redwater Creek[d]			
Niobrara River[a]	70		<1
(Platte River drainage)	3,300		13
North Platte River			

[a]Extreme headwater area only.

[b]Joins Powder River in Montana.

[c]Joins Cheyenne River in South Dakota.

[d]Joins Belle Fourche River in South Dakota.

The weighted annual temperature of the area is 44.8°F. Mean monthly averages range from 70°F in July to 21.4°F in January, though daily maximums greater than 110°F and minimums less than -40°F have been recorded.

HUMAN GEOGRAPHY

Population and Employment

Most of the Powder River basin is sparsely populated. The 1970 U.S. Census showed 107,364 persons in the eight counties of the basin. Preliminary 1980 Census data placed the eight county population at 157,052, indicating a 46 percent increase in 10 years. Population distribution is summarized in Table II-2. The three largest municipalities, Casper, Sheridan, and Gillette, account for approximately 50 percent of the total population. About 60,000 persons, representing 38 percent of the total population, reside in rural areas or towns with fewer than 2,500 people.

Agriculture and energy production are the area's major primary industries. Agriculture is dominated by cattle and sheep raising. Oil, uranium, and coal are all contributory to the energy industry, both in extractive and processing stages. In addition, significant employment is provided by government and the trade and service industries. The "boom-town" character and rapid industrial growth of the area have also made the construction industry important.

Land Use and Ownership

Agricultural activities account for about 89 percent of the land use in the basin. While most of this land is range, three percent is utilized as cropland. Mining and petroleum operations, human

Table II-2. Population distribution and change in Powder River basin counties and places within counties.

Area	1960[a]	1970[a]	1980[b]
Campbell County	5,861	12,957	24,363
Gillette	3,580	7,194	12,125
Converse County	6,366	5,938	14,025
Douglas	2,822	2,677	6,009
Glenrock	1,584	1,515	2,738
Crook County	4,691	4,535	5,303
Hulett	-	318	291
Moorcroft	826	981	1,011
Sundance	908	1,056	1,085
Johnson County	5,475	5,587	6,714
Buffalo	2,907	3,394	3,798
Kaycee	-	272	272
Natrona County[c]	49,623	51,264	71,589
Casper	38,930	39,361	50,704
Edgerton	512	350	505
Evansville	678	832	2,648
Midwest	-	604	635
Mills	1,477	1,724	2,152
Mountain View	1,721	1,641	-
Paradise Valley	-	1,764	-
Niobrara County[d]	3,750	2,924	2,928
Lusk	1,890	1,495	1,654
Sheridan County	18,989	17,852	25,025
Clearmont	154	141	191
Dayton	333	396	687
Ranchester	235	208	655
Sheridan	11,651	10,856	15,136
Weston County	7,929	6,307	7,105
Newcastle	4,345	3,492	3,584
Upton	1,224	987	1,206
8 County Region	102,684	107,364	157,052
State	330,066	332,416	468,954

[a] U.S. Census Data summarized in U.S. Department of the Interior, 1974.

[b] 1980 Census of Population and Housing Preliminary Report, U.S. Department of Commerce, Bureau of the Census, October 1980.

[c] 50 percent of county area, predominantly rural, is not within the study area.

[d] 30 percent of county area, including Lusk, is not within the study area.

habitations, and recreation areas occupy the majority of the nonagricultural lands in the basin center. Much of the basin margin land reported as non-farm is part of the Bighorn or Black Hills national forests, managed for multiple uses.

The major portion (67 percent) of basin land is privately owned, although state and federally owned lands are also present. Federally owned land is principally under the jurisdiction of the Bureau of Land Management (central basin) or the U.S. Forest Service (Thunder Basin National Grassland in the east-central basin, Bighorn and Black Hills national forests along the uplifts).

GEOLOGY

Stratigraphy

The Powder River basin has over 16,000 feet of sedimentary strata (Figure II-2), divisible into about 11,000 feet of Cambrian to Cretaceous pretectonic deposits and up to 5,000 feet of Tertiary deposits, associated with regional deformation. The older sequence, exposed only on the basin margins, is economically important for its oil production (see Figure II-2), while Tertiary deposits in the central area contain significant coal reserves. Both the Lower Cretaceous Fall River Formation and the Lower Tertiary Wasatch Formation contain uranium deposits in the Black Hills and central basin, respectively.

Paleozoic rocks are generally marine limestone or sandstones and are relatively uniform in composition and thickness throughout the area. Mesozoic rocks may be divided into three general lithologic sequences. The lowest consists of continental and shallow marine rocks of Triassic to early Cretaceous age, typically shale and claystone.

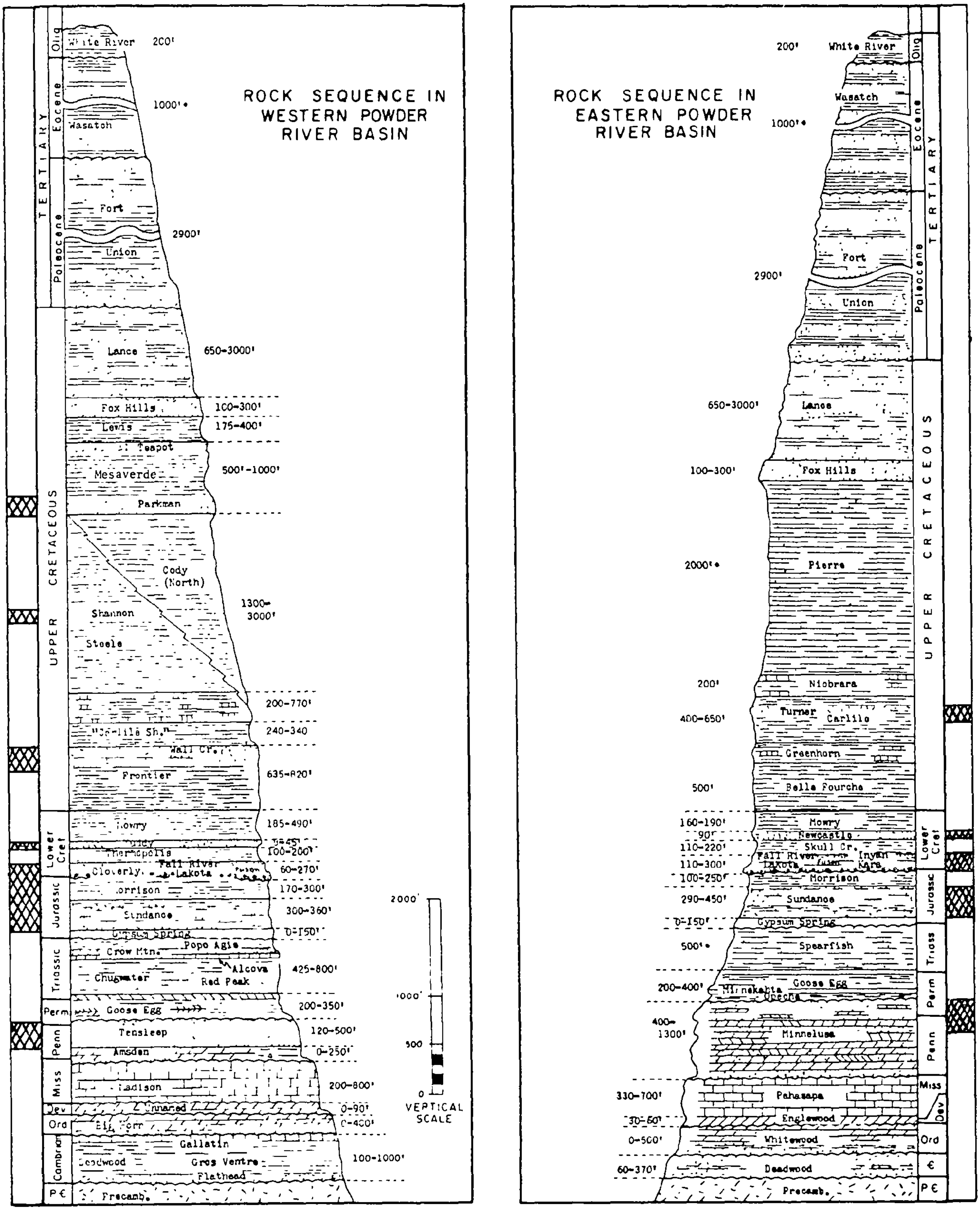


Figure II-2. Diagrammatic stratigraphy of rocks in the Powder River basin, Wyoming, indicating lithologies and thicknesses (from Wyoming Geological Association, 1964). Cross-hatching indicates oil producing zones.

The several recognized sandstone formations are irregular fluvial and deltaic deposits. The middle lithologic unit is a thick marine shale sequence of Upper Cretaceous age which intertongues with several sandstones in the western part of the basin. The uppermost Mesozoic rocks reflect retreat of the Cretaceous sea and include the marine Fox Hills Sandstone and sandy non-marine Lance Formation. Lower Tertiary strata are a thick sequence of variable basin-filling continental rocks that were generally deposited concurrently with uplift of the surrounding mountains. Locally, post-tectonic Tertiary continental rocks reflect the last phase of basin filling. Quaternary deposits include aeolian sands, landslide and slope deposits, and alluvial valley fills and terraces along major streams. Stratigraphic variations of water-bearing bedrock formations are discussed in more detail in Appendix B.

Structure

The Powder River structural basin (Figure II-3), a Laramide feature, is a broad, northwest-trending asymmetric syncline with up to 24,000 feet of structural relief, similar in structural style to intermontane basins to the west. Surrounding tectonic elements are broad uplifted blocks of two types. Mountain uplifts, typically broad asymmetric doubly-plunging anticlines with exposed Precambrian cores, include the Black Hills, Laramie Mountains, and Bighorn Mountains on the east, south, and west, respectively. Broad uplifts of lesser magnitude include the Hartville uplift to the southeast and the Casper arch to the southwest. These major elements are separated from the basin by narrow zones of large vertical relief. These zones include the

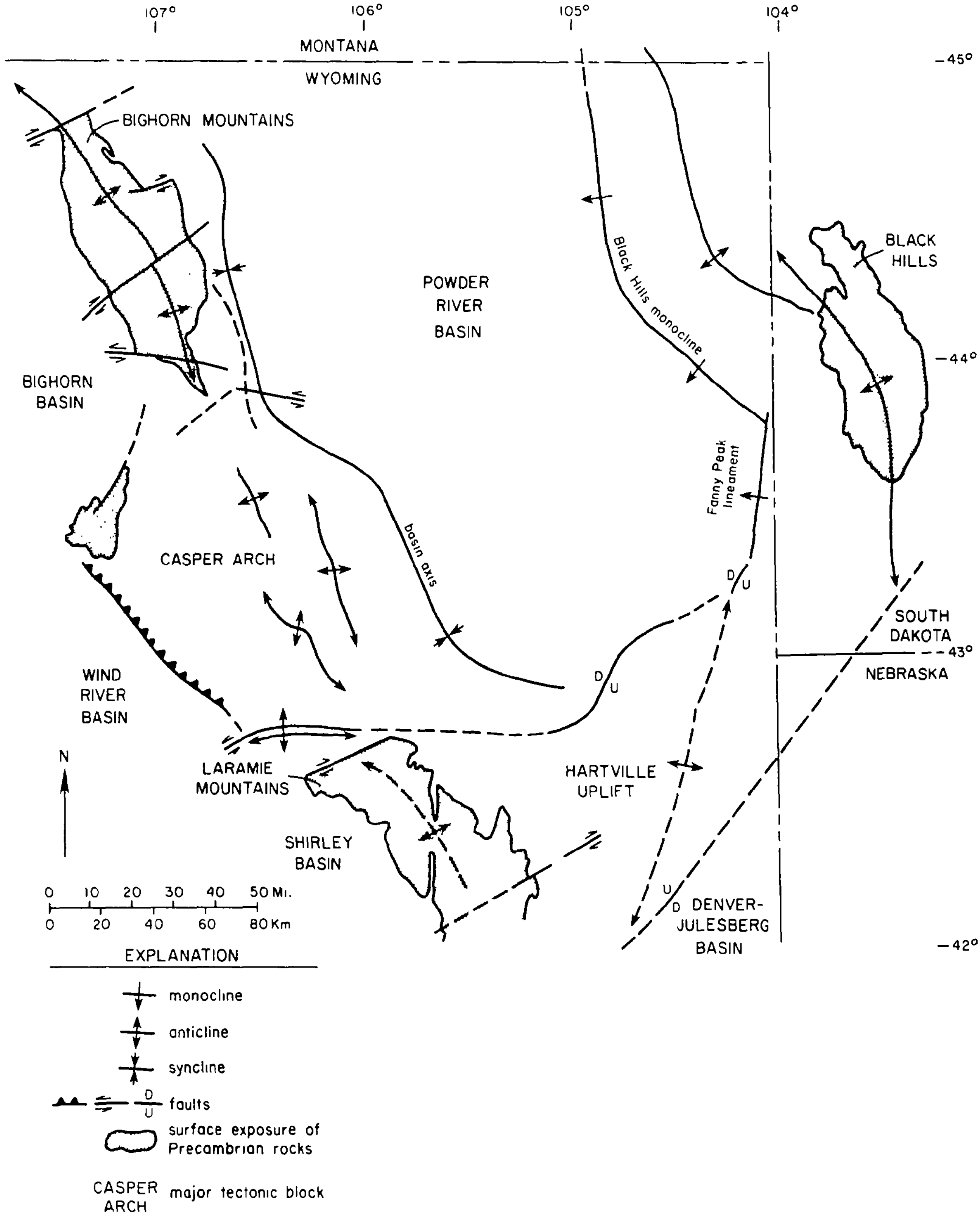


Figure II-3. Tectonic sketch map of Powder River basin, Wyoming and vicinity. Major tectonic blocks shown are: Black Hills uplift (BH), Bighorn Mountains (BM), Laramie Mountains (LM), Casper arch (CA), Hartville uplift (HU), Powder River basin (PRB), Bighorn basin (BHB), Wind River basin (WRB), Shirley basin (SB), and Denver-Julesberg basin (DJB). Structural features shown and named are the Black Hills monocline (bhm), the Fanny Peak lineament (fpl), and the basin axis (ba).

Fanny Peak lineament of Shapiro (1971), on the southeast with up to 2,000 feet displacement (Huntoon and Womack, 1975); the unfaulted Black Hills monocline, on the east; and unnamed structures on the south and west, with fault displacement of up to 4,000 feet (Blackstone, 1980). Subsidiary Laramide structures (see Plate 1) include folds parallel to the major trends, such as the Old Woman and Salt Creek structures, and folds and faults transverse to principal trends, such as those subdividing the Bighorn block.

Hydrostratigraphy

Virtually all geologic formations present within the Powder River basin locally yield water to shallow wells, although many of these formations are not considered "desirable" aquifers due to low yield, poor water quality, or both. Relatively few geologic formations are considered principal aquifers in previous basin-wide studies (Dana, 1962; Hodson and others, 1973), but several additional formations are considered minor water sources in parts of the Powder River basin (Dana, 1962; Whitcomb and Morris, 1964; Whitcomb and others, 1966; Crist and Lowry, 1972; Hodson and others, 1973). Deep burial in parts of the basin has in the past economically precluded development of many "desirable" aquifers.

Figure II-4 identifies the stratigraphic relationships of the principal aquifers, minor or local aquifers, and confining beds within the Powder River basin stratigraphic section. Aquifer systems indicated on Figure II-4 are defined as sequences of geologically similar water-bearing stratigraphic units, bounded by regional confining beds, which have similar recharge and discharge areas and therefore similar ground-

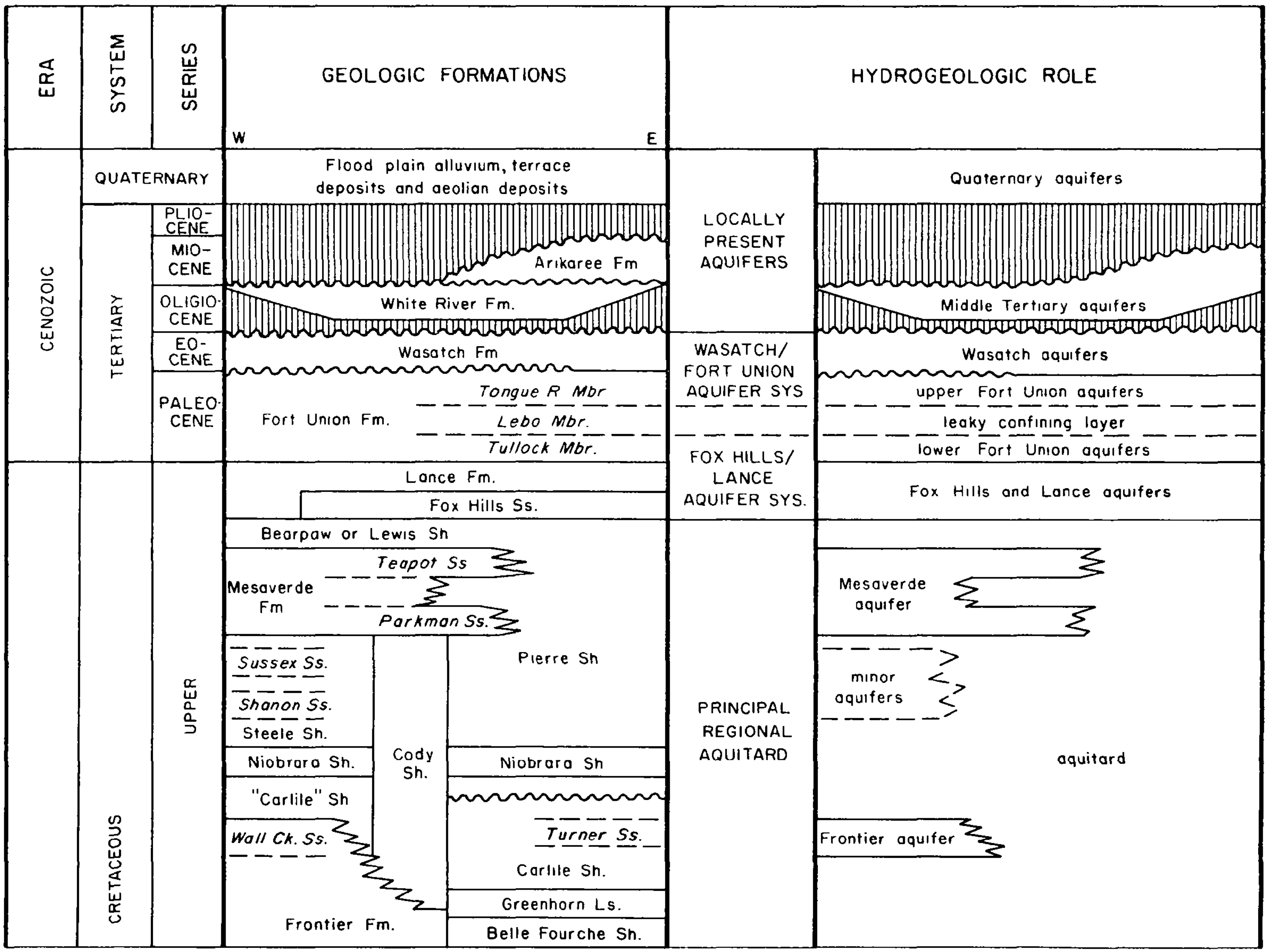
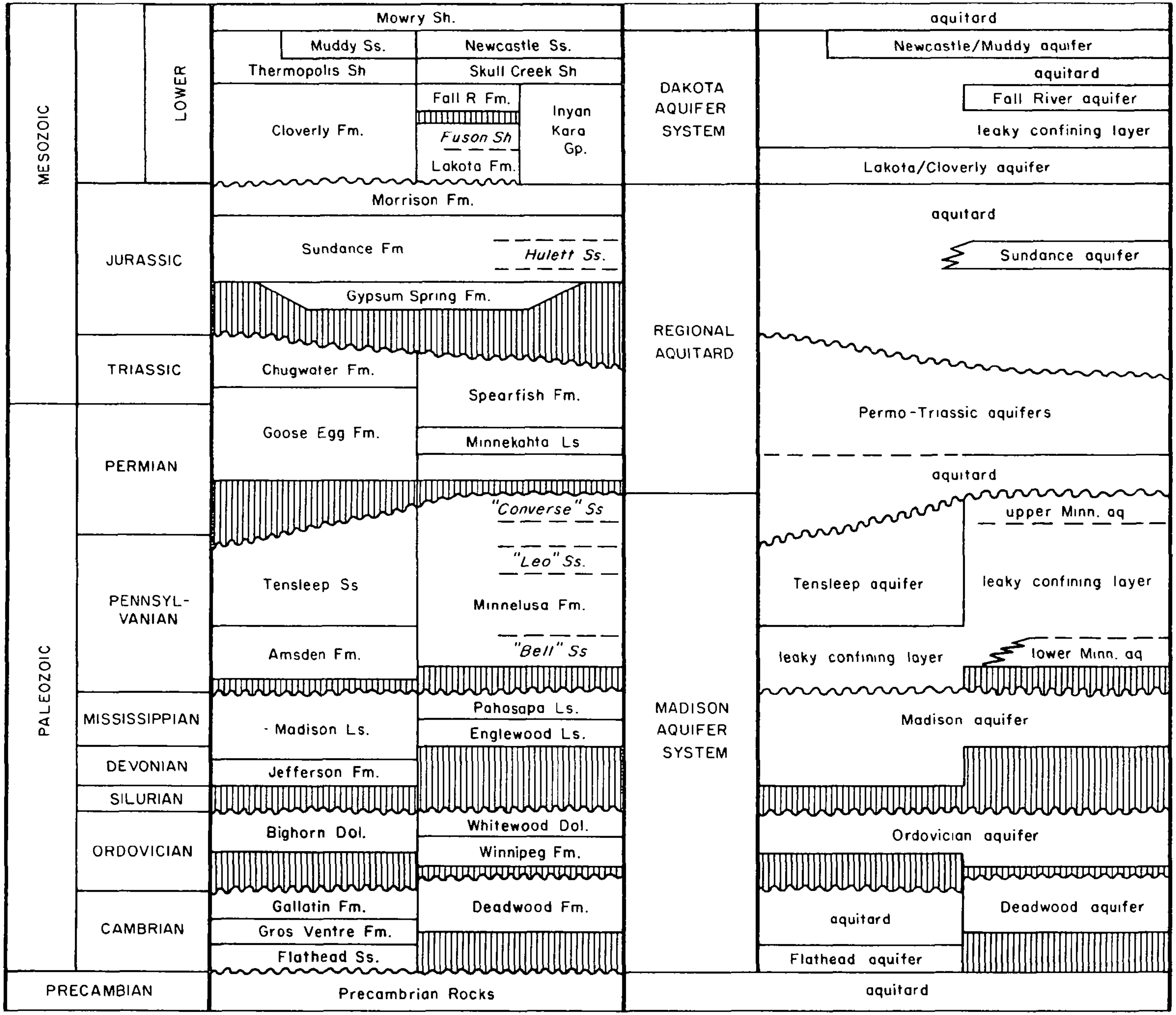


Figure II-4. Diagrammatic hydrostratigraphy of the Powder River basin.


MESOZOIC
PALEOZOIC
PRECAMBIAN
LOWER
JURASSIC
TRIASSIC
PERMIAN
PENNSYL-VANIAN
MISSISSIPPIAN
DEVONIAN
SILURIAN
ORDOVICIAN
CAMBRIAN
Mowry Sh.
Muddy Ss.
Newcastle Ss.
Thermopolis Sh
Skull Creek Sh
Fall R Fm.
Cloverly Fm.
Fuson Sh
Lakota Fm.
Inyan Kara Gp.
Morrison Fm.
Sundance Fm
Hulett Ss.
Gypsum Spring Fm.
Chugwater Fm.
Spearfish Fm.
Goose Egg Fm.
Minnekahta Ls
"Converse" Ss
"Leo" Ss.
Tensleep Ss
Minnelusa Fm.
Amsden Fm.
"Bell" Ss
Pahasapa Ls.
Madison Ls.
Englewood Ls.
Jefferson Fm.
Bighorn Dol.
Whitewood Dol.
Winnipeg Fm.
Gallatin Fm.
Deadwood Fm.
Gros Ventre Fm.
Flathead Ss.
Precambrian Rocks
DAKOTA AQUIFER SYSTEM
REGIONAL AQUITARD
MADISON AQUIFER SYSTEM
aquitard
Newcastle/Muddy aquifer
aquitard
Fall River aquifer
leaky confining layer
Lakota/Cloverly aquifer
aquitard
Sundance aquifer
Permo-Triassic aquifers
aquitard
upper Minn. aq
Tensleep aquifer
leaky confining layer
leaky confining layer
lower Minn. aq
Madison aquifer
Ordovician aquifer
aquitard
Deadwood aquifer
Flathead aquifer
aquitard

water flow paths. Aquifer systems may be locally subdivided by low-permeability units which inhibit hydraulic intercommunication of the aquifers comprising the system. Additionally, aquifers (either local or regional) are defined herein to include district hydrologic units that have recognizable geologic boundaries, and are typically capable of producing adequate amounts of water for exploitation.

For this report, four regionally important bedrock aquifer systems are identified in the Powder River basin. These are the Upper Paleozoic Madison, Lower Cretaceous Dakota, Uppermost Cretaceous Fox Hills/Lance, and Lower Tertiary Wasatch/Fort Union aquifer systems. This four-fold division is similar to regional ground-water concepts of the U.S. Geological Survey (Northern Great Plains Resource Program, 1974; U.S. Geological Survey, 1975, 1979).

Isolated sandstones within the Lower and Middle Mesozoic and Upper Cretaceous shale sequences are locally exploited as aquifers, although their areal importance is currently limited to zones near the outcrops. These sandstones include units in the Sundance and Spearfish formations in the eastern part of the basin (Dana, 1962; Whitcomb and Morris, 1964) and sandstones within the Cody Shale, Mesa-verde, Frontier, and Chugwater formations in the western part of the basin (Hodson and others, 1973; Crist and Lowry, 1972; Whitcomb and others, 1966). The Minnekahta Limestone also has water-bearing potential in the northeastern part of the study area.

In the southeastern part of the basin the Middle Tertiary Arikaree and White River formations are exploited, where present, by shallow wells with low yields. These local aquifers have only limited importance due to their small areal extent within the basin.

Unconsolidated Quaternary alluvial and terrace deposits are only present along major stream valleys but, where near population concentrations, have been extensively exploited as water sources.

The principal regional aquitard in the Powder River basin is the thick Upper Cretaceous shale sequence (including the Pierre and its equivalents), which is an effective barrier to ground-water flow and divides the deep (Madison and Dakota) and shallow (Fox Hills/ Lance and Wasatch/Fort Union) aquifer systems of the basin (Northern Great Plains Resource Program, 1974). Aquifers below the Pierre Shale are exposed only on the basin margins and have been deformed in the peripheral zones of structural disturbance. The regional flow patterns and geochemical trends of waters in these aquifers indicate principal recharge from the basin margin outcrops and also show discontinuities across intensely deformed zones. In contrast, aquifers above the Pierre occupy the less deformed basin center and are often exposed over large areas. The shallower flow patterns are more localized and reflect outcrop recharge and discharge, and also vertical leakage between aquifers. Geochemical trends are less well defined, and reported trends are often related to well depth, as an indicator of flow path length.

III. GROUND-WATER USE

III. GROUND-WATER USE

Ground water is utilized for domestic, municipal, industrial, and agricultural purposes within the Powder River basin. Lack of accurate records prevents precise quantification of the amounts of ground water used; this chapter reports estimated consumption by economic sector and also identifies the principal source aquifers. Appendix A details more fully community and industrial water use.

Approximately 128,000 to 148,000 acre-feet of ground water are used annually in the Powder River basin. Table III-1 summarizes amounts used by economic sector and source aquifers. Although the largest number of wells are permitted for private domestic and/or stock use, irrigation, municipalities, and the petroleum industry use the largest amounts of ground water. The principal sources of ground-water withdrawals in the basin are the Madison and Wasatch/Fort Union aquifer systems and Quaternary alluvial aquifers. Ground water accounts for roughly one-third of all water used within the basin, and over three-quarters of the non-irrigation water use.

Increased energy resource development, coupled with population growth, is placing new and large demands on sources of water for industrial and municipal use. Planned coal transport by slurry pipeline and synthetic fuel production indicate future additional water needs within the basin. Water consumption in the year 2020 is projected to be more than double present usage (Wyoming Water Planning Program, 1973).

Table III-1. Estimated annual use of ground water in the Powder River basin, Wyoming, by economic sector, indicating principal sources.

Economic Sector	Annual Water Use (acre-feet)	Principal Water Source
Domestic Use		
Municipal	16,378	Madison and Wasatch/Fort Union aquifer systems, Quaternary alluvial aquifers.
Non-Municipal Community	2,077	Wasatch/Fort Union aquifer system.
Non-Community	559	All shallow aquifers.
Private	6,500	All shallow aquifers.
Industry		
Petroleum — by-product water	59,645	All deep aquifers.
Petroleum — secondary recovery fresh (make-up) water	4,414+	Madison and Fox Hills/Lance aquifer systems.
Petroleum Refining	65+	Madison aquifer.
Coal Mining	1,200 - 7,400	Wasatch/Fort Union aquifer system.
Power Generation	1,147	Madison and Wasatch/Fort Union aquifer systems.
Uranium Mining	2,860 - 5,310	Wasatch/Fort Union aquifer system.
Agriculture		
Stock Watering	<11,000	All shallow aquifers.
Irrigation	22,000 - 34,000+	Quaternary alluvial aquifers, Madison aquifer system, Middle Tertiary aquifers.
TOTAL:	<127,845 - 148,495+	

Source: Compiled from various sources; see tables in Appendix A.

Further development potential of surface water is limited, and estimated at about 224,000 acre-feet/yr (Wyoming Water Planning Program, 1973). The Little Missouri and Cheyenne rivers have little additional dependable water available. A court decree limits development of additional supplies from the North Platte River. Interstate compacts govern development of the Tongue, Belle Fourche, and Powder rivers, and withdrawal of additional water from these drainages would entail construction of storage facilities.

Full development of surface water within the next thirty years is unlikely; therefore, deficit water requirements must be met by either transbasin diversions of surface water or additional development of the ground-water resources of the basin. Most present development pressure is on the Madison aquifer system because it is perceived as the least expensive source of large quantities of good quality water for municipal and industrial use (see, for example, Wyoming Water Planning Program, 1977, p. 37-51).

DOMESTIC GROUND-WATER USE

Drinking water supplies can be divided into public and private systems. Public systems are further divided into community supplies (more than 25 permanent residents served), which may be municipally or privately owned, and non-community supplies (less than 25 permament residents but a transient population of greater than 25 served). Within the basin 21 municipal, 75 non-municipal community, and 99 non-community systems are inventoried by the U.S. Environmental Protection Agency (see Table III-2 and Figure III-1).

Table III-2. Public water supply systems in the Powder River basin, Wyoming.

County	Community Supplies: Population Served	Community Supplies: Number of Systems[a]	Community Supplies: Average Production[b] gal/day	Community Supplies: Average Production[b] AF/yr	Non-Community Supplies: Population Served	Non-Community Supplies: Number of Systems	Non-Community Supplies: Average Production[b] gal/day	Non-Community Supplies: Average Production[b] AF/yr
Campbell	19,270	1/35	1,732,200	1,942	1,485	10	62,325	70
Converse[c]	10,849	2/7	2,054,975	2,303	3,800	19	192,325	216
Crook	2,920	3/3	415,075	465	1,135	12	14,825	17
Johnson[c]	5,080	2/3	629,100	705	1,020	11	25,100	28
Natrona[c]	62,529	5/14	12,261,300[d]	13,744[d]	17,670[e]	18	155,100[d]	174[d]
Niobrara	234	1/2	64,450	72	75	1	750[d]	0.8[d]
Platte	450	1/0	20,000	22	670	7	17,625	20
Sheridan[c]	15,550	4/8	5,375,030[d]	6,025[d]	1,610	18	27,420[d]	31[d]
Weston	6,870	2/3	781,200[d]	876[d]	135	3	2,800	3.1
TOTAL[c]	123,752	21/75	23,333,330[d]	26,155[d]	27,600[e]	99	498,270[d]	559[d]

[a]First number is municipal systems, second is nonmunicipal systems; municipal systems account for majority of population and production.

[b]Includes some water used for industrial or agricultural purposes.

[c]Some community supplies are wholly or partly surface water (see Table A-1, Appendix A).

[d]Includes water purchased from other systems; it is unknown if amount is included in seller's production.

[e]Includes a bottled water company reported to be serving 15,000 people.

Source: U.S. Environmental Protection Agency, 1979.

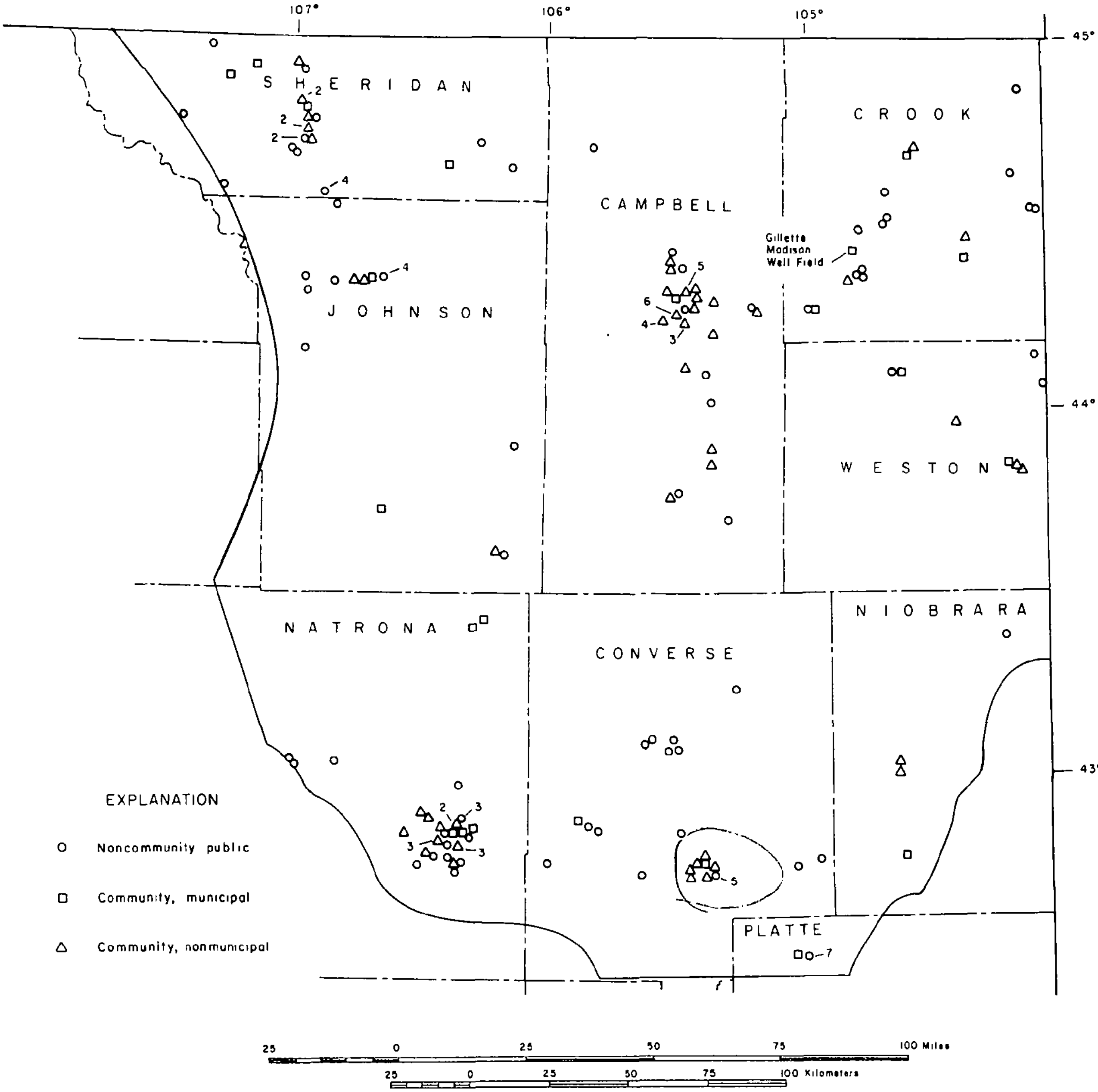


Figure III-1. Location of public drinking water supplies inventoried by the U.S. Environmental Protection Agency in the Powder River basin, Wyoming. (Six non-community and eight community systems included in the inventory are not precisely located; six are trailer parks near Gillette.)

The total number of permitted municipal and domestic water supply wells in the basin is 5,375 (Wyoming State Engineer's Office, computerized data base, February, 1980). The locations of these wells are shown on Plate 2, which also identifies source aquifers. Table III-3 summarizes the aquifers most often exploited for municipal, non-municipal community, non-community public, and private domestic water supplies.

Estimated public and private domestic drinking water use is about 33,200 acre-feet/yr, of which at least 7,700 acre-feet/yr is supplied by surface water. Use figures include commercial, industrial, and lawn watering applications, as well as water for direct human consumption. Based on current total basin population and use of 180 gal/day per capita, total domestic water use in the basin is estimated at 31,300 acre-feet/yr, in close agreement with the total derived from estimates of use by each supply class.

Community Systems

Community water supply systems are divisible into municipally and privately owned and operated systems and produce an average of 26,155 acre-feet/yr (Table III-2). Ground water supplies as much as 71 percent (18,455 acre-feet/yr). Municipalities account for 92 percent of the total production, and all the surface water use.

Municipal Systems

Municipalities within the Powder River basin depend upon groundwater sources for much of their water supply (see Appendix A, Table A-1). Ground water is used exclusively as a water source by Clearmont, Edgerton, Gillette, Glendo, Hulett, Manville, Moorcroft, Newcastle, Sundance,

Table III-3. Sources of water for municipal, community, non-community public, and private domestic supplies within the Powder River basin, Wyoming.

County	Municipal Supplies	Non-Municipal Community Supplies	Non-Community Public and Private Domestic Supplies[a]
Campbell	Wasatch/Fort Union aquifer system Fox Hills/Lance aquifer system Madison aquifer[b]	Wasatch/Fort Union aquifer system	Wasatch/Fort Union aquifer system Fox Hills/Lance aquifer system (north & east)
Converse	Madison aquifer system (spring) Quaternary alluvial aquifers Fox Hills/Lance aquifer system surface water (N. Platte R. drainage)	Middle Tertiary aquifers Fort Union aquifers	Middle Tertiary aquifers (south) Wasatch/Fort Union aquifer system Fox Hills/Lance aquifer system (west)
Crook	Madison aquifer system Fox Hills/Lance aquifer system	Minnelusa aquifer	Dakota aquifer system Fox Hills/Lance aquifer system (southwest) Sundance (Hulett) aquifer (central) Permo-Triassic aquifers (southeast)
Johnson	surface water (Powder River drainage)	Wasatch aquifers Fox Hills/Lance aquifer system	Wasatch/Fort Union aquifer system Upper Cretaceous aquifers (southwest) Fox Hills/Lance aquifer system (southeast)
Natrona	Quaternary alluvial aquifers surface water (North Platte River) Fox Hills/Lance aquifer system	purchased municipal water Quaternary alluvial aquifers Dakota aquifer system	Upper Cretaceous aquifers Quaternary alluvial aquifers (south) Fox Hills/Lance aquifer system (east)
Niobrara	Middle Tertiary aquifers	Dakota aquifer system? Quaternary alluvial aquifers?	Middle Tertiary aquifers (south) Fox Hills/Lance aquifer system (north)
Platte	Hartville aquifer (Madison aquifer system)	-	Middle Tertiary aquifers
Sheridan	surface water (Tongue River drainage) Wasatch/Fort Union aquifer system	Wasatch/Fort Union aquifer system? Quaternary alluvial aquifers?	Wasatch/Fort Union aquifer system Quaternary alluvial aquifers
Weston	Madison aquifer Dakota aquifer system	Madison aquifer	Fox Hills/Lance aquifer system (west) Dakota aquifer system (northeast)

[a]Parentheses indicate part of county where this aquifer is important.

[b]Beginning mid-1981, piped from wellfield in Crook County.

and Upton, while ground water is a substantial part of the water supply for Casper, Douglas, Glenrock, and Mills.

Average water production of municipal systems is 24,078 acre-feet/yr (see Table A-1), of which at least 7,700 acre-feet/yr is surface water, leaving about 16,400 acre-feet/yr as ground water use.

The Madison and Wasatch/Fort Union aquifer systems are the most extensively used sources of ground water for these municipalities. Table A-2 (Appendix A) lists all permitted ground water sources for municipalities, by well.

Non-Municipal Community Systems

Private community water systems within the basin include subdivisions, mobile home parks, and small communities; although not administered through a municipal utility, they supply water to more than 25 permanent users. These systems may be owned and operated by an individual, a corporation, or a water users' association.

The largest numbers of private or association-held community systems are concentrated near Casper, Gillette, and Sheridan (see Figure III-1). Unincorporated communities with central supply systems include Acme, Linch, Osage, and Wright. Table A-3 (Appendix A) lists inventoried provate community water supply systems. Quaternary alluvial aquifers and the Wasatch/Fort Union aquifer system are the most extensively exploited sources of water for private community systems.

Non-municipal community water systems have an inventoried average water production rate of 2,077 acre-feet/yr (see Table A-3).

Non-Community Systems and Private Domestic Wells

All non-community public systems in the basin use exclusively ground water for commercial, recreational, institutional, or industrial purposes. Inventoried non-community public water use is 559 acre-feet/yr (Table III-2).

Private household domestic wells are widely distributed throughout the basin (see Plate 2), normally of low yield (less than 25 gpm), and only pumped intermittently. Total water use is about 6,500 acre-feet/yr, based on that portion of the population not served by community systems, and a per capita consumption of 180 gallons per day.

Water availability at reasonable depths usually dictates which aquifer is used for a non-community or household water supply; Table III-3 lists the most frequently utilized aquifers in the basin.

INDUSTRIAL WATER USE

Petroleum Industry

The petroleum industry withdraws the largest amounts of ground water in the Powder River basin, principally as a by-product of petroleum production. Additional withdrawals are used for secondary recovery techniques, such as waterflooding, and used in refining processes, although much of the latter is surface water. The total volume of ground water used by the petroleum industry annually is estimated as 64,124 acre-feet, most of which is ground water derived from almost all of the pre-Tertiary aquifers in the basin.

Crude Oil Production

In 1967 an estimated 18,000 acre-feet of ground water were with-drawn during petroleum production in all of eastern Wyoming (Wyoming

Water Planning Program, 1971, 1972) and about nine-tenths of the oil fields included in this estimate are within the study area. Since 1967 the number of discovered oil fields has almost doubled (to about 450) and the number of waterflood units has increased 133 percent, although total oil production has not significantly changed.

In 1979 reported produced (by-product) water for the eight counties of northeast Wyoming was 59,645 acre-feet (Table III-4), representing either a substantial increase in water withdrawals or better data than used in previous estimates. Much of this produced water is injected for secondary recovery purposes, the remainder is either injected in disposal wells, evaporated, or discharged to surface drainages under Wyoming Department of Environmental Quality permits. For more detailed information on water disposal wells, refer to Collentine and others (1981).

Produced water is derived from all oil-producing horizons. These include the Minnelusa, Sundance, Fall River, and Newcastle (Muddy) formations in the eastern part of the basin, and the Tensleep, Cloverly, Muddy, Frontier, and Cody formations in the western part of the basin.

Secondary Petroleum Recovery

In 1979, 41,974 acre-feet of water were injected to enhance petroleum recovery by waterflooding (Table III-4).

Fresh water used during injection for secondary petroleum recovery in the Powder River basin is estimated to total at least 4,414 acre-feet/yr. This estimate is based on the difference between reported amounts of produced and injected water for oil fields with active injection projects. It assumes all produced water is subsequently

Table III-4. 1979 ground-water use by the petroleum industry in the Powder River basin, by county. Refinery use is excluded.

County	Produced (by-product) Water			Water Injected for Secondary and Tertiary Recovery[a]				Calculated Minimum Amount of Make-Up Water Injected[b]	Total Water Use	
	# Fields	# Wells	Amount (bbl.)	# Fields	# Units	# Wells	Amount (bbl.)	(bbl.)	(bbl.)	(acre-feet)
Campbell	188	1,466	75,319,873	35	43	253	76,472,321	22,013,766	97,333,639	12,546
Converse	58	958	17,517,936	4	9	108	13,071,180	822,849	18,340,785	2,364
Crook	60	350	12,847,891	11	13	43	7,593,704	1,590,077	14,437,968	1,861
Johnson	38	487	23,549,711	6	15	93	15,967,392	4,844,895	28,394,606	3,660
Natrona[c]	62	2,052	297,239,125	9	13	672	198,784,000	537,932	297,777,057	38,383
Niobrara	33	255	25,947,049	3	3	4	477,577	0	25,947,049	3,345
Sheridan	7	37	1,070,532	1	1	8	641,291	417,152	1,487,684	192
Weston	42	1,150	9,229,580	8	29	347	12,620,892	4,017,220	13,246,800	1,708
TOTAL	488	6,755	462,721,697 (59,645 AF)	77	126	1,528	325,628,357 (41,974 AF)	34,243,891 (4,414 AF)	496,965,588	64,059

[a]Active projects only.

[b]Calculated by subtracting reported produced water from reported injected water for each field (see Appendix A, Table A-4).

[c]Some oil fields included in produced water total are outside the Powder River basin.

Source: Calculated from files and compilations of the Wyoming Oil and Gas Commission.

injected and all additional injected water is from other ground-water sources. The field-by-field data are included in Appendix A (Table A-4). At several oil fields produced water may not be recycled by injection; as a result substantially more fresh water may be used, especially from the Madison aquifer (see Appendix A).

For a more detailed compilation of secondary recovery ground-water utilization data, refer to the Injection Well Inventory of Wyoming (Collentine and others, 1981).

Major sources of fresh water used for secondary oil recovery include the Madison, Dakota, and Fox Hills/Lance aquifer systems. The Madison aquifer system has been the principal source of fresh secondary recovery water utilized in oil fields in Converse, Johnson, Natrona, and Weston counties, while the Fox Hills/Lance system is the major fresh water source for secondary recovery purposes in Campbell County.

Refining

Most water used by refineries within the report area is surface water derived from the North Platte River (see Appendix A, Table A-5). The Wyoming Refining Company of Newcastle and C and H Refinery of Lusk use small amounts of ground water from the Madison and Arikaree aquifers, respectively. Estimated annual ground-water use totals about 65 acre-feet.

Coal Industry

Mining

Estimates of water used during the strip mining of coal in the Powder River basin range from 0.3 acre-feet per mine per day (Rechard,

1975) to 210 acre-feet per million tons of coal produced (Miller, 1974). This water is principally discharge resulting from pit dewatering, which is comprised of both surface runoff and ground water from the Wasatch/Fort Union aquifer system. Water used for domestic purposes at mine sites is usually produced from wells completed within Fort Union aquifers below the coal being mined, or is hauled in.

Using 1978 production figures from the 11 active mines in the study area (Glass, 1980), and the estimates cited above, estimated water use ranges from 1,200 to 7,400 acre-feet/yr. Table A-6 (Appendix A) details overall water use of the active mines in the report area. Water withdrawal estimates for the Wyoming part of the Powder River basin in 1990 range from 3,700 to 27,600 acre-feet/yr, based on the above estimates and 1990 tonnage forecasts for 34 active and proposed mines (Glass, 1980).

Power Generation

Four coal-fired stem generated electric power plants with a combined name plate generating capacity of 1,137.5 megawatts are presently active within the study area. Approximately 10,747 acre-feet of water were used for electricity generation by these plants in 1979 (see Appendix A, Table A-7). Of the total water used in 1979, 9,600 acre-feet were surface water and 1,147 acre-feet were ground water.

The Madison aquifer produces most ground water used directly for electricity generation, although the Fort Union aquifer also produces a small amount. The WYODAK #1 plant indirectly utilizes ground water from the Wasatch/Fort Union and Fox Hills/Lance aquifer systems, as its source of water is sewage effluent from the city of Gillette. With the completion of the Gillette Madison Project, the WYODAK plant will also indirectly utilize Madison aquifer water.

Synthetic Fuels Industry

Coal gasification and liquefaction plants within the Powder River basin are currently in planning and development stages. Water requirements for plant production of synthetic fuels include those associated with the mining of coal, plant conversion processes, cooling processes, and solid waste disposal.

Although it is not within the scope of this report to determine water use requirements for the synthetic fuels industry, some previous estimates will be cited. In order to produce the equivalent of 1×10^6 barrels of crude oil, or the equivalent in other fuels of 5.8×10^{12} BTU per day, water requirements have been estimated at 45,000 to 190,000 acre-feet/yr for gasification and 67,000 to 134,000 acre-feet/yr for liquefaction (Gold and Goldstein, 1976, p. 231). The wide range of estimated water requirements is due to different processing and cooling methods.

Slurry Transport of Coal

Energy Transportation Systems Inc. (ETSI) is currently (1981) in the active planning stages for the construction of a coal slurry pipeline from Wyoming to Arkansas. The pipeline will originate in southeastern Campbell County and is projected to transport an estimated 25 million tons of coal per year. ETSI is tentatively planning to pump water from the Madison aquifer in the eastern part of the basin at the rate of 15,000 to 20,000 acre-feet/yr for use in this coal slurry pipeline.

Uranium Industry

As of January 1, 1980, three open-pit uranium mines, two mills, one underground mine, and two commercial-scale solution mining operations were active in the Powder River basin (Hausel and others, 1979; Collentine and others, 1981). Seven mines, two mills, and two additional commercial-scale solution mines are proposed or pending (Hausel and others, 1979), and eleven other solution mining projects are in various stages of research and development (Collentine and others, 1981). Although most of the solution mining projects are for deposits in the Wasatch or Fort Union formations, projects tapping the Fox Hills Sandstone or the Teapot Sandstone of the Mesaverde Formation are among those proposed.

Overall water use by active uranium mines and mills is given in Table A-8 (Appendix A). Mining and milling operations utilize both surface-water runoff and ground water from the Wasatch/Fort Union aquifer system, generally derived as pit discharge. Based on the range of reported pit discharges, total water use is from 2,860 to 5,310 acre-feet/yr.

Volumes of ground water withdrawn as a result of solution mining are generally small, as much of the produced water is recycled through injection. Post-mining restoration may use significant amounts of ground water if a water sweep is employed (see Collentine and others, 1981).

AGRICULTURAL WATER USE

Irrigation

In 1969-1970 252,685 irrigated acres were inventoried within the drainages of the Powder, Tongue, Belle Fourche, Cheyenne, and

Niobrara rivers, and the Platte River between Pathfinder and Whalen dams (Wyoming Water Planning Program, 1971, 1972). No more recent tabulation of irrigated acreage has been made; however, no substantial increases in irrigated acreage are known. In 1971, approximately 90 percent of this acreage was actually irrigated, using roughly 270,000 acre-feet of water (Wyoming Water Planning Program, 1971, 1972). Approximately 165,000 acres of irrigated land in the area produced harvested crops in 1979, and 90 percent of this irrigated acreage produced hay (Wyoming Crop and Livestock Reporting Service, 1979).

Ground water is permitted as a water source for only about 15 percent of the inventoried irrigated acreage in the eight counties of northeastern Wyoming, and almost half this acreage is outside the basin boundary in southern Niobrara County. Table III-5 summarizes the distribution of acreage permitted for irrigation by ground water, by county.

Trelease and others (1970) determined annual irrigation water requirements for grass, at 14 climate stations in the study area, using the Blaney-Criddle method. The average was 20.24 inches of water per acre per year. On the basis of this calculated water requirement and acreage permitted for ground-water irrigation, irrigation uses about 34,000 acre-feet/yr of ground water in the basin, exclusive of Niobrara County. An additional 29,000 acre-feet/yr, most outside the study area, are used in Niobrara County. Assumptions incorporated into this estimate include: (1) irrigation of 100 percent of the acreage permitted for irrigation by ground water, (2) all of the irrigated land is grass or has similar water needs, (3) 100 percent of the calculated water need is met, and (4) no excess water is applied and lost as waste.

Table III-5. Acreage permitted for irrigation by ground water in the Powder River basin, Wyoming, by county.

County	Number of Permitted Wells	Permitted Acres Supplied by Ground Water Original Supply	Supplemental Supply	Total
Campbell	26	4904.56	820.	5724.56
Converse	42	1962.87	699.8	2662.67
Crook	29	1070.28	975.92	2046.20
Johnson	42	937.8	1601.91	2539.71
Natrona	102	2068.08	1823.8	3891.88
Niobrara*	161*	15783.77*	1284.7*	17068.47*
Sheridan	22	241.73	744.8	986.53
Weston	17	2230.8	120.88	2351.68
TOTAL	441	29199.9	8071.8	37271.7

*Most irrigated acreage is outside the boundary of the Powder River basin.

Source: Compiled by Wyoming State Engineer, July, 1980.

Based on total irrigated acreage and estimated water use from 1971 the average amount of irrigation water applied was about 14.3 inches per acre per year. Using this figure and an estimated actual irrigated acreage of 90 percent, ground-water use values of 19,000 and 22,000 acre-feet/yr are calculated for all Niobrara County and the rest of the basin, respectively.

Ground-water use for irrigation is not expected to increase within the Powder River basin, due to competition for available water supplies by municipal and industrial users.

Source aquifers for irrigation water within the basin are not well identified, due to incomplete well information and unknown status of many permitted projects. Eisen and others (1980, 1981) determined that in the eastern part of the basin most wells permitted for irrigation use tap Quaternary alluvial aquifers, or bedrock aquifers with good quality water which are capable of high yields. Within the basin the Madison aquifer system and the Middle Tertiary aquifers often have yields adequate to support irrigation use and generally contain water of good quality.

Livestock

Ground-water consumption by livestock within the basin is estimated to be not more than 11,000 acre-feet/yr, based on 1979 livestock populations of 492,000 cattle and 520,000 sheep within the eight-county northeast Wyoming area (Wyoming Crop and Livestock Reporting Service, 1979) and average daily consumption values of 15 and 3 gallons per head for cattle and sheep, respectively (Wyoming Water Planning Program, 1972). This estimate compares well with an earlier estimate

(9,000 acre-feet/yr for the area, excluding the Powder River drainage; Wyoming Water Planning Program, 1972). Additional water consumption by swine, horses, and other types of livestock is estimated at not more than 1,000 acre-feet/yr. All stock water is assumed to be from underground sources.

Ground water from all aquifers within the area is used for livestock watering purposes. Most wells permitted for livestock or domestic/livestock purposes have been completed within the shallowest aquifer which provides adequate yield. The majority are in the Fox Hills/Lance or Wasatch/Fort Union aquifer system. Municipal and industrial ground-water supplies are also used locally for livestock watering. The largest number of wells permitted within the study area is used for stock watering purposes. Typical stock well yields are 10 to 15 gpm, but this amount is only intermittently produced.

IV. H Y D R O G E O L O G Y

IV. HYDROGEOLOGY

Hydrologic properties and ground-water flow of the regional aquifer systems and minor and local aquifers within the Powder River basin are discussed in this section. Aquifer lithologies and hydrologic properties are summarized in Tables IV-1 to IV-3, while Appendix B describes in more detail the bedrock stratigraphic variations. The Madison aquifer system has been discussed in greater detail than other systems due to extensive interest in its exploitation and the many investigations this interest has fostered.

MADISON AQUIFER SYSTEM

The Paleozoic Madison aquifer system contains adequate supplies of good quality water, is already extensively utilized for municipal and industrial supplies, and is currently being further developed (Wyoming Water Planning Program, 1977; Montgomery, 1979; Bureau of Land Management, 1980).

Composed of the Cambrian to Pennsylvanian age shallow marine carbonate and sandstone sequence, the aquifer system's thickness varies from less than 1,000 to about 3,000 feet, although some included formations are not considered economically viable aquifers. Its most important and extensively developed aquifer is the Mississippian Madison (Pahasapa) Limestone. The Ordovician Bighorn and Whitewood dolomites, only present in the northern third of the basin, also have potential for development (Hodson and others, 1973). The Pennsylvanian Tensleep Sandstone and Permian sands of the Minnelusa Formation are

Table IV-1. Lithologic and hydrologic characteristics of bedrock units exposed on the east flank of the Powder River basin, Wyoming (compiled from numerous sources).

Erathem	System	Geological Unit	Thickness[a] (ft)	Lithologic Character	Hydrologic Character[b,c]
MESOZOIC	Cretaceous	Pierre Shale	2000± 2500-3100	Shale with some bentonite, thin siltstones, lenticular carbonates and sandstones. Contains Great Sandstone bed (0-125 ft) in north.	Regional aquitard but some low-yield wells in outcrop. Reported yield, none to 12 gpm; specific capacity, <0.1 gpm/ft.
		Niobrara Fm.	150-225 100-250	Shale, calcareous shale and marl with numerous thin bentonite beds.	Aquitard but some low-yield wells in outcrop.
		Carlile Shale	500-700 460-540	Shale, locally sandy. Contains middle Turner sandy member in north.	Aquitard but some low-yield wells in outcrop. Oil field data: porosity, 15%; permeability, 0.02 gpd/ft^2; transmissivity, 0.2-0.4 gpd/ft.
		Greenhorn Fm.	70-370 30-70	Shale, limey shale and marl with thin limestone beds.	Aquitard; no published records of wells. Oil field data: see Carlile Shale.
		Belle Fourche Sh.	450-850 400-850	Shale, dark gray to black, containing iron and limestone concretions and bentonite layers.	Aquitard but some wells near outcrop.
		Mowry Shale	180-230 220±	Siliceous shale with numerous bentonite layers.	Aquitard but some wells near outcrop; fractures enhance yield.
		Newcastle Ss.	0-60 0-100	Sandstone, fine- to medium-grained, locally conglomeratic, lenticular, with interbedded siltstone, shale and claystone.	Minor unit of Dakota aquifer system, exploited near outcrop only; often excessive pumping lift. Oil field data: porosity, 5-27%; permeability, <11 gpd/ft^2; transmissivity, 0-140 gpd/ft.
		Skull Creek Sh.	200-250 160-200	Shale, black, with iron concentrations.	Aquitard; no reports of wells.
		INYAN KARA GROUP:			
		Fall River Fm.	95-150 35-85	Sandstone, fine- to coarse-grained, with interbedded shale and siltstone.	Unit of Dakota aquifer system. Flowing yield 1-10 gpm; wells often also completed in Lakota Fm. Specific capacity, <0.5 gpm/ft. Oil field data: porosity, 11-23%; permeability, 0-36 gpd/ft^2; transmissivity, 1-900 gpd/ft.

Table IV-1. (continued)

Erathem	System	Geological Unit	Thickness[a] (ft)	Lithologic Character	Hydrologic Character[b,c]
		Lakota Fm.	45-300 115-200	Sandstone, fine- to coarse-grained, in places conglomeratic, very lenticular, irregularly interbedded with shale which becomes dominant at top (Fuson Sh.).	Unit of Dakota aquifer system. Flowing yield 1-10 gpm, up to 150 gpm. Water well data: specific capacity, 0.01-1.4 gpm/ft; permeability, 2-14 gpd/ft^2; transmissivity, 220-810 gpd/ft for 2 wells also in Fall River.
		- Unconformity -			
	Jurassic	Morrison Fm.	0-150 150-220	Varicolored claystone with thin beds of limestone or sandstone; locally fine-grained sandstone predominant.	Yields up to 10 gpm in outcrop area. Water well data: specific capacity, 0.2 gpm/ft; permeability, 5 gpm/ft^2; transmissivity, 160 gpm/ft. Oil field data: porosity, 11%; permeability, 0-74 gpd/ft^2; transmissivity, 0-260 gpd/ft.
		Sundance Fm.	300-400 330-365	Sandy and silty shale with thin limestones and thin to thick sandstones (e.g., Hulett Mem., 55-90 ft).	Minor aquifer (Crook County). Flowing yields up to 5 gpm, pumped yields up to 50 gpm in and near outcrop: specific capacity, <0.1 gpm/ft. Oil field data: porosity, 11-30%; permeability, 0-23 gpd/ft^2; transmissivity, <1250 gpd/ft.
		- Unconformity -			
		Gypsum Springs Fm.	0-125 absent	Massive white gypsum with interbedded red shale and cherty limestone.	Not considered an aquifer but may yield water to wells obtaining major supply from Sundance Fm.
		- Unconformity -			
MESOZOIC and PALEOZOIC	Triassic and Permian	Spearfish Fm.	450-825 550-600	Red shale, siltstone and fine-grained silty sandstone with lenses of gypsum, increasing in lower part.	Minor aquifer (Crook County). Yields average 13 gpm in outcrop area. Water well data: specific capacity, 0.6 gpm/ft; permeability, 6-8 gpd/ft^2; transmissivity, 150-370 gpd/ft.
PALEOZOIC	Permian	Minnekahta Ls.	40± 30-50	Fine-grained thinbedded limestone and dolomitic limestone.	Minor aquifer (Crook County). Yields average 7 gpm. USGS test: flowed 12 gpm; specific capacity, 0.1 gpm; permeability, 33 gpd/ft^2; transmissivity, 330 gpd/ft.
		Opech Fm.	60-90 50-100	Maroon sandstone, fine-grained, silty and shaley, alternating with siltstone, shale, claystone, and gypsum.	Aquitard; no published record of wells.

Table IV-1. (continued)

Erathem	System	Geological Unit	Thickness[a] (ft)	Lithologic Character	Hydrologic Character[b,c]
		- Unconformity -			
	Pennsylvanian and Permian	Minnelusa Fm. (Hartville Fm.)[d]	600-800 1000±	Sandstone, fine- to coarse-grained, interbedded with limestone, dolomite, and shale, locally gypsiferous, especially at top.	Upper part is unit of <u>Madison aquifer system</u>, middle is aquitard, lower is minor aquifer in hydraulic connection with Madison. Flowing yields over 200 gpm possible; specific capacity, 1-5 gpm/ft. Oil field data: porosity, 6-25%; permeability, <0.1-18 gpd/ft^2; transmissivity, 2-900 gpd/ft.
		- Unconformity -			
	Mississippian	Pahasapa Ls. (Madison Ls.) (Guernsey Fm., part)[d]	550-900 250±	Massive fine-grained limestone and dolomitic limestone, locally cherty or cavernous.	Principal unit of <u>Madison aquifer system</u>. Flowing or pumped yields up to 1000 gpm; specific capacity, 0.5-50+ gpm/ft, flow-dependent; transmissivity, 1000-60,000 gpd/ft, locally to 300,000+.
	Devonian	Englewood Ls. (Guernsey Fm., part)[d]	30-60 0-50±	Thin-bedded limestone, locally shaley.	Minor unit of <u>Madison aquifer system</u>; no published reports of water wells. USGS test: porosity, 15-18%; permeability, <0.1 gpd/ft^2
		- Unconformity -			
	Ordovician	Whitewood Dol.	50-60 absent	Massive bedded dolomite, locally cherty.	Minor unit of <u>Madison aquifer system</u>; the few existing wells also produce from the Madison aquifer. USGS test: porosity, 10-25%; specific capacity, 15 gpm/ft; permeability, <0.1-11 gpd/ft^2; transmissivity, 6400 gpd/ft.
		Winnipeg Fm.	60-70 absent	Clayey siltstone (Roughlock), shale and silty shale (Icebox), fine- to medium-grained sandstone near base (Aladdin).	Aquitard
		- Unconformity -			

Table IV-1. (continued)

Erathem	System	Geological Unit	Thickness[a] (ft)	Lithologic Character	Hydrologic Character[b,c]
	Ordovician and Cambrian	Deadwood Fm.	300-500 0-50+(?)	Sandstone, locally dolomitic or conglomeratic, with interbedded shale, limestone, dolomite and siltstone.	Unit of Madison aquifer system but deep burial limits exploitation. USGS test: porosity, 13-20%; permeability, <20 gpd/ft^2.
		- Unconformity -			
PRECAMBRIAN	-	-	-	Complex of igneous and metamorphic rocks.	Locally yields water to shallow wells and springs in outcrops.

[a]First thickness range refers to northeastern basin while second refers to southeastern basin.

[b]Oilfield (and USGS test) data are variously derived resulting in internal inconsistencies in this compilation. Permeabilities are measured on cores or derived from other data and transmissivities are from drill stem tests or calculated from permeability. Test data are usually for limited horizons of high anticipated yields and are not therefore representative of the formation as a whole.

[c]Reported yields may reflect development needs rather than aquifer capability; higher yields can sometimes be expected, with corresponding drawdown increases. Reported water well transmissivities or permeabilities may be for wells completed in two aquifers or screened in only part of a single aquifer.

[d]Nomenclature for equivalent strata exposed in the Hartville uplift on the southeastern basin flank.

Table IV-2. Lithologic and hydrologic characteristics of bedrock units exposed on the west flank of the Powder River basin, Wyoming (compiled from numerous sources).

Erathem	System	Geological Unit	Thickness[a] (ft)	Lithologic Character	Hydrologic Character[b,c]
MESOZOIC	Cretaceous	Lewis Shale (Bearpaw Shale)	200-900± 470	Grey marine shale with sandy shale and thin lenses of fine-grained sandstone (Teckla).	Regional aquitard but some low-yield wells near outcrop.
		Mesaverde Fm.	355 900±	Fine- to medium-grained sandstone with interbedded grey marine shale. Upper part is Teapot Ss. (50 ft) in south, Lower part is Parkman Ss. (500±).	Minor aquifer (entire basin flank). Flowing yields up to 4 gpm; pumped yields up to 120 gpm reported in Natrona Co.; specific capacity, 0.1-0.2 gpm/ft. Oil field data: porosity, 15-21%; permeability, 5 gpd/ft^2; transmissivity, 120 gpd/ft.
		Cody Shale (Steele Shale is upper part)	3700± 3000-5000	Dark grey shale, limey near base with some bentonitic beds and interbedded, lenticular fine-grained often shaley sandstones (Shannon, 200 ft; Sussex, 200-500 ft).	Aquitard but sandstone lenses have low-yield flowing and pumped wells near outcrop. Oil field data porosity, 12-25%; permeability, 8 gpd/ft^2; transmissivity, 85 gpd/ft.
		Frontier Fm.	515± 900	Dark grey to black marine shale with interbedded thin to massive bedded fine- to medium-grained sandstones (Wall Creek sands).	Minor aquifer (southwest basin). Flowing yields 1-10 gpm (Natrona Co.); specific capacity, 0.02 gpm/ft (Sheridan Co.). Oil field data porosity, 12-26%; permeability, 0.09-9 gpd/ft^2, transmissivity, 150 gpd/ft.
		Mowry Shale	525± 200-300	Grey weathering siliceous shale with bentonitic beds, non-siliceous black shale at base.	In Natrona Co., flowing yields up to 2 gpm; pumped yields up to 10 gpm.
		Muddy Ss. (Newcastle Ss.)	0-40± 6±	Light grey, fine-grained, lenticular sandstone and siltstone often termed a member of Thermopolis shale.	Minor unit of Dakota aquifer system. Oil field data: porosity, 5-20%, permeability, <7 gpd/ft^2; transmissivity, <150 gpd/ft.
		Thermopolis Sh. (Skull Creek Sh.)	175± 200	Black marine shale with some siltstone partings in north.	Aquitard; no published record of wells.
		Cloverly Fm.	150 140	Interbedded dark shale and brown siltstone with 15-45 feet of basal fine- to coarse-grained well sorted sandstone.	Lower part is unit of Dakota aquifer system. Flowing yields of 1-40 gpm, up to 250 gpm reported for pumped wells; specific capacity, 0.2 gpm/ft. Oil field data: porosity, 15-18%; permeability, 0.4-4 gpd/ft^2; transmissivity, 7-230 gpd/ft.

Table IV-2. (continued)

Erathem	System	Geological Unit	Thickness[a] (ft)	Lithologic Character	Hydrologic Character[b,c]
		- Unconformity -			
	Jurassic	Morrison Fm.	185 130-220	Variegated shale and claystone with some lenticular fine-grained sandstones.	No published record of wells.
		Sundance Fm.	280 300	Shale, greenish grey, sometimes calcareous, sandier at top and base.	A few water wells, some flowing up to 2 gpm. Oil field data: porosity, 14-20%; permeability, 8 gpd/ft^2; transmissivity, 8-132 gpd/ft.
		- Unconformity -			
		Gypsum Spring Fm.	120-185 absent	Red shale and claystone with thin bedded limestone and gypsum.	Not generally considered an aquifer and no published record of wells.
		- Unconformity -			
	Triassic	Chugwater Fm.	750-800 700-800	Red siltstone, claystone and fine-grained sandstone with thin limestones.	Aquitard but a few wells, some flowing several gpm.
MESOZOIC and PALEOZOIC	Triassic and Permian	Goose Egg Fm.	180-250 380	Interbedded red shale and siltstone with thin limestone and gypsum beds.	Aquitard but a few wells near outcrop.
		- Unconformity -			
PALEOZOIC	Permian and Pennsylvanian	Tensleep Ss.	50-250 <500	Fine- to medium-grained, massive, crossbedded sandstone with occasional thin dolomite beds.	Unit of Madison aquifer system. Flowing yields up to 400 gpm; specific capacity, 1 gpm/ft. Oil field data: porosity, 0-24%; permeability, 0-21 gpd/ft^2; transmissivity, 0-1900 gpd/ft.
	Pennsylvanian	Amsden Fm.	150-300 0-200	Red and purple shale with some sandstone, cherty dolomite and limestone.	Aquitard unless fractured.
		- Unconformity -			
	Mississippian	Madison Ls.	1100± 200-400	Limestone, dolomitic limestone and dolomite sandy at base.	Principal unit of Madison aquifer system. Flowing yields over 3000 gpm but highly variable; specific capacity, <1 to 50 but is flow-dependent; transmissivity, 500-90,000 gpd/ft or higher and highly variable.

Table IV-2. (continued)

Erathem	System	Geological Unit	Thickness[a] (ft)	Lithologic Character	Hydrologic Character[b,c]
		- Unconformity -			
	Ordovician	Bighorn Dolomite	400-500 absent	Massive dolomite, becoming thin-bedded at top and sandy at base.	Unit of Madison aquifer system. Local outcrop wells only.
		- Unconformity -			
	Cambrian	Gallatin and Gros Ventre Fms., undivided	645± 0-500	Upper limestone, limestone conglomerate, interbedded with middle micaceous shale and a basal, brown, medium- to coarse-grained sandstone.	Aquitard; no published reports of wells.
		Flathead Ss.	345± 90	Tan to reddish sandstone, locally conglomeratic, interbedded with green shale and siltstone.	Minor unit of Madison aquifer system. Not exploited due to deep burial but a few wells yield water near outcrops.
		- Unconformity -			
PRECAMBRIAN	-	-	-	Complex of igneous and metamorphic rocks.	Locally yields small amounts of water to shallow, outcrop wells.

[a]First thickness range refers to northwestern basin, second refers to southwestern basin.

[b]Oilfield data are variously derived resulting in internal inconsistencies in this compilation. Permeabilities are measured on cores or derived from other data and transmissivities are from drill stem tests or calculated from permeability. Test data are usually for limited horizons of high anticipated yields and are not therefore representative of the formation as a whole.

[c]Reported yields may reflect development needs rather than aquifer capability; higher yields can sometimes be expected, with corresponding drawdown increases. Reported water well transmissivities or permeabilities may be for wells completed in two aquifers, or screened in only part of a single aquifer.

Table IV-3. Lithologic and hydrologic characteristics of "shallow" geologic units (including Quaternary, Tertiary and Latest Cretaceous deposits) of the central Powder River basin, Wyoming (compiled from numerous sources).

Erathem	System	Series	Geologic Unit	Thickness (ft)	Lithologic Character	Hydrologic Character[a]
CENOZOIC	Quaternary	Holocene and Pleistocene	Alluvium and Terrace deposits	0-100+	Silt, sand and gravel; unconsolidated and interbedded; present along most streams.	Quaternary alluvial aquifers. Yield of 1000 gpm possible, often through induced recharge. Terraces topographically high and often drained. Specific capacity, 0.3-18 gpm/ft; porosity, 28-45%; permeability, 0.1-1100 gpd/ft^2; transmissivity, 15-64000 gpd/ft; specific yield, 2-39%. Coarser deposits have better aquifer properties.
			- Unconformity -			
	Tertiary	Miocene	Arikaree Fm.	0-500 (southeast only)	Tuffaceous sandstone, fine-grained, with silty zones, coarse sand lenses and concretionary zones.	Middle Tertiary aquifer. Yields up to 1000 gpm; specific capacity up to 232 gpm/ft; porosity, 5-24%; permeability, <1-300 gpd/ft^2; transmissivity, up to 77,000 gpd/ft.
			- Unconformity -			
		Oligocene	White River Gp.	0-1500 (isolated outliers except in SE)	Tuffaceous siltstone in upper part, underlain by claystone, both locally contain fine- to coarse-grained sandstone and conglomerate channel deposits.	Middle Tertiary aquifer. Not extensively developed because overlain by Arikaree Fm. in most places. Yields generally low and unpredictable. Specific capacity, <0.5 gpm/ft; permeability, 0.0002-0.03 gpd/ft^2, increases with fracturing.
			- Unconformity -			
		Eocene	Wasatch Fm.	Up to 1600	Fine- to coarse-grained lenticular sandstones interbedded with shale and coal, coarser in south and southwest, conglomeratic in west.	Part of Wasatch/Fort Union aquifer system. Yields generally <15 gpm, locally flowing wells exist. Specific capacity, 0.10-2 gpm/ft; porosity, 28-30%; permeability, 0.01-65 gpd/ft^2, transmissivity, average 500 gpd/ft, range 1-4000 gpd/ft.
			- Unconformity -			

Table IV-3. (continued)

Erathem	System	Series	Geologic Unit	Thickness (ft)	Lithologic Character	Hydrologic Character[a]
		Paleocene	Fort Union Fm.	1100-2500+	Sandstone, fine- to medium-grained, lenticular, interbedded with siltstone, coal and shale. Middle part may be shalier in north, upper part siltier in south. "Clinker" associated with coal outcrops.	Part of Wasatch/Fort Union aquifer system. Flowing yields of 1-60 gpm were confined. Pumped yields up to 250 gpm with several hundred feet of drawdown. Specific capacity, 0.1-2 gpm/ft; permeability, 0.01- 100 gpd/ft^2; transmissivity, 1- 5000 gpd/ft. Coal and clinker generally better aquifer properties than sandstones. Locally clinker transmissivity up to 3,000,000 gpd/ft; specific capacity over 2000 gpm/ft. Anisotropy and leaky confining layers are common.
MESOZOIC	Cretaceous	Upper Cretaceous	Lance Fm.	500-1000 (N) 1600-3000 (S)	Sandstone, fine- to medium-grained, lenticular, interbedded with sandy siltstone and claystone.	Unit of Fox Hills/Lance aquifer system. Yields up to 350 gpm but with large drawdowns and long perforated intervals. Locally flowing wells exist. Specific capacity, 0.05-2 gpm/ft; permeability, 6-35 gpd/ft^2; transmissivity, 170-2100 gpd/ft.
			Fox Hills Ss.	150-200 (N) 400-700 (S)	Sandstone, fine- to medium-grained, interbedded with shale and siltstone.	Unit of Fox Hills/Lance aquifer system. Yields up to 350 gpm but with large drawdowns and long perforated intervals. Locally flowing wells exist. Specific capacity, 0.05-2 gpm/ft; permeability, 34 gpd/ft^2; transmissivity, 76-1600 gpd/ft for wells also completed in Lance.

[a]Reported yields may reflect development needs rather than aquifer capability; higher yields can sometimes be expected, with corresponding drawdown increases. Reported water well transmissivities or permeabilities may be for wells completed in two aquifers or screened in only part of a single aquifer. Reported ranges include varying amounts of data.

also significant aquifers although they can produce poor quality water. The Cambrian Flathead and Deadwood sandstone aquifers are present only in the northern part of the basin, often produce water of lesser quality and quantity, and are currently almost unexploited.

The system outcrops along most basin margins but is buried by up to 15,000 feet of overlying rock in the central basin (see Plate 3). Current exploitation has generally been limited to areas where drilling depths are less than 3,000 feet, although industrial wells over 8,000 feet deep are used.

The Madison aquifer system has not been uniformly defined by authors studying its hydrology. Several studies have specifically considered only the Madison Limestone aquifer (Wyoming State Engineer, 1974; Rahn, 1975; Huntoon and Womack, 1975; Konikow, 1976). Various additional aquifers have been included by other workers (Crist and Lowry, 1972; Huntoon, 1976; Woodward-Clyde, 1980). The U.S. Geological Survey Madison Study (U.S. Geological Survey, 1975) is specifically investigating the entire Paleozoic rock sequence in northeastern Wyoming, although most available data and research emphasis pertain to the Madison and Minnelusa aquifers (e.g., Head and Merkel, 1977; Swenson and others, 1976). In this report the broad U.S. Geological Survey definition of the aquifer system is used, although the Madison Limestone, the most important aquifer of the system, receives the most emphasis.

The aquifer system as defined is bounded by relatively impermeable Precambrian and Permian rocks. Trotter (1963) considers the Permian Opeche Shale, the basal member of the Goose Egg Formation, an effective impervious barrier to fluid movement, isolating the Paleozoic section below it. Huntoon (1976) considers the Goose Egg an effective aquitard in the western Powder River basin, even where intensely fractured; however, Crist and Lowry (1972) report that high-yielding springs issuing from Permo-Triassic rocks are Madison system water migrating upward along structures. Only north of Newcastle, at Salt Springs, has local upward leakage of water through undisturbed Opeche Shale been specifically postulated in Wyoming (Brobst and Epstein, 1963); although in the Black Hills Rahn and Gries (1973) place the aquifer system boundary stratigraphically higher, at the Spearfish Formation.

note

Note

note

The degree of hydraulic interconnection of aquifers comprising the Madison aquifer system varies and is incompletely known. Ordovician shales in the northwest part of the basin separate the Flathead aquifer from overlying units (Huntoon, 1976). Similar shales are present in Crook County and, although potentiometric heads in the U.S. Geological Survey test well suggest interconnection of the Deadwood to Madison rock squence, chemical quality data indicate hydrologic isolation.

The Minnelusa Tensleep and Madison aquifers have been interpreted as wither in hydraulic connection (Head and Merkel, 1977; Swenson and others, 1976) or hydraulically isolated (Eisen and others, 1981; Old West Regional Commission, 1976; Wyoming State Engineer, 1974). Huntoon (1976) states that in the western part of the basin the intervening Amsden is not an effective aquitard where fractured, based on spring studies. Eisen and Collentine (1981) and Woodward-Clyde (1980) consider the middle Minnelusa Formation carbonates a leaky confining layer in the eastern part of the basin. In the Newcastle area geochemical data indicate the basal Minnelusa ("Bell" sandstone) is hydraulically connected with the upper Madison (see Chapter V).

Impeded communication between the Whitewood (Red River) and Madison aquifers in Crook County has been suggested (Woodward-Clyde, 1980). Although Huntoon (1976) considers the Bighorn and Madison aquifers hydraulically connected, he notes that lower permeability horizons in the Madison Limestone affect control on spring locations.

Hydrologic Properties

Hydrogeology of the Madison aquifer has been extensively investigated due to recent development pressure (e.g., Wyoming State Eningeer, 1974; Konikow, 1976; Office of Technology Assessment, 1978; Woodward-Clyde, 1980), but is still not fully understood. With the exception of the Madison and oil-bearing parts of the Minnelusa/Tensleep, little is known about other aquifers comprising the Madison aquifer system.

Yield and Specific Capacity

Although Madison aquifer wells with flowing yields of several hundred to several thousand gallons per minute are common, these yields are associated with drawdown of several hundred feet of pressure head. The resultant specific capacity (yield per unit drawdown) is considered somewhat low for high-yield development by some guidelines (U.S. Bureau of Reclamation, 1977). Similar large well drawdowns are required for high yields from pumped Madison wells.

Madison aquifer specific capacities reported in the literature or calculated from available data range from less than 0.5 to almost 50 gpm per foot of drawdown (Table IV-4). Some of the larger values are from wells tested at low yields or restricted flows; Kelly and

Table IV-4. Calculated specific capacities (yield per unit drawdown) of Madison aquifer wells, Powder River basin, Wyoming.

Well # (T/R-Sec., ¼, ¼)	Date	Test Duration (hrs)	Drawdown (ft)	Yield (gpm)	Specific Capacity (gpm/ft)	Data Source	Remarks
			CONVERSE COUNTY				
33/75-8 DBB	4/27/63	7 days	1330?	510	0.38	1	
	-/-/63	168	800	510	0.64	2	
33/76-13 CB-	1/-/62	?	16	75	4.7	2	
		?	53	220	4.1	2	
		?	92	320	3.5	2	
34/76-7 DAB	unk	?	550	330	0.60	3	
			CROOK COUNTY				
51/66-6 BCB	5/8/79	-	134	82	0.61	5	-Step discharge test
		-	223	128	0.57	5	30 min. steps.
		-	296	171	0.58	5	pre acid frac.
		22.75	301	166	0.55	5	final step, 20 + hrs.
	6/28/79	-	19	82	4.3	5	-Step discharge test
		-	34	128	3.8	5	30 min. steps
		-	49	171	3.5	5	post acid frac.
		-	93	280	3.0	5	
		-	151	430	2.8	5	
		-	242	590	2.4	5	
		-	274	635	2.3	5	
		15.25	295	635	2.2	5	final step, 12 + hrs.
+52/63-25 DC	-/-/71?	1	58	175	3.0	1	"Held for 24 hours"
		1	14	190	13.6	1	"Held for 30 days"
	-/-/72	24	74	200	2.7	2	
53/65-18 BBD	9/26/62	140 min.	1	15	15.0	2	-Step discharge and
		80 min.	4	25	6.2	2	recovery tests
		120 min.	6	30	5.0	2	
		110 min.	9	37	4.1	2	
		95 min.	10	40	4.0	2	
		12	13	45	3.5	2	
		16	19	55	2.9	2	
57/65-15 DAC	10/20/76	-	-	-	2.1	4	from drill stem test (#15)
		-	-	-	1.1	4	from drill stem test (#16)

Table IV-4. (continued)

Well # (T/R-Sec., ¼, ¼)	Date	Test Duration (hrs)	Drawdown (ft)	Yield (gpm)	Specific Capacity (gpm/ft)	Data Source	Remarks
			JOHNSON COUNTY				
41/78-1 BC	1/22/67	8	173?*	788	4.6	1	
	7/-/72	?	208*	700	3.4	3	
41/81-9 CDB	-/-/62	?	116*	900 E	7.8	3	
41/84-19 AB	-/-/63	3	60	15	0.25	2	
42/80-30 BDB	6/-/62	?	716*	900	1.3	3	
42/81-25 CBD	5/-/63	?	520*	1100	2.1	3	
43/80-34 DAD	-/-/63	24	647*	525	0.81	1,3	Flow through 4" ID pipe
	6/-/73	?	139	170	1.2	2	
		?	219	315	1.4	2	
49/83-27 DBC	3/1/74?	?	8.3*	5	0.60	1	
			NATRONA COUNTY				
39/78-26 CDC	7/-/73	?	231	150	0.65	3	
39/79-11 AAD	6/29/62	24	843*	4746	5.6	1,3	
+40/79-2 AD	4/-/71	?	286	297	1.0	2	
	7/-/71	?	292	320	1.1	2	
	10/-/71	?	298	359	1.2	2	
	1/-/72	?	274	336	1.2	2	
40/79-23 DDB	4/-/71	?	133	726	5.5	2	
	7/-/71	?	100	706	7.1	2	
	10/-/71	?	122	684	5.6	2	
	1/-/72	?	112	491	4.4	2	
40/79-26 CAA	-/-/71	?	869*	9000 E	10.4	3	
	4/-/71	?	182	5599	31.	2	
	7/-/71	?	202	5110	25.	2	
	10/-/71	?	163	4580	28.	2	
	1/-/72	?	152	4121	21.	2	
40/79-31 BCA	2/25/62	?	693	437	0.63	1	
	-/-/62	?	693	430	0.62	3	

Table IV-4. (continued)

Well # (T/R-Sec., ¼, ¼)	Date	Test Duration (hrs)	Drawdown (ft)	Yield (gpm)	Specific Capacity (gpm/ft)	Data Source	Remarks
			NATRONA COUNTY (cont.)				
40/79-35 ACB	-/-/61	?	35	1663	47.5	1,3	-Tests in 4/71, 7/71,
		?	176	3996	22.7	1,3	10/71, 1/72 respectively
		?	296	5858	19.8	1,3	per source #2
		?	418	7015	16.8	1,3	
40/79-35 CCC	4/-/71	?	23	593	26.	2	
	7/-/71	?	25	650	26.	2	
	10/-/71	?	17	557	34.	2	
	1/-/72	?	11	482	44.	2	
			NIOBRARA COUNTY				
+36/62-28 AB1	-/-/74	24	95	57	0.60	1	
	4/24/74	108	88	57	0.65	6	
+36/62-28 AB2	-/-/74	3	370	170	0.46	1	
	5/-/74	179 min.	217	104	0.48	2	
		204 min.	386	180	0.47	2	
	5/3/74	120	266	125	0.47	6	
	5/19/74	198?	390	180	0.46	6	-Discharge reduced after
		24½ days	330	150	0.45	6	8½ days pumping.
	8/28/74	96	370	170	0.46	6	
	9/7/74	48	370	170	0.46	6	
39/62-2 AAB	-/-/62	?	36	30	0.83	2,3	swab test
	2/26/63	1	36	60	1.7	1	
			WESTON COUNTY				
44/63-26 CAC	6/6/67	5	23	250	10.9	1	
	6/-/67	5	175	250	1.4	3	
45/61-20 DCA	-/-/49	?	462*	1600	3.5	1	
	unk	?	173	600	3.5	3	-Static water level pre-
		?	277	1000	3.6	3	sumed equal to original
		?	462	1500	3.2	3	shut-in pressure (+462 ft)
	unk	?	127	600	4.7	2	-Static water level pre-
		?	231	1000	4.3	2	sumed equal to 1962 shut-
		?	416	1500	3.6	2	in pressure (+416 ft)
45/61-20 DCC	-/-/78	?	381*	640	1.7	1	

Table IV-4. (continued)

Well # (T/R Sec., ¼, ¼)	Date	Test Duration (hrs)	Drawdown (ft)	Yield (gpm)	Specific Capacity (gpm/ft)	Data Source	Remarks
			WESTON COUNTY (cont.)				
45/61-21 CBD	4/-/66	72	200	460	2.3	3	
	9/1/66	72	141?	463	3.3	1	-Reported drawdown may not include SIP component
	unk	?	60*	50	0.83	2	
+45/61-28 AB-	-/-/62?	3 wks.	270*	1200	4.4	1,2	
	7/-/65	?	18	276	15.3	3	
45/61-29 CBB	5/20/60	8 min.	462*	117	0.25	1	
	unk	?	346*	120	0.35	2	
45/61-30 ADB	7/-/60?	?	300*	650	2.2	2	
45/61-33 AB	4/-/64?	?	323*	290	0.90	1,2	"restricted surface flow"
46/63-10 CDA	8/28/79	739 min.	638?	579	0.91	1	
46/63-15 BDC	-/-/51	?	393*	500	1.3	2	
	unk	?	393*	190	0.48	2	
46/63-17 CBC	-/-/69	?	531*	800	1.5	1	"Flow through 2 inch hose"
	-/-/69?	?	647*	800	1.2	1,2	Different reported SIP
	8/-/73	?	427*	800	1.9	2	Flow may not be 1973 data
46/64-13 CCA	-/-/60?	?	92*	30	0.33	2	Yield may not be 1960 data
+46/64-19 BDC	-/-/56?	?	80	280	3.5	3	Plugged, 1965
46/64-23 CCB	3/5/65	6	65	70	1.1	1	Swab test
	6/-/72	sev. wks.	293	308	1.1	3	
46/65-20 CDD	9/19/60	6	295?	425	1.4	1	
46/65-23 BAD	6/-/72	2 mos.	76	225	3.0	3	
	unk	?	400	600	1.5	2	
46/66-25 DBB	4/16/62	1	30	354	11.8	1	
	6/-/72	4 mos.	211	360	1.7	3	
47/60-4 AA	8/9/65	36	5?	8	1.6	1	
48/65-25 CBB	-/-/49	55 min.	517	15.4	0.03	1	
	6/-/72	6	110	210	1.9	3	
48/65-35 CC-	6/-/72	5	101	155	1.5	3	6 hrs. per source #2

others (1980a) report "low yield specific capacity" of 90 gpm/ft for one (unspecified) Madison well. Typically, high yields are required from Madison wells, and in general specific capacities at high yields are less than 5 gpm/ft, somewhat lower (less than 1 gpm/ft) in the southeastern basin, and over 10 gpm/ft only at the Salt Creek Oil Field, north of Casper.

Madison wells with step-discharge data often exhibit nonlinear head losses. At Devils Tower these are interpreted as well losses due to small casing diameter by Whitcomb and Gordon (1964). Kelly and others (1980a) attribute the head losses to turbulent flow in near-well fractures.

Yields and specific capacity data for other aquifers comprising the Madison system are sparse. Reported Minnelusa/Tensleep yields are generally less than 200 gpm. One Tensleep well in the outcrop area in Johnson County (47/83-15) was tested for five hours at 0.3 gpm per foot of drawdown (Whitcomb and others, 1966). Minnelusa well specific capacity in Crook County is 1.4 and 4.7 gpm/ft at Devils Tower and Hulett, respectively (Wyoming Water Planning Program, 1972). In the northeastern part of the basin Eisen and others (1981) report three upper Minnelusa specific capacities between 0.1 and 0.3 gpm/ft, and one greater than 10 gpm/ft. The Red River Dolomite was tested at 15 gpm/ft at the U.S. Geological Survey Test Well (57/65-15) (Blankennagel and others, 1977).

Permeability

The evidence below indicates most Madison aquifer permeability is secondary, associated with restricted zones of solution and/or fracture. Miller (1976) specifically noted the importance of fracture permeability in southern Montana, and Woodward-Clyde (1980) view the upper part of the aquifer as containing randomly distributed local zones of well-developed secondary porosity and permeability. The permeable zones of the Madison and Red River carbonate aquifers can be considered typicaly of good aquifers, but the sandstone aquifers of the system are poor, especially by comparison.

Madison aquifer permeability, measured on cores from the U.S. Geological Survey Crook County test well, ranges from less than 0.01 to 789 millidarcies (up to 16 gpd/ft^2 for water at 60°F), whereas Madison permeability calculated from two drill stem tests on the same well is higher, averaging 2,112 and 279 gpd/ft^2 for the intervals tested (Blankennagel and others, 1977). The difference may reflect the influence of bedding plane partings and fractures, which do not affect the core data, or may reflect basic differences between methods of determination.

Secondary development of porosity by solution and/or fracturing is an important factor in Madison water well productivity. For example, driller's logs (Wyoming State Engineer's Office permit files) of several Madison water wells in the eastern basin report restricted zones within the upper Madison which provide most of the well yield. Often reported are water-filled voids, totalling 40 percent of one 15-foot interval in the Devils Tower well (53/65-18 bbd). At the Gillette well field, developed along the axis of a Laramide syncline in western Crook County, lost circulation zones associated with high secondary solution permeability are present in some wells (Kelly and others, 1981), and these wells are the best producers.

Tabulated Minnelusa/Tensleep permeabilities (Table IV-5) are for producing oil sands; the method of determination, sample interval, and quality of data are all unknown. The reported values range up to almost 20 gpd/ft^2, but most oil fields in the basin average an order of magnitude lower. Minnelusa permeabilities measured on core samples taken from a water test well in northern Crook County were somewhat comparable, though generally lower, ranging from nil to 11 gpd/ft^2 (Blankennagel and others, 1977).

Ordovician rock permeability, measured on cores from the U.S. Geological Survey test well in Crook County, ranges up to 89 gpd/ft^2, with the Red River Formation exhibiting zones of high permeability (Blankennagel and others, 1977). Data from drill stem tests indicated "an average permeability to the produced fluid of 35,139.8 md [640 gpd/ft^2] for the estimated 10 feet of effective porosity within the total 180 feet of interval tested" (Blankennagel and others, 1977, p. 76). Cambrian sandstone core permeability in the same well ranged from 2 to 18 gpd/ft^2.

Transmissivity

Transmissivity of the Madison aquifer is poorly known and no regional map has been published. Estimated values reported in the literature range from less than 1.0 north of the study area in Montana (Miller, 1976) to over 300,000 gpd/ft (see Table IV-6). Reported values may not be comparable due to the variety of estimating techniques used: drill stem tests, flow net analysis, estimation from specific capacity, and pump test interpretation. Konikow (1976) indicates that individual point aquifer tests do not reflect regional transmissivity

Table IV-5. Hydrologic properties of Permo-Pennsylvanian rocks of the Madison aquifer system, Powder River basin, Wyoming, determined from oil field data.

Field	Approximate Location (T/R)	Pay Thickness (ft)	Porosity (%)	Permeability* (md)	Calculated† Transmissivity (gpd/ft)	Data Source
Upper Minnelusa Fm. ("Converse" sands):						
Basin	47/70	24	14.7	61.8	27	5
		30	-	62	34	4
		45	-	46	38	4
Basin Northwest	47/70	-	12.7	48.4	-	5
Bishop Ranch	48/70	180	-	100	328	4
Bishop Ranch South	48/70	-	15.1	100	-	5
C-H Field	52/70	100	-	230	419	4
Deadman Creek	53/67	18	17.6	-	-	5
Dillinger Ranch	47/69-70	30	16.8	100	55	5
Duvall Ranch	49/69	-	17	88.8	-	5
Donkey Creek Area	49-50/68	0-50	8-25	20-1000+	<910	1
Guthery	51/68	-	18.9	184	-	5
Halverson Ranch	49/69	37	14.3	132	89	2
		-	13	56	-	5
Hamm	51/69	35	19.7	239	152	5
Kuehne Ranch	51/69-70	-	14.7	64.1	-	5
		-	13.8	32.1	-	5
		18	15.8	100	33	5
Kummerfeld	50-51/68	-	17	208	-	5
Lance Creek	35-36/65	30	16	3	2	3,5
Mellott Ranch	52/68	25	16	-	-	5
Pickrel Ranch	48/69	-	16.1	126	-	5
Pleasant Valley Ranch	51/69	-	11.1-14	29	-	5
Prong Creek	50/67	36	8.6-24.6	13-936	9-613	2
		26	18.5	411	194	2
		45	23	834	683	2

Table IV-5. (continued)

Field	Approximate Location (T/R)	Pay Thickness (ft)	Porosity (%)	Permeability* (md)	Calculated† Transmissivity (gpd/ft)	Data Source
Rainbow Ranch	49/71	10-35	17	170	31-108	2
		20	16	90	33	2
Raven Creek	48/69	15-65	<19	<200	<237	2
		30	13	60	33	2
		35	15	50-200	32-127	3
		38	15	92	64	5
Robinson Ranch	50/67	18 ±	14	200	66	3
		22 ±	21	440	176	3
Roehrs	53/70	-	17.3	115	-	5
Rozet South	50/70	-	17.8	212	-	5
Stewart	50-51/69	-	5.8-14.8	10.7-134	-	5
Timber Creek	49/70	40	16	80	58	2
		20	16	80	29	2
Whisler	50-51/70	12.1	18.6	242.2	-	5
Middle Minnelusa Fm. ("Leo" sands):						
Lance Creek	35-36/65	100	8-23	0.5-324	1-590	3
Tensleep Ss.:						
Horse Ranch	36/81	20	13.5	12.2	5	3
Meadow Creek	41/78	17	11	14	4	5
North Fork	44/81-82	90	1.9-24.3	54-1140	88-1867	1
		90	13	116	190	1
Notches	37/85	20	17-20	100-400	36-146	3
South Casper Creek	33-34/83	35	16	200	127	3
Sussex-Meadow Creek Area	41-43/78-80	60	11	14	15	1
Sussex	42/78	103	0.4-18.6	0.01-271	0.02-508	5
Tiesdale East	41/81	30	20	700	382	3

Table IV-5. (continued)

NOTES

*Md × 18.2 × 10^{-3} = gpd/ft^2, assuming fluid is water at 60°F.

†Assuming fluid is water at 60°F and pay thickness equals aquifer thickness.

Data Sources: 1 - Wyoming Geological Association, 1958
2 - Wyoming Geological Association, 1963
3 - Wyoming Geological Association, 1957 (supplemented, 1961)
4 - Wyoming State Oil and Gas Commission files
5 - Collentine and others, 1981

Table IV-6. Reported transmissivities and storage coefficients for the Madison aquifer in the Powder River basin, Wyoming.

Area	Transmissivity (gpd/ft)	Storage Coefficient	Source	Method Used
USGS Test Well (57/65-15)	3,000-21,000	-	Blankennagel et al., 1977	Drill stem tests
Gillette Well Field (51/66-6)				
Well CR-4	150,000	2×10^{-4}	Wyoming Water Planning Program, 1977	Single well pump test
Well CR-4	150,000-300,000	-	Montgomery, 1979	2-well pump test and other data
Well City #1	~10,000	-	Montgomery, 1979	2-well pump test and other data
Newcastle Area	5,000-15,000	10^{-4}	Wyo. St. Eng., 1974	Estimate
	58,000	9×10^{-5}	Woodward-Clyde, 1980	Flow and recovery, 2 wells
Well # 45/61-28	29,920	-	Swenson et al., 1976	Specific capacity based estimate
Well # 45/61-20	11,000	-	Woodward-Clyde, 1980	Constant discharge test
Near Hartville Hills in S.E.	1,000-3,000	$1 \times 10^{-4} - 5 \times 10^{-5}$	Wyo. St. Eng., 1974	-
ETSI Wellfield (Niobrara Co.)	1,000-3,000	5×10^{-5}	Stockdale, 1974, also Anderson and Kelly, 1974	Hantush method for leaky aquifers
	4,900-7,320	$4.5 \times 10^{-5} - 7.8 \times 10^{-5}$	Rahn, 1975	Jacob Method
	2,420-3,400	$7.7 \times 10^{-4} - 9.2 \times 10^{-5}$	Rahn, 1975	Theis curve, no leakage
Near Douglas, in South	500-1,000	10^{-4} (est)	Wyo. St. Eng., 1974	-
Midwest Area	8,400	-	Konikow, 1976	Flow net analysis
	6,462-16,156	-	Konikow, 1976	Steady state model calibration
Near Bighorn Mts. in N.W.	8,000-89,000	$4.3 \times 10^{-4} - 3.2 \times 10^{-4}$	Wyo. St. Eng., 1974	-
Entire Basin Average	6,460-25,850	-	Konikow, 1976	Recharge based steady state model calibration
	6,460-23,260*	-	Konikow, 1976	Potentiometric based steady state model calibration

* Value temperature dependent.

accurately due to the variability of local secondary permeability. Kelly and others (1981) propose a conceptual model which considers the Madison a "vertically zonated double-transmissivity aquifer" to explain observed data.

Miller (1976) used drill stem tests to estimate transmissivity of the Madison Group in the Powder River basin in Montana, arriving at a range of values from 0.07 to 40,000 gpd/ft. At the U.S. Geological Survey Madison test well in Crook County drill stem tests gave values of about 21,000 and 3,000 gpd/ft for two intervals in the Madison (Blankennagel and others, 1977).

Konikow (1976), using flow net analysis, estimated a regional average transmissivity value of 8,400 gpd/ft for the Madison north of Casper, Wyoming, but felt incomplete pumpage data severely limited the values' accuracy.

Swenson and others (1976), estimating from specific capacity corrected for calculated well losses, determined transmissivity at a Madison well near Newcastle (45/61-28) to be 30,000 gpd/ft, much higher than the general estimate of 5,000 to 15,000 gpd/ft for the Newcastle area reported by the Wyoming State Engineer (1974). Kelly and others (1980a) imply that most previous Madison transmissivity estimates from specific capacity are too low because they do not consider drawdown associated with turbulent flow in near-well fractures. Localized Madison transmissivity estimates in excess of 100,000 gpd/ft are derived by Kelly and others (1980a) from "low yield specific capacities" of Madison wells.

Interpretations of recent Madison aquifer pump tests have been discussed by several workers (Office of Technology Assessment, 1978;

Eisen and others, 1980; Woodward-Clyde, 1980). The reported transmissivity values are summarized in Table IV-6.

Little transmissivity data are available for water wells completed in other formations comprising the Madison aquifer system. Drill stem tests of the Red River Formation at the U.S. Geological Survey test well in Crook County indicate a transmissivity of about 6,400 gpd/ft (Blankennagel and others, 1977). Data interpreted from oil field pay thickness and permeabilities indicate the upper Minnelusa and Tensleep generally have transmissivities of several hundred gpd/ft or less (Table IV-5). These oil field data may not be comparable with water well data. Reported pay thickness is often less than total aquifer thickness due to arbitrary porosity cutoffs imposed in interpretation. Additionally, oil field tests are generally for the most porous and permeable intervals within a formation and, if translated for the entire aquifer thickness, give liberal transmissivity estimates.

Ground-Water Movement

The general circulation pattern of Madison aquifer water is basinward flow from exposed outcrop recharge areas, with subsequent northward subsurface outflow to Montana (Eisen and others, 1980; U.S. Department of the Interior, 1974; Wyoming State Engineer, 1974). Subsurface outflow to the southeast has been tentatively inferred, as has subsurface inflow across the Casper arch from the west (Wyoming State Engineer, 1974; Rahn, 1975). Interpretation of Madison aquifer water flow is complicated by both structure-related aquifer inhomogeneity and the possibility of vertical leakage.

In the upper Minnelusa aquifer there is shallow outcrop-related water circulation, with water moving down-dip, dissolving gypsum, then migrating upsection to emerge as springs (Bowles and Braddock, 1963). Eisen and others (1981) report regional flow paths in the upper Minnelusa in the northeastern part of the basin are similar to those in the Madison.

Available Madison head data have been compiled into potentiometric maps by several workers (Eisen and others, 1980; Wyoming State Engineer, 1974; U.S. Department of the Interior, 1974; Swenson, 1974; Swenson and others, 1976; Konikow, 1976). Since essentially the same data were used by most workers, the maps produced are similar; a representative example is shown in Figure IV-1. The map must be considered only a general characterization of the potentiometric surface (Swenson and others, 1976) due to sparse data, a thirty-year range in data age, and variable data sources, including shut-in pressures, water level elevations, and drill stem tests.

Sparse data prohibit detailed interpretation of flow in the basin center. The apparent gradient decrease is thought by Swenson and others (1976) to be associated with either little water circulation or high transmissivities. Konikow's (1976) hypothesis of central basin temperature-associated effective transmissivity increase supports Swenson and others' second alternative. Conversely, Huntoon (1976) considers central basin permeabilities lower than those of outcrops in the Bighorn Mountains.

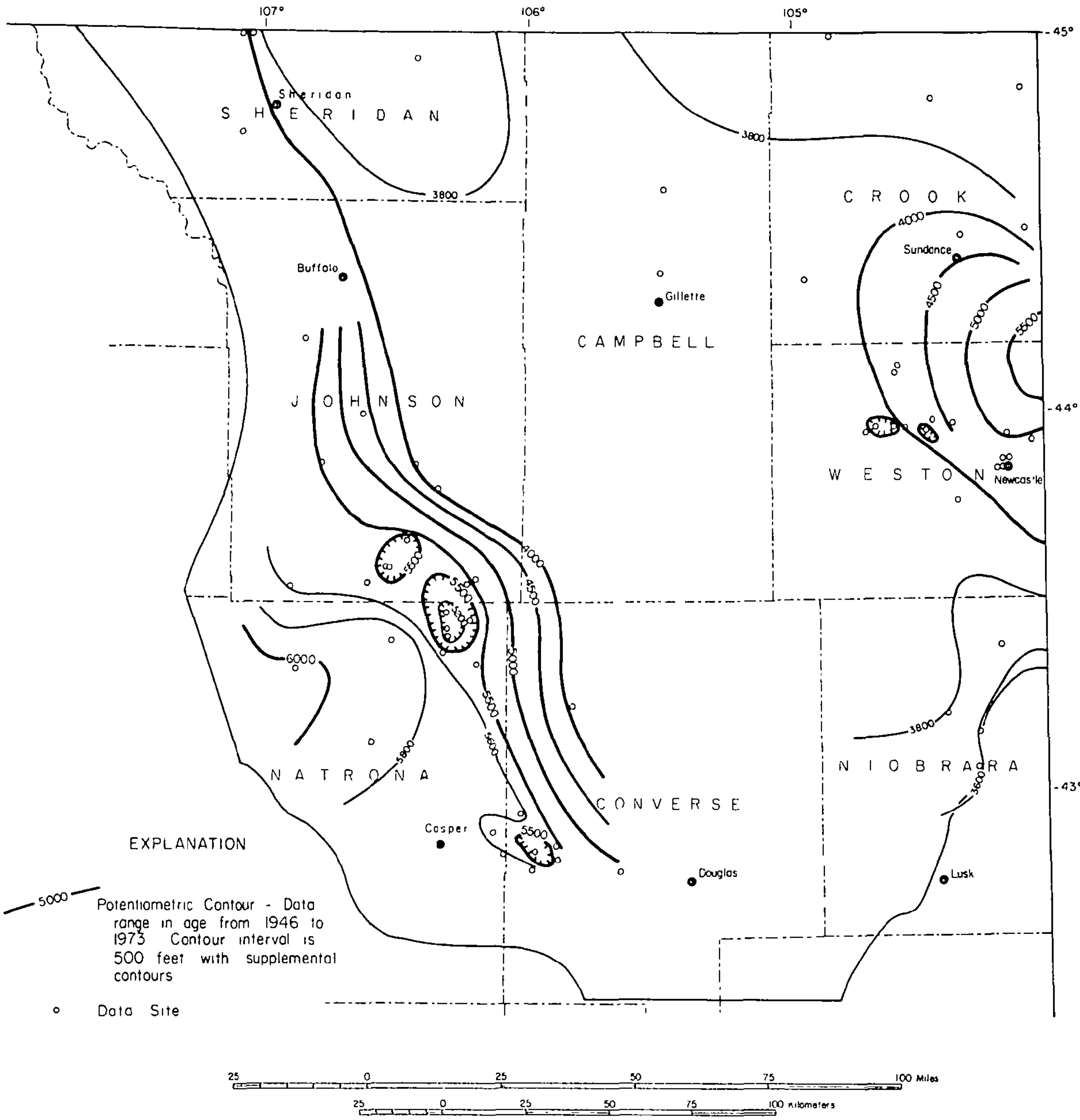


Figure IV-1. Potentiometric surface in the Madison aquifer (after Swenson and others, 1976).

Effects of Structure

Fracture zones may divide the Madison into discrete hydrologic units but the exact hydrologic effects of these boundaries are as yet undetermined (Cushing, 1977). Steep potentiometric gradients in the eastern basin are associated with the Black Hills monocline, and steep gradients in the western and southern basin are associated with the structurally steep and faulted basin axis. Woodward-Clyde (1980) consider these areas likely low-transmissivity zones. Blackstone (1981) considers the faulted west basin flank a total hydrologic discontinuity in the Madison. Konikow (1976) interpreted the western and southern basin marginal areas as low-transmissivity boundaries, impeding basinward flow, but did not do so for the eastern area. In the northeastern and southeastern parts of the basin there is a major change in total dissolved solids of Madison water across both the monocline and the Fanny Peak lineament (Eisen and others, 1980), indicating these features are hydrologic boundaries. Similar water quality differences and conclusions are noted for the upper Minnelusa aquifer at the Black Hills monocline (Woodward-Clyde, 1980).

Alternatively, fracture areas have been interpreted as local high-transmissivity zones. For example, the Fanny Peak lineament in the southeastern basin provides a partially recharging zone near the proposed ETSI Niobrara County well field (Office of Technology Assessment, 1978). In the western basin Huntoon (1976) calculates 30 percent of the deep-basin recharge occurs along geographically limited permeable zones associated with Laramide structures subsidiary to the Bighorn Mountains.

Vertical Leakage

Vertical leakage between the Madison aquifer and stratigraphically adjacent aquifers has been proposed (Eisen and Collentine, 1981; Woodward-Clyde, 1980; Konikow, 1976). Eisen and Collentin (1981) estimated the middle Minnelusa vertical leakage coefficient to be between 5×10^{-11} and 10^{-13} sec^{-1}, based on sulfate mass balance computations. Woodward-Clyde (1980) specified the leakage coefficient between the Madison and Red River as 10^{-9} sec^{-1}. The leakage coefficient between the Minnelusa and Madison has been specified as either 10^{-10} to 10^{-11} sec^{-1} (Woodward-Clyde, 1980) or 10^{-11} to 10^{-13} sec^{-1} (Konikow, 1976) in the models of the Madison aquifer.

Recharge

Recharge to the Madison aquifer within the Powder River basin is principally through direct infiltration of precipitation in outcrop areas; there are no reports of extensive interformational vertical leakage or stream losses. Most published reports on recharge have specifically considered recharge to Madison Limestone outcrops rather than to the entire Madison aquifer system. Recharge estimates range from 75,250 acre-feet/yr (Old West Regional Commission, 1976) to 8,300 acre-feet/yr (Rahn, 1975). Also often cited is an estimate of recharge "considerably in excess of 100,000" acre-feet/yr (Bishop, 1975). Discrepancies reflect varying definitions of recharge and different techniques of calculation. Eisen and others (1980) have recently reviewed recharge estimates for the Madison in the Powder River basin. They point out that the highest recharge estimates incorporate shallow infiltration which resurfaces at springs and does not enter the regional ground-water circulation; they also note that Rahn's (1975) estimate erroneously included a porosity correction.

The Old West Regional Commission (1976) study of net stream gains and losses concluded that Madison water lost to streams contributes a significant portion of base flow. Exceptions were noted in the central Bighorn Mountains and possibly the northern Laramie Mountains. Net aggregate stream gain from the Bighorn and Madison aquifers was estimated as 78 cfs (56,000 acre-feet/yr). Included field reports note additional gains and losses across the Tensleep Sandstone but for the Commission study the Tensleep was not considered part of the Madison system. Gries and Crooks (1968) found that similar measurements of stream gains and losses across Madison outcrops in the eastern Black Hills in South Dakota were significantly affected by underflow in valley alluvium, a factor not addressed in the Commission study.

PERMO-TRIASSIC AQUIFERS

Within the Powder River basin Permo-Triassic rocks are locally developed as low-yielding water sources. The Minnekahta Limestone is developed in the northeastern part of the basin, and redbeds of the Chugwater (Spearfish) Formation are tapped both in the northeastern part of the basin and by a few wells in Natrona County.

In Natrona County, Crist and Lowry (1972) report 9 wells, all yielding less than 20 gpm, drilled into the Chugwater, although two were later abandoned and a third deepened. Springs, yielding over 100 gpm, which issue from the Permo-Triassic are considered Madison aquifer system water rising along geologic structures (Crist and Lowry, 1972).

In the northeastern part of the Powder River basin 83 wells tapping the Spearfish aquifer have been inventoried (Eisen and others, 1980, 1981), of which the vast majority are stock and/or domestic wells in southeastern Crook County. Average yield of the inventoried wells is about 13 gpm. Two pump tests of Spearfish wells northeast of Hulett, in central Crook County, have reported specific capacities of 0.5 and 0.6 gpm/ft of drawdown, permeabilities of 6 and 8 gpd/ft^2, and transmissivities of 150 and 370 gpd/ft (Whitcomb and Morris, 1964).

Minnekahta aquifer wells inventoried by Eisen and others (1980, 1981) in the northeastern part of the basin numbered 29, with an average yield of 7 gpm. Whitcomb and Morris (1964) did not consider the Minnekahta Limestone to have development potential but at the U.S. Geological Survey Madison test well it showed good potential for low-yield development (Blankennagel and others, 1977). At this well, the Minnekahta flowed 12 gpm, had a specific capacity of 0.1 gpm/ft of drawdown, and had an effective transmissivity of 330 gpd/ft. The average permeability for the estimated 10 feet of effective porosity was 33 gpd/ft^2.

SUNDANCE AQUIFER

The middle Hulett Sandstone Member of the Sundance Formation is an important local shallow aquifer in Crook County, where wells are generally capable of yielding more water than required for domestic and stock purposes (Whitcomb and Morris, 1964). Other sandstones present within the Sundance also yield water in Crook County, although it may be of lesser quality (Whitcomb and Morris, 1964). Sandstones in the Sundance in the southeastern and southwestern parts of the basin often yield oil.

Eisen and others (1980, 1981) inventoried 177 wells in the eastern part of the basin which produce from the Sundance aquifer; most are domestic/stock wells in central Crook County with an average yield of 9 gpm. One reported pump test (Whitcomb and Morris, 1964) showed a specific capacity of 0.1 gpm/ft of drawdown.

Data from oil fields with Sundance producing zones are presented in Table IV-7. In general, porosity is 10 to 25 percent, permeability is less than 8 gpd/ft^2, and calculated transmissivity is less than 150 gpd/ft. At Lance Creek higher than typical pay thickness results in calculated transmissivity of about 400 gpd/ft.

DAKOTA AQUIFER SYSTEM

The U.S. Geological Survey (1979) defines the Dakota aquifer system to include all Early Cretaceous age sandstones present in the Powder River basin, together with intervening shales. The principal aquifers comprising the system, generally marine, fluvial, or deltaic lenticular sandstones, are, in the east, the Fall River ("Dakota") and lower Lakota formations, members of the Inyan Kara Group; and, in the west, the lower part of the stratigraphically equivalent Cloverly Formation. The Newcastle (Muddy) Sandstone is a minor aquifer included in the aquifer system due to geologic similarity. The Newcastle is a lateral equivalent of the upper Dakota Sandstone, which is the most important aquifer of the system in South Dakota.

Aggregate thickness of the aquifer system ranges from 350 to 800 feet, although much of this interval is shaley horizons which

Table IV-7. Hydrologic properties of the Sundance aquifer in the Powder River basin, determined from oil field data.

Field	Approximate Location (T/R)	Pay Thickness (ft)	Porosity (%)	Permeability* (md)	Calculated† Transmissivity (gpd/ft)	Data Source
Casper Creek South	33-34/83	23	14	20	8	1
Lance Creek	35-36/65	55	20-30	0-1250	<1250	1
		64	21	338	394	3
Lightning Creek	36/65-66	8	11.5	<1	0.15	1
Poison Spider	33/82-83	35	20	200	127	1
		30	18	241	132	3
Sussex/Meadow Creek	41-43/78-80	15	20	440	120	2

*Md $\times$ 18.2 $\times$ 10^{-3} = gpd/ft^2, assuming fluid is water at 60°F.

†Assuming fluid is water at 60°F and pay thickness equals aquifer thickness.

Data Sources: 1 - Wyoming Geological Association, 1957
2 - Wyoming Geological Association, 1958
3 - Collentine and others, 1981

do not produce significant amounts of water. The Dakota aquifer system is extensively developed in the northeastern Powder River basin, often by wells completed in more than one component aquifer, and serves as a shallower water source than the Madison aquifer system. Wells in the central part of the basin, where the Dakota is relatively deeply buried (see Plate 1), often produce oil, especially from the Muddy Sandstone. Unproductive oil tests occasionally are left as flowing water wells for stock watering purposes. In the southern Powder River basin the Dakota system is locally tapped for stock and industrial use. In the western part of the basin the outcrop band is narrow, the sandstones are less extensively developed, and current utilization of the aquifer system is limited because steep dips result in a narrow band of economically attractive drilling depths. Potential artesian yield to deep wells is postulated (Lowry and Cummings, 1966; Whitcomb and others, 1966).

Claystones of the Jurassic Morrison Formation are the lower boundary of the aquifer system; the upper boundary is the bentonitic Mowry Shale. The U.S. Geological Survey (1979) proposes a model that includes vertical leakage, implying there is some flow through these bounding shales. The Skull Creek Shale and shaley upper part of the Lakota Formation may be partial hydrologic barriers, subdividing the aquifer system. Available data are inadequate to determine such division regionally, although local evidence indicates that at least the individual Muddy/Newcastle sandstone bodies are hydraulically isolated (Stone, 1972; Wulf, 1963). Harris (1976) considers the Skull Creek Shale a sealing caprock for petroleum accumulations.

Hydrologic Properties

Hydrologic properties of the aquifer system have not been extensively investigated; therefore only general characterizations are possible. Regional variability of lithologies and sparse data prohibit comprehensive description. Completion of wells in more than one aquifer of the system further complicates interpretation. Aquifer properties indicate only moderate ground-water development potential compared to other systems in the basin, although high-capacity wells have been developed at the expense of hundreds of feet of drawdown.

Yield and Specific Capacity

Moderate yields are obtainable from the aquifer system. In the northeastern part of the basin wells flowing 1 to 10 gpm are common and yields up to 150 gpm are reported (Whitcomb and Morris, 1964). In Natrona County Cloverly aquifer wells flow 1 to 40 gpm, yields are usually 5 to 20 gpm, and pumped yields of up to 250 gpm are possible (Crist and Lowry, 1972).

Reported Dakota aquifer system specific capacities generally range from about 0.1 to less than 1.0 gpm/ft (Table IV-8). Most of the tabulated data are for the Lakota aquifer. No consistent differences between wells completed only in the Lakota and other completion zones are identifiable due to the limited reported data base. Specific capacities exceeding 4.0 gpm/ft have been reported for two wells in southern Niobrara County identified as completed in the Inyan Kara Group (Whitcomb, 1965). At both these wells the Inyan Kara is directly overlain by the White River Formation, which may contribute to the yield. No relationship between specific capacity and saturated aquifer

Table IV-8. Reported specific capacities (yield per unit drawdown) of wells in the Dakota aquifer system, Powder River basin, Wyoming.

Well Location (T/R-Sec. ¼ ¼)	Geologic Formation(s)	Test Date	Test Duration (hrs)	Drawdown (ft)	Discharge (gpm)	Specific Capacity (gpm/ft)	Data Source	Remarks
				CROOK COUNTY				
55/61-8 DC	Kfr & Klk	8/3/56	2	33.5	3.2	0.10	1	flowing well
56/62-28 BB	Kfr & Klk	7/21/56	4	21.2	9.2	0.47	1	flowing well
-29 DD	Klk	7/21/56	2	12.3	2.9	0.24	1	
56/65-8 CC	Klk	11/2/56	?	20.	25.	1.2	1	flowing well
				JOHNSON COUNTY				
41/80-30 DB	Kcv	10/-/60	-	125	2	0.02	2	
41/81-25 DA	Kcv	?	-	120	18	0.15	2	
				NIOBRARA COUNTY				
34/65-1 BB	Kik	10/-/59?	-	50 E	60	1.2	3	
-1 BC	Kik	10/-/59?	-	50 E	220	4.4	3	
35/65-35 AB	Kik	-/-/41	-	35	140	4.0	3	flowing well test
36/61-24 CC	Klk	7/-/60?	2	300	40	0.13	4	
37/62-1 BA	Klk	6/17/71	-	15	7	0.47	4	bailer test
38/62-25 DC	Klk	5/10/67	7	44	30	0.68	4	
40/60-29 BD	Klk	-/-/69	24	120	6	0.05	4	
40/61-25 CDD	Kik	6/15/70	72	350	8	0.02	4	

Table IV-8. (continued)

Well Location (T/R-Sec. ¼ ¼)	Geologic Formation(s)		Test Duration (hrs)	Drawdown (ft)	Discharge (gpm)	Specific Capacity (gpm/ft)	Data Source	Remarks
WESTON COUNTY								
44/62-11 CC	Kfr & Klk	1/15/70?	4.5	350	66	0.19	4	pumped flowing well; drawdown may not include pressure head component
45/62-22 CC	Klk	1/13/73?	2.5	300	88	0.29	4	swab test on flowing well; drawdown may not include pressure head component
46/63-18 AD	Klk	10/30/59	21	70	18.9	0.27	4,5	flowing well
46/64-13 AA	Kfr & Klk	8/15/77?	-	28	10	0.36	4	flowing well
-13 CCA	Klk	8/-/59	-	150	58	0.39	5	flow test
		6/16/59	1	150	210	1.4	4,5	flow test
		8/19/60	~9 mos.	175	75	0.43	5	long term pumpage
-24 ADA	Klk	2/1/46	?	46	42	0.91	4,5	flow test
-24 ADA	Klk?	7/9/77?	?	69	5	0.07	4	flow test
47/63-30 CC	Klk	9/25/60	?	30 E	8.5	0.28	5	flow test
47/65-1 DAB	Klk	5/1/76?	2.5	400	4	0.01	4	
48/65-25 CAB	Klk	-	72	490	38	0.08	4	
-35 AB	Kfr?	-	3	510	4.5	0.01	4	
-35 CCB	Klk?	-	72	405	35	0.09	4	

Abbreviations: Kik = Inyan Kara Group
Kfr = Fall River Formation
Klk = Lakota Formation
Kcv = Cloverly Formation
E = Estimated

Data Sources: 1 - Whitcomb and Morris, 1964
2 - U.S. Department of the Interior, 1974
3 - Whitcomb, 1965
4 - Wyoming State Engineer's Office permit files
5 - Whitcomb, 1960

thickness penetrated by the well is apparent; values vary by three orders of magnitude. No geographic trends in specific capacity are noticeable. Variability of Dakota system specific capacities is probably associated with local lithologic changes.

<u>Permeability</u>

Most available permeability measurements for aquifers of the Dakota system are from tests conducted in producing oil fields (Table IV-9); values range up to 36 gpd/ft^2. The Fall River Formation exhibits slightly higher values than the Lakota and Newcastle. The most variability in permeability values is for the Newcastle/Muddy Sandstone, reflecting lithologic variations.

Only two aquifer tests, which determined permeability of the whole Inyan Kara stratigraphic interval, have been noted in the ground-water literature (Whitcomb and Morris, 1964). The reported permeabilities, 14 and 2 gpd/ft^2 at wells 56/62-28 and 55/61-8, respectively, are comparable to the oil field data. They represent an aquifer average since permeabilities were calculated by dividing transmissivity by aquifer thickness.

<u>Transmissivity</u>

Transmissivities of 810 and 220 gpd/ft, for wells 56/62-28 and 55/61-8, respectively, are the only two published values for Dakota system water wells and are considered only order-of-magnitude estimates due to short test duration (Whitcomb and Morris, 1964).

Transmissivity values calculated from oil field data range from one to less than 1,000 gpd/ft (Table IV-9). These values are calculated using permeabilities and pay thicknesses reported in the literature.

Table IV-9. Hydrologic properties of Lower Cretaceous rocks of the Dakota aquifer system, Powder River basin, Wyoming, determined from oil field data.

Field	Approximate Location (T/R)	Pay Thickness (ft)	Porosity (%)	Permeability* (md)	Calculated† Transmissivity (gpd/ft)	Data Source
Newcastle/Muddy Ss.						
Bertha	54/69	4	23	334	24	1
Big Muddy East	33/75-76	7	17	80	10	1
Chan	56/73	-	14.2	44	-	7
Clareton	42-43/65-66	-	9.3	5	-	7
Cole Creek	35/77	4	5	0.01	<0.001	1
Collums	55/73	110[a]	19.3	62.6	125	7
Fence Creek	57-58/76	10	16	70	13	7
Fiddler Creek West	45-46/65-67	5.8	20	1-18	0.1-2	7
Fiddler Creek East	46/64-65	50[a]	18.6	3-6	3-5	7
Gas Draw	53-55/72-73	8	20.2	188	27	7
Glenrock South	33/75-76	7	20	200	25	6
		4-30	14	82	6-45	6
Hilight	43-46/69-71	-	20.3	104	-	7
Hunter Ranch	57/72	-	19.5	47	-	7
Joe Creek	47/72	29	12.2	-	-	7
Kitty	50/73	22	16	345	138	3
Lance Creek	35-36/65	10-20	17	20	4-7	7
Lazy "B"	49/73-74	100-300[a]	13.6	14.1	26-77	7
Lightning Creek	35/65-66	0-12	19.5	10	<2	7
		6	21	13	1	1
Lonetree Creek-Lodgepole Creek	44-45/66-67	4	-	<1	-	1
L-X Bar Ranch	56/75	15.1	16.5	-	-	7
O'Conner	52/69	7	15	58	7	1
Oedekoven	55/73-74	-	17.2	-	-	7

Table IV-9. (continued)

Field	Approximate Location (T/R)	Pay Thickness (ft)	Porosity (%)	Permeability* (md)	Calculated† Transmissivity (gpd/ft)	Data Source
Osage	46/63-64	5	22.8	44.2	4	7
		-	23	25.9	-	7
		8	18.1	87.7	13	7
		-	21.1	51	-	7
		10	23.3	428	78	7
		8	22	55	8	7
		8-13	19.1	2-87.7	0.3-21	7
Poison Spider	33/82-83	5	14.2	8	1	1
Recluse	56-57/74	0-40	<27	<1200	<875	3
	57/74-75	20	20	400	146	2
	56-57/74-75	-	16.8	87	-	7
Rozet East	50/69	-	15	63	-	7
Rozet	50/69-70	10-45	20	58	11-48	1
Skull Creek	44-45/62	8-38	15.8	89	13-62	7
Slattery	49/69	4	20	15	1	1
Springen Ranch	50-51/71	-	2-15	2.4-588	-	7
Steinle Ranch	39/69-70	6	12.6	8.3	1	2
		6	13.5	133.8	15	2
Timber Creek	49/70	20	20	100	36	4
Ute	57-58/72	-	16.8-21.3	-	-	7
Whitetail	56/72	-	22.4	148	-	7
		-	16.5	-	-	7
Fall River/Dakota Ss.						
Big Muddy East	33/75-76	10	14	75	14	1
Bridge Creek	39/61	4	23.5	733	53	1
Burke Ranch	37/78	12	15	44	10	1
		20	13	40	15	5
		12	14	29	6	7

Table IV-9. (continued)

Field	Approximate Location (T/R)	Pay Thickness (ft)	Porosity (%)	Permeability* (md)	Calculated† Transmissivity (gpd/ft)	Data Source
Cole Creek South	34-35/76-77	20	11	21	8	1
		16	11	21	6	6
Coyote Creek	48-49/68	40	14.5	200	146	1
Coyote Creek South	48-49/68	60	18	200	218	3
Donkey Creek Area	49-50/68	20	16	150	55	1
		0-20	15	<10	<4	5
		0-20	15	<5	<2	5
		0-50	13	10-1000	<900	5
Glenrock South	33/75-76	25	14	50-100	23-46	1
		4-70	14	3-1900+	-	6
		27-28	14	75	37	7
Kummerfeld	50-51/68	28	19	250	127	1
		>30	17	100-2000+	-	4
Lance Creek East	36/64	30	15	0-302	<165	1
Lonetree Creek- Lodgepole Creek	44-45/ 66-67	10	15	200	36	1
Miller Creek	51/68	26	18.5	200	95	1
		35	18.5	200	127	4
Sage Spring Creek	36-37/77	35-40	13	22-406	<300	5
Dakota-Lakota Interval						
Big Muddy	33/76	10-20	24.5-24.2	90	16-32	1
Cole Creek	33/77	2-20	13.5	43	2-16	1
Lakota/Cloverly Fm.						
Cole Creek South	34-35/76	25	15	40	18	6
Meadow Creek	41/78	20	15	40-200	15-73	7
		15	11	14	4	7

Table IV-9. (continued)

Field	Approximate Location (T/R)	Pay Thickness (ft)	Porosity (%)	Permeability* (md)	Calculated† Transmissivity (gpd/ft)	Data Source
Sherwood	40/77	15	16	<25	<7	5
Sussex	42/78-79	25	15.8	-	-	7
Sussex-Meadow Creek Area	41-43/ 78-80	20	15	40-200	15-73	5
Tisdale North	41/81	65	18	195	231	5

* Md × 18.2 × 10^{-3} = gpd/ft^2, assuming fluid is water at 60°F.

† Assuming fluid is water at 60°F and pay thickness equals aquifer thickness.

[a] Reported as gross formation thickness rather than net pay.

Data Sources: 1 - Wyoming Geological Association, 1957 (supplemented, 1961)
2 - Wyoming Geological Association, 1976
3 - Wyoming Geological Association, 1968
4 - Wyoming Geological Association, 1963
5 - Wyoming Geological Association, 1958
6 - Wyoming Geological Association, 1954
7 - Collentine and others, 1981

They are not strictly comparable to ground-water tests, as they represent values interpreted for only the most porous, and oil containing, sandy intervals. Because these intervals have the best aquifer properties of the formation, the values reflect a liberal estimate of transmissivity if translated for the total aquifer thickness.

The estimated transmissivity range from specific capacity data is a few hundred to a few thousand gpd/ft. Due to uncertainties in well construction, test procedure, and well efficiency, it is only possible to obtain an order-of-magnitude estimate using this technique. Additional uncertainty is introduced because the technique's assumption of an isotropic, homogeneous aquifer is not strictly met.

Ground-Water Movement

Few potentiometric maps and little potentiometric data have been published for the Dakota aquifer system in the Powder River basin. M. E. Lowry of the U.S. Geological Survey (personal communication, November, 1979) suggested that varying completion practices and partial hydrologic isolation of individual aquifers may necessitate separate head compilations for each component aquifer due to head differences of several tens of feet.

A preliminary potentiometric-surface map of heads in the Lower Cretaceous rocks of the basin (Lobmeyer, 1980) is reproduced as Figure IV-2. The map shows a low-pressure anomaly, located at the Montana-Wyoming state boundary, for which several tentative explanations have been offered (Hoxie and Glover, 1981).

The regional structural character, artesian nature of the aquifer system, and thick extensive confining shales imply that principal

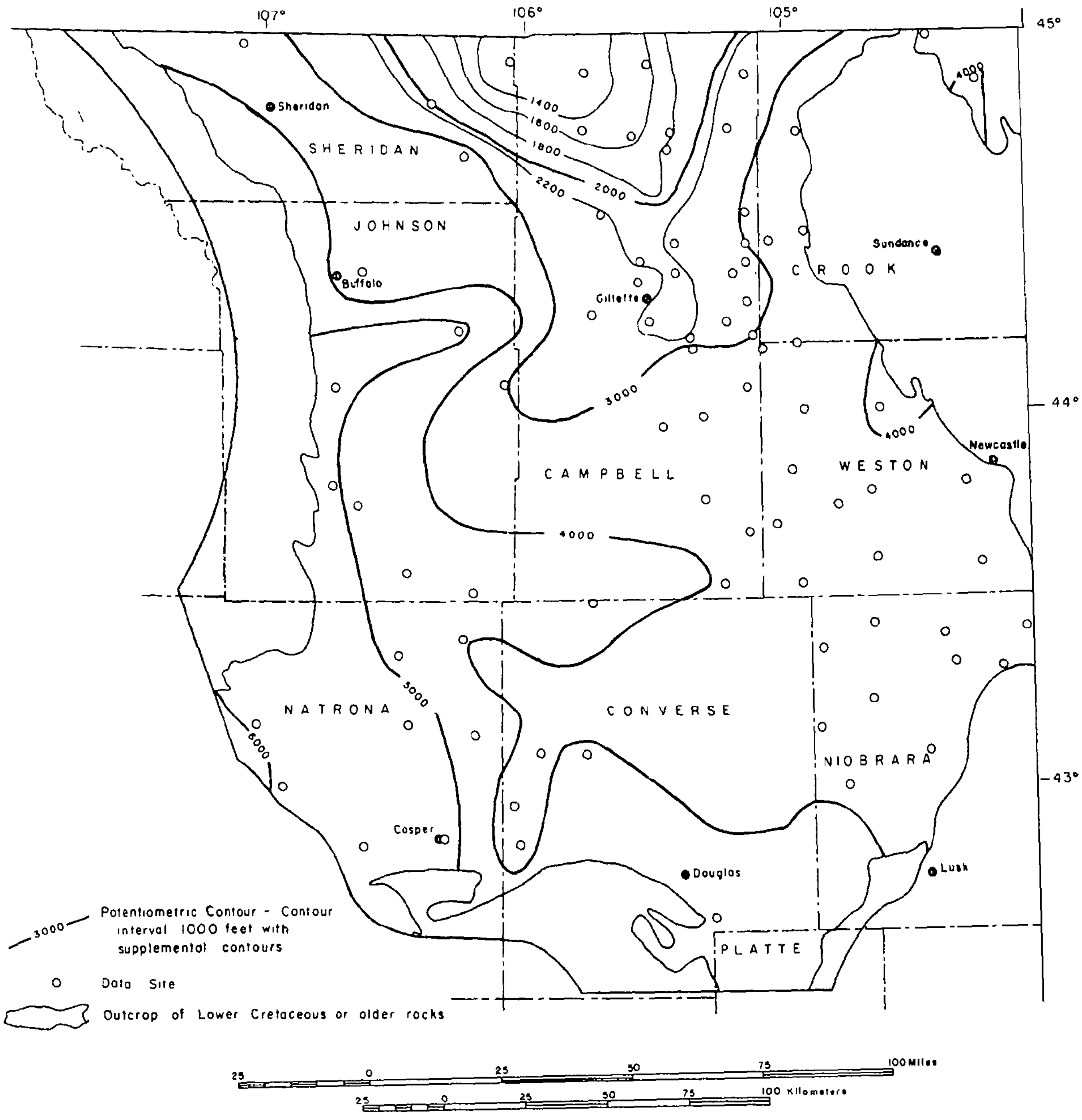


Figure IV-2. Potentiometric surface in the Dakota aquifer system (from Lobmeyer, 1980).

recharge is to basin-marginal outcrops, with subsequent down-dip flow. This flow pattern is substantiated by potentiometric data, total dissolved solids variations, and compositional changes reflecting postulated geochemical evolution of the waters (see Chapter V). Eisen and others (1981) report down-dip flow into South Dakota from outcrop recharge areas at the Old Woman anticline on the southeastern basin margin.

Geochemical evidence (Chapter V) suggests that the Black Hills monocline influences ground-water flow and composition. There is not sufficient evidence to conclude whether the monocline partially impedes recharge to the deeper part of the aquifer system or enhances interformational mixing.

Bowles (1968) suggested there is recharge to the Dakota from the Minnelusa aquifer. This deep upwelling is hypothesized to occur along breccia collapse pipes associated with gypsum dissolution in the Minnelusa. Available potentiometric data are insufficient to support Bowles' geochemically based conclusion.

Whitcomb (1960) reported declines in flowing yields and potentiometric elevations during the 1950's. He attributed the declines to either deteriorated well conditions, increased withdrawals, or subnormal recharge.

ISOLATED UPPER CRETACEOUS SANDSTONE AQUIFERS

Isolated sandstones which are capable of yielding water to wells are locally present within the thick Upper Cretaceous shale sequence of the Powder River basin. They are most significant and numerous in the southwestern part of the basin where, in ascending order, they include the Frontier Formation (Wall Creek sands), Shannon and Sussex sands of the Cody Shale, and the Mesaverde Formation (Parkman and Teapot sands).

The Frontier aquifer yields up to 10 gpm to flowing wells (Crist and Lowry, 1972) north and west of Casper, on the Casper arch. Yields up to 50 gpm are considered possible (Crist and Lowry, 1972). Northeast of Casper, where the Casper arch bounds the Powder River basin, the Wall Creek sands of the Frontier Formation are oil-bearing. Available hydrogeologic data are limited to areas of oil production (Table IV-10) and, at producing oil fields, reported permeabilities range from 0.1 to 9.0 gpd/ft^2, with most below 2 gpd/ft^2. All transmissivities calculated using reported permeabilities and pay thicknesses are less than 150 gpd/ft (Table IV-10).

The Shannon and Sussex aquifers are shale-isolated elongate marine sand bodies within the Cody Shale. Few water wells tap these sands; Crist and Lowry (1972) estimate a likely maximum yield of 20 gpm. Where the Powder River basin bounds the Casper arch the Shannon produces oil, its permeability ranges from nil to 8 gpd/ft^2, and calculated transmissivity ranges up to 85 gpd/ft (Table IV-10).

The Mesaverde Formation is considered a potentially important aquifer in the western part of the basin (Hodson and others, 1973). Few wells tap the aquifer and little hydrologic data are available because in most of the basin the formation is absent or overlain by the Fox Hills/Lance aquifer system. One well about 20 miles north of Casper is reported to have a yield greater than 100 gpm, but in general expected yields are 10 to 20 gpm (Crist and Lowry, 1972). In the Dead Horse-Barber Creek area in west-central Campbell County,

Table IV-10. Hydrologic properties of sandstone aquifers within the Upper Cretaceous shale sequence, Powder River basin, Wyoming, determined from oil field data.

Field	Approximate Location (T/R)	Pay Thickness (ft)	Porosity (%)	Permeability* (md)	Calculated† Transmissivity (gpd/ft)	Data Source
Frontier Fm. (Wall Creek Sands):						
Big Muddy	33-34/76	38	20	20-100	14-69	1
	33/76	28	26.2	84	43	2
Big Muddy South	33/76	60[a]	-	70	76	1
Brooks Ranch	33/77	0-25	18-20	1-15	0-7	3
		7.7	16.9	3.1	0.4	1
Castle Creek	38/81	10-15	20	516	94-141	2
Coyote Creek South[b]		-	14.3	4.1	-	1
Meadow Creek	41/78	12-20	15	-	-	1
Meadow Creek North	42/78	26-63[a]	11.9	0.5	0.2-0.6	1
Salt Creek	39-40/78-79	80	16	80	116	1
		59	18	100	107	1
	39/78-79	25	16	4	2	1
Salt Creek East	40/78	28	19	26	13	1
Salt Creek West	40/79	40-45	21.1	24	17-20	2
Thornton	48-49/66	20	16	1.0	0.4	2
Twenty Mile Hill	36-37/78-79	10-20	17	3.0	0.6-1.	2
Wakeman Flats[b]	49/66	10-20	15	1.0	0.2-0.4	2
Shannon Sand of Cody Shale:						
Ask Creek	58/84-85	15[c]	23	240-290	66-79	3
		5[d]	19	210-430	19-39	3
		17	22	275	85	1
Cole Creek	35/77	17.5	19	56	18	1,2
Cole Creek South	34/76	7.5	19	54	7	1
Dugout Creek	42/78-79	17	25	-	-	1
Meadow Creek	41/78	16	25	-	-	1
Sussex	42/78-79	12	12.4	2	0.4	1
		38	18.6	-	-	1
Teapot East	38-39/78	10	20	250	46	3

Table IV-10. (continued)

Field	Approximate Location (T/R)	Pay Thickness (ft)	Porosity (%)	Permeability* (md)	Calculated† Transmissivity (gpd/ft)	Data Source
Sussex Sand of Cody Shale:						
Sussex	47/78-79	26	21	32	15	1
		33	20.7	-	-	1
Cody Shale:						
Poison Spider	33/82	-	10-12	<1	-	1
Mesaverde (Parkman) Fm.						
Barber Creek	50/76	-	18.3	76.9	-	1
Deadhorse Creek/ Barber Creek	48-50/75-76	25	15-21	<265	<120	2
Deadhorse Creek	47-49/75-76	-	18	50	-	1
		15-35	16	0-68	0-43	3
Poison Draw[e]	38-40/68-69	21	17.3	-	-	1

* Md × 18.2 × 10^{-3} = gpd/ft^2, assuming fluid is water at 60°F.

† Assuming fluid is water at 60°F and pay thickness equals aquifer thickness.

[a] Gross sand thickness

[b] Turner and Greenhorn formations

[c] Upper sand

[d] Lower sand

[e] Tecla sand

Data sources: 1 - Collentine and others, 1981
2 - Wyoming Geological Association, 1957
3 - Wyoming Geological Association, 1958

the formation contains oil; permeability and calculated transmissivity are less than 5 gpd/ft^2 and 120 gpd/ft, respectively (Table IV-10).

FOX HILLS/LANCE AQUIFER SYSTEM

The Fox Hills/Lance aquifer system includes the latest Cretaceous Fox Hills Sandstone and Lance Formation and also the Paleocene Tullock Member of the Fort Union Formation. It is composed of numerous individual, often lenticular, sandstone aquifers, isolated by interbedded shales and siltstones. Definition of the aquifer system is in part based on water well development, because the system corresponds to the stratigraphic interval for which supply wells at the Hilight Oil Field (Lowry, 1972) and deep wells at Gillette (Northern Great Plains Resource Program, 1974) are perforated. In Montana the upper Hell Creek (Lance) Formation is shalier, and excluded from the aquifer system (Northern Great Plains Resource Program, 1974). The Pierre Shale is the lower aquifer system boundary.

The upper boundary is a regional stratigraphic horizon of low expected well yields, which in the northern part of the basin is stratigraphically equivalent to the Lebo Shale Member of the Fort Union Formation. The Lebo Shale is less pronounced in the southern part of the basin, and the shaley upper Fort Union Formation may serve as the upper aquifer system boundary. Shaley horizons may also locally subdivide the aquifer system hydrologically (Eisen and others, 1981).

The aquifer system crops out in a narrow band on the northeastern basin margin and in wide areas on the southeastern and southwestern margins. In the south and west it is buried by younger rocks along the bordering mountain flanks. In the central basin, it is buried by over 3,000 feet of younger sediments. Its aggregate thickness increases southward, ranging from 2,000 to 3,500 feet.

The Fox Hills/Lance aquifer system has been extensively developed in outcrop areas for stock and domestic supply. It is utilized for industrial applications at the Hilight Oil Field, in southeastern Campbell County, and at Rozet, in east-central Campbell County. Fox Hills/Lance wells at Gillette, Glenrock, Edgerton, and Moorcroft contribute water to the municipal systems.

Hydrologic Properties

Most hydrologic data for the Fox Hills/Lance aquifer system are for shallow wells near the outcrop zone. Because these are commonly low-yield stock wells extensive aquifer testing is not conducted and reported data are usually a single yield/drawdown test result.

Yield and Specific Capacity

Available data indicate moderate to good potential for development of relatively low-yield wells (under 20 gpm). Large-drawdown high-capacity industrial wells which are perforated for the entire stratigraphic interval have yields up to 380 gpm.

Specific capacity of Fox Hills/Lance aquifer system wells averages about 0.6 gpm/ft of drawdown. Values generally range from 2 to less than 0.1 gpm/ft (Table IV-11), but two anomalously high values of 5 and 60 gpm/ft are present in one data compilation (Northern Great Plains Resource Program, 1974). High-capacity wells in southeastern Campbell County with an average yield of 323 gpm have an average specific capacity of only 0.3 gpm/ft.

Table IV-11. Reported specific capacities (yield per unit drawdown) of wells in the Fox Hills/Lance aquifer system, Powder River basin, Wyoming.

Well Location (T/R-Sec. ¼ ¼)	Geologic Formation(s)	Test Date	Test Duration (hrs)	Drawdown (ft)	Discharge (gpm)	Specific Capacity (gpm/ft)	Data Source	Remarks
CAMPBELL COUNTY								
44/71-12 BB	Kfh,Kl,Tft			1728	309	0.18	1	
45/70-8 BB	do			1021	265	0.26	1	
-9 BD	do			610	378	0.62	1	
-16 AB	do			1050	356	0.34	1	
-18 AD	do			584	379	0.65	1	
45/71-14 DA	do			1707	231	0.14	1	
-36 BB	do			1428	251	0.18	1	
46/71-34 AD	do			1600	380	0.24	1	
-34 DD	do			2200	357	0.16	1	
50/72-21 CC	Kfh			240	90	0.38	2	
52/70-2 DC	Kfh			345	1688	4.9	3	
CROOK COUNTY								
49/68-16 CA	Tft	6/4/56	-	4.1	2.3	0.56	4	
-27 BC	Tft	6/1/56	-	17.3	3.2	0.18	4	
-28 AB	Tft	6/2/56	-	12.2	5.0	0.41	4	
-29 BC	Tft	6/2/56	-	14.0	1.3	0.09	4	
-36 DB	Kl	6/19/56	2	3.4	1.4	0.41	4	aquifer test
50/68-14 CD	Kl	6/21/56	2.5	2.6	4.4	1.7	4	aquifer test
-14 DD	Kl	6/-/56	-	28.6	4.4	0.15	3	
-24 CD	Kl	6/21/56	2	3.8	5.8	1.5	4	aquifer test
53/67-8 BB	Kfh	11/6/56	4	26.4	5.5	0.21	4	aquifer test
53/68-15 CD	Kl	11/2/56	-	50.	10.	0.20	4	

Table IV-11. (continued)

Well Location (T/R-Sec. ¼ ¼)	Geologic Formation(s)	Test Date	Test Duration (hrs)	Drawdown (ft)	Discharge (gpm)	Specific Capacity (gpm/ft)	Data Source	Remarks
				JOHNSON COUNTY				
45/79-20 BD	Kl	3/-/69		1008	124	0.12	3	
46/82-22 BB	Kl	1/5/61		35	7	0.20	5	
48/82-9 AD	Kl	9/-/56		15	10	0.67	5	
-10 CB	Kl	11/13/59		54	10	0.19	5	
49/82-20 BA	Kl	9/28/60		48	15	0.31	5	
				NATRONA COUNTY				
40/78-11 ABC	Kfh,Kl	9/9/65	8	-	25	0.03	6	6 hour step testing
-11 AC	Kfh	6/-/63	-	249	22	0.09	3	
-11 DBA	Kfh,Kl	10/13/65	8	-	11	0.04	6	8 hour step testing
-15 ABB	Kfh	-/-/53	7	-	10.9	0.37	6	
				NIOBRARA COUNTY				
36/64-18 CC	Kfh	11/-/59		47.5	3 E	0.06	7	
36/63-2 BB	Kfh	10/-/59		100	6 E	0.06	7	
-13 CA	Kfh	10/-/59		20	5 E	0.25	7	
-13 CB	Kfh	10/-/59		140	5 E	0.04	7	
38/63-25 BD	Kfh	10/-/59		40	100	2.5	7	
38/64-18 AC	Kl	3/-/60		31	6 E	0.19	7	
39/62-3 AB	Kfh	10/-/59		22	4 E	0.18	7	
39/64-32 DD	Kl	10/-/59		25	30	1.2	7	
40/64-15 CA	Kl	9/-/59		70	30	0.43	7	

Table IV-11. (continued)

Well Location (T/R-Sec. ¼ ¼)	Geologic Formation(s)	Test Date	Test Duration (hrs)	Drawdown (ft)	Discharge (gpm)	Specific Capacity (gpm/ft)	Data Source	Remarks
				SHERIDAN COUNTY				
55/85-7 AB	Kl	7/-/59		93 R	3 R	0.03	8	
57/87-1 BD	Kl	4/20/60		70 R	8 R	0.11	8	
				WESTON COUNTY				
42/65-6 CA	Kfh	8/-/60		200	47	0.24	3	
-30 BC	Kl	10/-/68		0.5	30	60.	3	

Abbreviations:
Kfh = Fox Hills Sandstone
Kl = Lance Formation
Tft = Tullock member of Fort Union Formation
E = Estimated

Data Sources:
1 - Lowry, 1972
2 - Littleton, 1950
3 - Northern Great Plains Resource Program, 1974
4 - Whitcomb and Morris, 1964
5 - Whitcomb and others, 1966
6 - Crist and Lowry, 1972
7 - Whitcomb, 1965
8 - Lowry and Cummings, 1966

No general geographic trends of specific capacity values are apparent. No relationship exists between specific capacity and either geologic formation or location with respect to outcrop zones.

In the Hilight Oil Field in southeastern Campbell County nine Fox Hills/Lance water wells show a specific capacity range of about 0.1 to 0.3 gpm/ft per thousand feet of aquifer penetrated. These data indicate there is localized hydrologic variability within the aquifer system but lack of specific geologic and completion information for the wells prohibits further interpretation.

Permeability

In Crook County Lance Formation permeability has been estimated at 6 to 35 gpd/ft^2 (Whitcomb and Morris, 1964) and in Natrona County Fox Hills permeability has been estimated at 34 gpd/ft^2 (Crist and Lowry, 1972). These values were derived through dividing estimated transmissivity by penetrated saturated thickness (see Table IV-12), but may only be order-of-magnitude estimates due to uncertainty of the estimated transmissivity (Whitcomb and Morris, 1964).

Transmissivity

The general range of reported Fox Hills/Lance transmissivities is from 100 to 2,000 gpd/ft (Table IV-12). Testing of wells has been limited to two areas, and methodology was not specified for most of the tests.

Transmissivities derived from specific capacity data using the method described by Theis and others (1963) range from less than 100 to over 5,000, with most below 2,000 gpd/ft. Lowry (1972) determined a minimum transmissivity of about 250 gpd/ft for the entire aquifer

Table IV-12 . Reported transmissivities and permeabilities for wells in the Fox Hills/Lance aquifer system, Powder River basin, Wyoming.

Well Location (T/R-Sec. ¼ ¼)	Geologic Formation	Test Date	Test Duration (hr)	Saturated Aquifer Thickness (ft)	Transmissivity (gpd/ft)	Calculated* Permeability (gpd/ft^2)	Data Source/Remarks
				CROOK COUNTY			
49/68-36 DB	Lance	6/19/56	2	29	170	6	Whitcomb and Morris, 1964 order of magnitude estimate due to short test duration.
50/68-14 CD	Lance	6/21/56	2½	40	1060	26	Same as above
-24 CD	Lance	6/21/56	2	60	2100	35	Same as above
				NATRONA COUNTY			
40/78-11 ACB	Fox Hills & Lance	9/7/65	8	-	76	-	Crist and Lowry, 1972
-11 DBA	do	10/13/65	8	-	166	-	Crist and Lowry, 1972
-15 ABB	Fox Hills	/53	7	47	1600	34	Babcock and Morris, 1953; Crist and Lowry, 1972 Theis recovery method.

*Calculated by dividing transmissivity by the saturated aquifer thickness.

system thickness in southeastern Campbell County using similar methods. With this transmissivity, and a time-prodution-drawdown data set from a single observation well, Lowry (1972) also estimated a storage coefficient of 1.8×10^{-4} using the Theis equation.

Ground-Water Movement

Potentiometric data (Figure IV-3) indicate northward flow in the aquifer system in the Gillette area (Northern Great Plains Resource Program, 1974). Recent data (Eisen and others, 1981) also indicate northward flow from outcrops in Niobrara County. However, a comparison of potentiometric elevations in these two areas indicates a ground-water divide exists in southernmost Campbell County.

Recharge

Vertical leakage from the overlying Wasatch/Fort Union aquifer system has been proposed as the major recharge mechanism for the Fox Hills/Lance (Lowry, 1972; Northern Great Plains Resource Program, 1974; U.S. Department of the Interior, 1974). The evidence cited is that potentiometric heads in the overlying strata are several hundred feet higher than those in the aquifer system. Some recharge from eastern outcrops of the aquifer system is also indicated by potentiometric data (Northern Great Plains Resource Program, 1974; Eisen and others, 1981). No quantification of aquifer recharge has yet been attempted. Available geochemical data are too sparsely distributed to use in verification of the postulated recharge mechanisms.

Discharge

The principal discharge mechanism of the aquifer system is subsurface underflow into Montana, where upward leakage occurs at

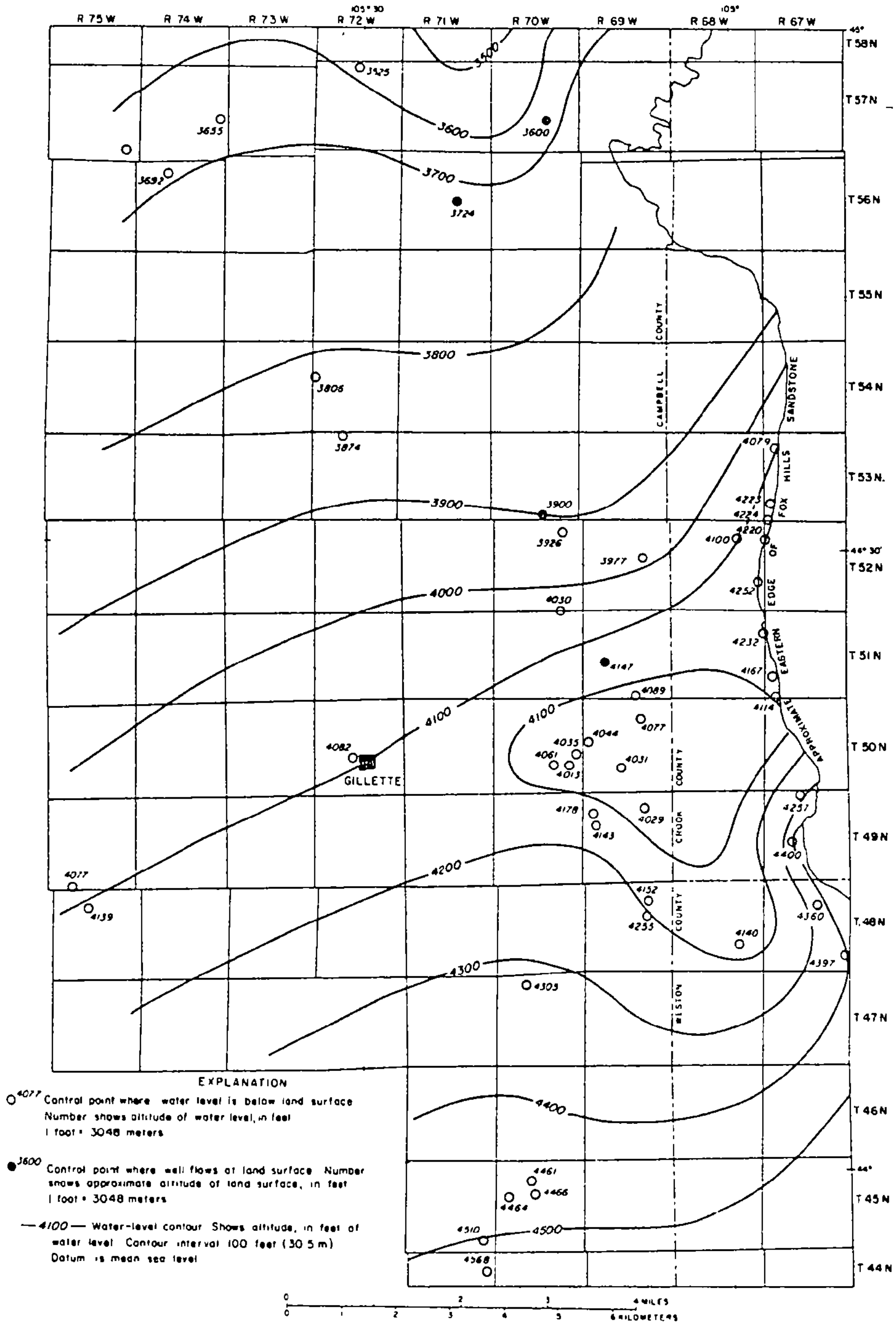


Figure IV-3. Contours on water levels in wells finished in the Fox Hills Sandstone, Lance Formation, and lower part of Fort Union Formation in the Gillette area, Wyoming (from Northern Great Plains Resource Program, 1974).

topographically low areas associated with the Yellowstone River (Northern Great Plains Resource Program, 1974). The U.S. Department of the Interior (1974) noted that in Wyoming local discharge areas on its potentiometric map were coincident with major drainages. One of their examples east of Gillette is co-located with an area of industrial water withdrawal, complicating this idealized interpretation. The potentiometric data in Niobrara County, in conjunction with the postulated Campbell County ground-water divide, indicate the topographically low Cheyenne River is an additional local discharge area (Eisen and others, 1981).

WASATCH/FORT UNION AQUIFER SYSTEM

The shallowest bedrock aquifer system in the central part of the Powder River basin is the Lower Tertiary Wasatch/Fort Union aquifer system. It consists of up to 3,000 or more feet of highly variable lenticular fine-grained sandstones, shales, claystones, and coals. High lithologic variability prevents identification of any extensive water-bearing zone--most of the coals and sandstones can produce water if saturated, but yields and quality vary greatly.

Most existing wells are private low-yielding domestic and stock wells, over 90 percent of which are less than 300 feet deep (King, 1974). In general, drilling depths are the minimum at which desired yields are found; yield generally increases with well depth as more water-bearing sands are penetrated.

The lower aquifer system boundary is ill-defined, represents a deep zone not generally exploited due to low expected yield, is approximately equivalent stratigraphically to the Lebo Shale of the

Fort Union Formation in the north, and may be equivalent to the shaley upper part of the Fort Union Formation in the south.

Hydrologic Properties

Local investigations of the hydrologic properties of the Wasatch/ Fort Union aquifer system have been made either to assess impacts of energy resource development or to plan water development projects. In the remaining basin area available data are limited to yield/drawdown reports of drillers. Lenticularity and lithologic variability of the individual water-bearing units result in extreme local variability of aquifer properties, although a characteristic range is present.

Yield and Specific Capacity

Yields over 250 gpm may be obtained from wells penetrating thick saturated sandstones, locally occurring coarse sand lenses, zones of high secondary fracture permeability, areas in hydrologic connection with surface waters, or areas adjacent to "clinker" recharge zones. Most shallow wells in areas that are void of these features produce less than 20 gpm.

Specific capacity (yield per unit drawdown) data for the aquifer system are widely distributed geographically but are generally limited to the upper few hundred feet of rock and represent an "averaging" of numerous individual water-bearing sands. Because most wells in the system are partially penetrating and developed for low yields, the available specific capacity data may not truly reflect the overall aquifer system development potential.

Reported specific capacities of the aquifer system range from less than 0.1 to 3.0 gpm/ft of drawdown. Averages reported for the

Wasatch in Johnson and Sheridan counties are 0.23 and 0.33 gpm/ft, respectively (Whitcomb and others, 1966; Wyoming Water Planning Program, 1972). Average values for the Fort Union Formation are 0.42 and "less than 1.0" for Sheridan County and the eastern basin, respectively (Wyoming Water Planning Program, 1972). Values over 1 gpm/ft in the western basin may be associated with coarser, conglomeratic aquifers. Extremely high values, up to 2,250 gpm/ft (Littleton, 1950), are associated with "clinker" areas.

Some driller's logs (Hodson, 1971a) for flowing wells report increased flow as deeper sands are tapped, indicating either increased specific capacity or head with depth. Although available data do not permit further analysis, increased heads with depth are not compatible with postulated downward leakage (see "Ground-Water Movement").

Permeability

Permeability of the various aquifer materials comprising the Wasatch/Fort Union aquifer system is lithologically dependent and very variable. Reported values cover a range of four orders of magnitude. The "clinker" is most permeable, followed by coals and then sandstones.

Most reported permeability data have been derived from pump test determined transmissivities (Table IV-13). Clinker permeability is several hundred gpd/ft^2 or higher, and coal is generally between 1 and 100 gpd/ft^2. Wasatch sandstones are very variable and reported permeabilities range from over 10 to less than 0.1 gpd/ft^2. Data for Fort Union sands are sparse but suggest a similar range. Permeability measurements of 15 to 25 gpd/ft^2 have been obtained from Wasatch Sandstone cores at the Highland Mine in central Converse County (Wyoming Department of Environmental Quality mine plan files).

Table IV-13. Transmissivities of the Wasatch/Fort Union aquifer system, Powder River basin, Wyoming.

Site Name	Location (T/R)	Test Date	Test Type[a]	Tested Thickness (ft)	Transmissivity (gpd/ft)[b]	Permeability (gpd/ft^2)[b]	Storage Coefficient	Data Source	Remarks
Fort Union Formation									
Black Thunder Mine	43/70	-	pumped well & recovery	-	7200	-	-	1	Jacob method, data skewed
Belle Ayr Mine	48/71	-	pump & recovery	60	1528		2.2×10^{-3}	2	
		10/6/76	slug	20	100	5.0C	$\sim4\times10^{-4}$	3	
		10/6/76	slug	20	-	-	-	3	no recovery after 15 min.
		10/6/76	slug	20	-	-	-	3	no recovery after 15 min
USGS Tests	49/68	6/21/56	pumped well	30	160	6	-	8	2.5 hour test
		6/22/56	pumped well	87	430	5	-	8	7 hour test
		6/22/56	pumped well	107	60	0.5	-	8	2 hour test
		6/27/56	pumped well	70	30	0.5	-	8	3 hour test
East Gillette Mine	50/71	10/26/76	slug	20	371	19.0C	1×10^{-5}	4	bad packer seal shaley material in interval tested
Fort Union Mine	50/71	-	slug?	140	148-183C	.87-1.07	-	4	
City of Gillette		2/1/77	pump	150	1320	8.8C	3.9×10^{-4}	5	Jacob method on pumped well
					2750	18.3C	2.1×10^{-4}	5	Jacob method on obs. well
		2/14/77	pump	150	1100	7.3C	3.8×10^{-3}	5	Jacob method on pumped well
					3830	25.5C	2.2×10^{-4}	5	Jacob method on obs. well
USGS Test	54/84	-	pumped well & recovery	-	95	7.9		6	24 hr. test, both Jacob & Theis methods
USGS Test	55/84	-	recovery	-	10	2.5		6	1.3 hr. recovery test
Sheridan Enterprises	57/84	-	fall. head	-	-	0.007	-	4	
Welch #1 Mine		-	-	-	-	0.002	-	4	
Coal									
Black Thunder Mine	43/70		pumped well & recovery		3800			1	Jacob method
			do		5600			1	Jacob method, data skewed
			do		3800			1	Jacob method, data skewed
			do		4400			1	Jacob method, data skewed
			do		4600?			1	Jacob method, data erratic
			do		4500			1	Jacob method, data erratic
			do		450			1	Jacob method, data erratic

Table IV-13. (continued)

Site Name	Location (T/R)	Test Date	Test Type[a]	Tested Thickness (ft)	Transmissivity (gpd/ft)[b]	Permeability (gpd/ft)[b]	Storage Coefficient	Data Source	Remarks
Black Thunder Mine (cont.)			do		32			1	Jacob method, data erratic
			recovery		100?			1	Jacob method, data skewed
			recovery		32			1	Jacob method, data skewed
			recovery		1300			1	Jacob method, data erratic
			pump & recovery		3400		$4.4x10^{-4}$	1	Leaky aquifer method
			pump & recovery		5600		$2.5x10^{-4}$	1	Theis method, slightly skewed data
			pump &		650		$1.5x10^{-6}$	1	Theis method, poor curve fit
			recovery		300		$6.0x10^{-4}$	1	Theis method, better fit than leaky
			pump		25000		$7.0x10^{-3}$	1	Jacob method, slightly skewed data
			pump		750		$2.0x10^{-3}$	1	Jacob method
Bell Ayr Mine	48/71	-	pump & recovery	62	1353		0.01	2	excessive drawdown after 1 hr. at 1 gpm
		-	pump & recovery	60	3542		$3.8x10^{-3}$	2	
		10/6/76	slug	80	>1000	>13C	-	3	complete recovery 3 min.
		10/6/76	slug	20	4.5	0.2C	$\sim 4x10^{-5}$	3	
		10/6/76	slug	20	5.3	0.3C	~ 0.4	3	
		10/27/76	slug	2	>256	>128C	-	3	complete recovery 2 min.
East Gillette Mine	50/71	10/22/76	pump	-	-	-	-	4	near "clinker"
				100	361	3.6C	$3.5x10^{-5}$		
				104	441	4.2C	$8.8x10^{-3}$		
		10/12/76	pump	-	-	-	-	4	recharging image well effects
				105	13	0.12C	$1.4x10^{-3}$		
				105	63	0.60C	1.2x10-3		
		11/3/76	pump	-	-	-	-	4	recharging image well effects
				94	8730	93C	0.33		
				100	1420	14C	$5.8x10^{-3}$		average of two obs. wells
		10/29/76	pump	100	392	3.9C	$1.2x10^{-3}$	4	
		8/7/76	pump	80	1421-815	-	$7.3x10^{-4}$	4	analyzed for anistropy
		10/25/76	slug	20	74	3.7C	0.01	4	
		10/25/76	slug	20	1	0.05C	$1x10^{-3}$	4	
		10/26/76	slug	20	165	8.3C	$2x10^{-4}$	4	
		10/26/76	slug	20	106	5.3C	$1x10^{-4}$	4	
		10/26/76	slug	20	5	0.25C	$1x10^{-4}$	4	
		10/26/76	slug	20	12	0.60C	$1x10^{-3}$	4	
Fort Union Mine	50/71	-	slug?	?	11-18.8	5.5-3.2	-	4	includes thin ss lens
		-	slug?	4	6.13	1.02	-	4	
		-	slug?	2	0.3	0.15	-	4	
		-	slug?	2½	0.45	0.18	-	4	includes shale

Table IV-13. (continued)

Site Name	Location (T/R)	Test Date	Test Type[a]	Tested Thickness (ft)	Transmissivity (gpd/ft)[b]	Permeability (gpd/ft^2)[b]	Storage Coefficient	Data Source	Remarks
USGS Test	54/81	-	pumped well & recovery	-	520	6.5	$2.4x10^{-2}$	6	24 hr. test, both Jacob and Theis methods
Sheridan Enterprises Welch #1 Mine	57/84	-	rising head	-	57	19	-	4	
		-	falling head	-	14	0.72	-	4	
		-	pump	-	100	4.2	$3x10^{-4}$	4	
Sheridan Area Coal	-	-	-	-	454	18	$1.8x10^{-5}$	4	Dietz #1 coal average of 9 test
		-	-	-	542	38	$1.8x10^{-3}$	4	Dietz #2 coal average of 6 test
		-	-	-	449	11	$5.3x10^{-4}$	4	Dietz #3 coal average of 2 test
"Clinker"									
East Gillette Mine	50/71	1/19/76	pump	14	-	-	-	4	pumped well in coal/clinker
				14	>8500	>610C	~0.16		obs. well in coal
				15	200	13C	~0.35		obs. well in coal
		10/22/76	pump	-	-	-	-	4	pumped well in coal
				104?	-	-	-		obs. well in clinker, no drawd[illegible]
				104?	974	9.4C	-		obs. well in clinker
				100	361	3.6C	$7.8x10^{-4}$		obs. well in coal/clinker
Fort Union Mine	50/71	-	slug?	13	2757	215		4	
			slug?	23	1150	50		4	well also in sandstone
Wasatch Formation									
Teton Nedco	34/74	-	pump	50	716	14.3C	$5.5x10^{-5}$	4	Theis method, avg. of 6 obs we[illegible]
					703	14.1C	$1.2x10^{-4}$	4	Cooper Jacob method, avg of 6 obs. wells
					689	13.8C	-	4	Theis recovery method, avg of [illegible] wells
			pump	50	419	8.4C	$1.9x10^{-4}$	4	Theis method, avg of 4 obs we[illegible]
					415	8.3C	$3.2x10^{-4}$	4	Cooper Jacob method, avg of 4 obs. wells
					398	8.0C	-	4	Theis recovery method, ave of wells
Highland Mine	36/72	-	core analysis	23	516C	22.5	-	4	
		-	do	22	412C	18.7	-	4	
		-	do	23	340C	14.8	-	4	
		-	do	31	768C	24.8	-	4	
		-	do	25	366C	14.7	-	4	
		-	do	15	274C	18.3	-	4	
		-	do	24	554C	23.1	-	4	
Belle Ayr Mine	48/71	-	pump & recovery	100	6175	62C	1.8x10-3	2	
		-	do	54	3495	65C	$5.4x10^{-3}$	2	
		10/6/76	slug	20	93	4.7C	~0.20	3	
		10/6/76	slug	10	82	8.2C	~0.04	3	

Table IV-13. (continued)

Site Name	Location (T/R)	Test Date	Test Type[a]	Tested Thickness (ft)	Transmissivity (gpd/ft)[b]	Permeability (gpd/ft^2)[b]	Storage Coefficient	Data Source	Remarks
East Gillette Mine	50/71	12/6/76	slug	20	38	1.9C	3×10^{-3}	4	shaley zone tested
USGS Test	51/82	9/2/61	pumped well	145	2500	17	-	7	3.75 hr. test
USGS Test	57/83	-	recovery	-	2200	-	-	6	3.5 hr. recovery test

[a] "pump" indicates existence of observation wells; "pumped well" indicates no observation wells.

[b] C indicates table entry is derived by calculation from other, reported values.

Data Sources:
1 - Bergman and Marcus, 1976
2 - Davis, 1975
3 - Davis and Rechard, 1977
4 - Wyoming Department of Environmental Quality mine plan files
5 - Wyoming Water Development Commission files
6 - Lowry and Cummings, 1966
7 - Whitcomb and others, 1966
8 - Whitcomb and Morris, 1964

Coal permeability is principally fracture-related (Northern Great Plains Resource Program, 1974), and anisotropic conditions related to fracturing are apparent in several coal aquifers (Wyoming Department of Environmental Quality Mine Plan Files). Stone and Snoeberger (1977) reported maximum and minimum permeabilities of 6.6 and 3.7 gpd/ft^2, respectively, in the Felix coal of the Wasatch Formation at a study site 15 miles south of Gillette, and found cleat (joint) orientation produced directional anisotropy.

Transmissivity

Transmissivity determinations (Table IV-13) have generally been limited to areas of proposed mining development, and many have been specifically limited to coal horizons. Many different techniques, including slug tests, recovery tests, and pump testing, have been used in determination of reported transmissivities. Interpretations have been complicated by interformational leakage, poor well completion data, recharging boundaries, and anisotropic conditions.

Coal transmissivity ranges from less than 1 to over 5,000 gpd/ft, reflecting variable thickness and occurrence of fracture permeability. The higher reported values appear to be related to isolated local faults or fracture zones (Davis and Rechard, 1977). Gypsum fracture infillings apparently can reduce coal transmissivity by two orders of magnitude (Davis, 1976), locally negating increases associated with fracturing.

Most tests on sandstones of the aquifer system have been in the Wasatch of the southern basin, where the average transmissivity is about 500 gpd/ft. Brown (1980) reports a range of 1 to 4,000 gpd/ft near Gillette. Fort Union sandstones have transmissivities of several thousand gpd/ft near Gillette.

High-yield pump tests with no observed drawdown have been conducted in "clinker" zones and interpreted as indicating permeabilities and transmissivities "too high to allow accurate determination of aquifer characteristics by pump test methods" (Wyoming Department of Environmental Quality Mine Plan Files). Davis (1976) states transmissivities up to 3,000,000 gpd/ft are present.

The wide range of reported storage coefficients (Table IV-13) indicate hydrologic conditions vary from water table to fully confined.

Ground-Water Movement

Several site-specific studies of a single coal or sandstone aquifer or a shallow (less than 500 feet) multiaquifer system have been conducted throughout the area, primarily in conjunction with coal or uranium resource development (Davis, 1975; Bergman and Marcus, 1976; Dahl and Hagmaier, 1976; Davis and Rechard, 1977). Local areal studies have also been conducted (King, 1974; Northern Great Plains Resource Program, 1974); an example is shown in Figure IV-4. No regional studies of aquifer system flow have been completed.

Interpretation of ground-water movement in the aquifer system is complicated by poor stratigraphic control, inadequate well completion data, improper well construction, multiple completion zones in some wells, and the lenticularity and discontinuities of component aquifers. An additional complication is the probable presence of a gas-pressure head component in wells completed in coal-rich horizons (Lowry and Cummings, 1966).

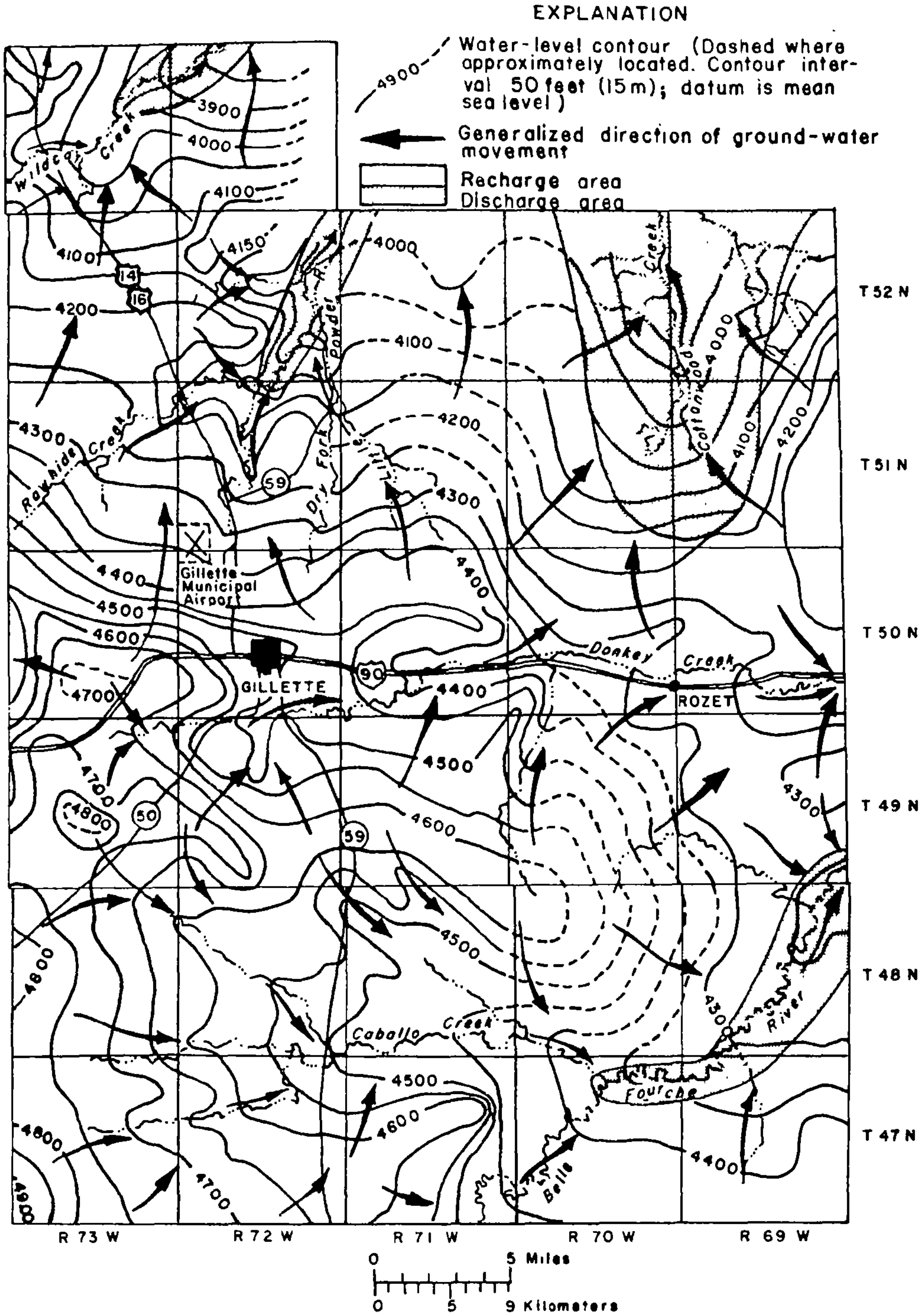


Figure IV-4. Water levels and direction of horizontal movement of ground water in the Fort Union and Wasatch formations in the Gillette area, Wyoming (modified after King, 1974; from Northern Great Plains Resource Program, 1974).

Based on a comparative review of existing study results the following conclusions can be made about flow in the Wasatch/Fort Union aquifer system: (1) flow within the aquifer system is primarily within several local flow regimes and no regional circulation patterns are known; (2) in general, recharge is to topographic high points, which are often outcrops of the resistant aquifer lithologies (sandstone and clinker bodies); (3) discharge areas are usually colocated with topographic lows; (4) topographic control of flow is typical (see King, 1974); and (5) in confined aquifers, flow tends to follow structure.

Potentiometric data indicate that downward leakage through the system recharges deeper aquifers; but little leakage may actually occur due to low vertical permeability (Northern Great Plains Resource Program, 1974; Davis and Rechard, 1977). No regional estimate of recharge rates has been published. Two local estimates of infiltration rate were both 0.15 inches/yr (Davis and Rechard, 1977; Brown, 1980). Local variability of recharge rates due to variable microclimates, surficial geologic materials, and topography is likely.

Areas underlain by clinker are considered very favorable local recharge sites for coal aquifers (Lowry and Cummings, 1966; Davis, 1976) but can also act as ground-water sinks (Brown, 1980). Low permeability of coal-associated clays indicates almost all coal aquifer recharge may be from coal outcrops and associated clinker zones, rather than downward leakage (Davis and Rechard, 1977). Coal aquifer recharge from surface waters and associated alluvial aquifers is locally documented in areas where the coal subcrops in the floor of alluvium-filled valleys and potentiometric gradients are downward (Davis and Rechard, 1977).

Discharge from the aquifer system is typically to stream valleys (Dahl and Hagmaier, 1976; Northern Great Plains Resource Program, 1974). Davis (1976) indicates recharge to the Fort Union Formation in the eastern part of the basin probably flows down-dip and discharges in the western part of the basin to the Tongue River, maintaining the base flow.

MIDDLE TERTIARY AQUIFERS

The Middle Tertiary White River and Arikaree formations are only extensively present within the study area in southern Converse and Niobrara counties, where their total thickness is between 1,000 and 1,500 feet. They are exploited as shallow water sources where present, and are extensively developed southeast of the basin boundary in the Denver-Julesberg basin.

Although most data available are for wells specifically developed for low yield, yields in excess of 1,000 gpm are reported in Niobrara County. Reported specific capacities (yield per unit of drawdown) range from less than 0.1 to 232 gpm/ft (see Table IV-14) but most lie between 0.2 and 4 gpm/ft.

Little permeability data are available. Measured permeabilities of the White River Formation range from 0.0002 to 0.03 gpd/ft^2, whereas reported Arikaree Formation permeabilities range from 0.001 to 80 gpd/ft^2 (Whitcomb, 1965). Permeability interpreted from pump test data for the Arikaree aquifer east of Lusk is 30 to 310 gpd/ft^2. Fractures and joints increase permeability of the Middle Tertiary aquifers, especially the White River aquifer.

Table IV-14. Specific capacities of wells completed in Middle Tertiary aquifers of the Powder River basin, Wyoming.

Location	Completion Date	Total Depth (ft)	Test Duration (hr)	Yield (gpm)	Drawdown (ft)	Specific Capacity (gpm/ft)	Remarks
			CONVERSE COUNTY				
29/72-14 dc	7/20/74	108	5 min.	15	60	0.25	
30/72-22 da	11/9/73	40	?	18	18	1.0	
31/68-10 bb	9/1/76	200	1	25	25	1.0	
31/69-21 dc	1/10/70	123	1	20	50	0.40	
31/70-23 bd	1/15/74	290	½	10	30	0.33	flowing well
31/70-24 bb	10/7/70	84	2	5	-	-	"complete" drawdown
31/71-2 ac	5/10/78	300	6	25	-	-	"zero" drawdown
31/71-14 cd	7/7/78	65	7	15	45	0.33	
32/69-22 ad	12/15/61	150	1	15	90	0.16	
32/71-7 dd	10/31/75	40	1	10	1	10.	
32/71-16	8/13/70	170	2	25	20	1.2	
32/71-16 bb	1/29/76	40	3	10	3	3.3	
32/71-16 bd	4/12/78	24	12	3	2	1.5	
32/71-17 aa	5/15/70	104	1.5	25	5	5.0	
32/71-17 ac	7/24/78	173	4	20	70	0.29	
32/71-17 ad	6/2/79	230	3	10	65	0.15	
32/71-17 bb	6/10/78	80	4	15	2	7.5	
32/71-17 da	2/19/76	100	2	10	65	0.15	
32/71-18 ad	4/30/77	120	3	20	-	-	"zero" drawdown
32/71-18 da	10/30/76	118	2.5	15	10	1.5	
32/71-18 da	7/12/78	200	1	20+	-	-	"zero" drawdown
32/71-18 dd	4/1/64	60	0.5	13	9	1.44	
32/71-18 dd	5/15/74	220	10	20	-	-	drawdown: "none"
32/71-19 ba	4/19/79	150	1	22	30	0.73	
32/71-21 ac	2/25/72	250	3	6	150	0.040	
32/71-21 bb	10/20/75	200	24	50	30	1.7	
32/71-28 bc	10/14/78	30	5	2.5	12	0.21	

Table IV-14. (continued)

Location	Completion Date	Total Depth (ft)	Test Duration (hr)	Yield (gpm)	Drawdown (ft)	Specific Capacity (gpm/ft)	Remarks
32/71-35 cc	4/25/79	325	1	12	-	-	drawdown: "no"
32/72-10 db	8/28/75	100	1	10	10	1.0	
32/72-12 ac	-/-/20	200	2	20	150	0.13	
32/72-13 cb	7/26/79	90	24	25	5	5.0	
32/72-13 dd	5/27/74	120	2	25	-	-	drawdown: "none"
32/72-23 cc	12/20/76	100	2	25	7	3.6	
32/72-23 cc	10/1/77	200	1	25	30	0.83	
32/72-23 da	5/20/77	100	4	15	-	-	drawdown: "no"
32/72-24 ab	-/-/44	71	1	10	20	0.50	
32/72-24 ac	4/28/77	120	2	25	30	0.83	
32/72-24 ac	3/31/78	210	2	10	60	0.16	
32/72-24 ad	7/20/77	140	1	18	20	0.90	
32/72-24 ba	11/7/78	216	2	15	40	0.37	
32/72-24 ba	11/8/78	200	?	25	40	0.62	
32/72-24 bd	5/18/75	127	4	25	10	2.5	
32/72-24 bd	9/5/76	105	4	16	?	-	
32/72-24 bd	10/10/78	385	2	25	50	0.50	
32/73-3 aa	5/21/73	80	1	10	5	2.0	
32/73-9 bc	10/7/74	80	1	20	15	1.3	
34/67-8	7/-/62	415	3	10	75	0.13	flowing well
			NIOBRARA COUNTY				
31/65-5 cb	-/-/58	210	?	15	30	0.5	Whitcomb (1965)
31/66-20 cc	-/-/59	60	?	10	10	1.0	Whitcomb (1965)
32/64-13 ac	-/-/47	122	24	30	-	-	"zero" drawdown
32/64-13 ac	-/-/-	145	24	200	41	4.9	
32/64-13 bd	-/-/80	100	48	20	10	2.0	
32/64-14 db	8/26/77	140	6	25	40	0.62	
32/64-18 bd	-/-/-	78	36	135	-	-	drawdown: "none"
32/64-18 bd	-/-/49	110	?	1000	14	71.	Whitcomb (1965)
32/64-24 da	-/-/55	59	?	650	2.8	232.	Whitcomb (1965)
32/65-1 bc	-/-/-	200	?	125	4	31.	Whitcomb (1965)

Table IV-14. (continued)

Location	Completion Date	Total Depth (ft)	Test Duration (hr)	Yield (gpm)	Drawdown (ft)	Specific Capacity (gpm/ft)	Remarks
32/65-1 cb	-/-/50	108	?	350	14	25.	Whitcomb (1965)
32/65-13 ac	-/-/-	260	12	90	10	9.0	
32/65-13 ac	-/-/-	70	1	30	-	-	"total" drawdown
32/66-17 cc	-/-/58	200	?	60	170	0.35	Whitcomb (1965)
33/65-17 dc	-/-/59	225	?	5	20	0.25	Whitcomb (1965)
33/66-17 da	12/18/59	100	2	40	-	-	"zero" drawdown
33/67-25 ab	11/10/74	268	1	9	?	-	
34/63-26 ca	-/-/-	150	?	7	15	0.47	Whitcomb (1965)
34/64-9 ac	-/-/52	100	?	6	4	1.5	Whitcomb (1965)
34/64-9 db	11/8/47	130	12	10	40	0.25	
34/66-25 db	2/23/67	85	120	25	2	12.5	
35/65-28 dd	5/29/77	98	0.25	10	60	0.17	
			PLATTE COUNTY				
29/67-15 cb	-/-/50	125	1	7	10	0.7	
29/68-8 aa	9/25/77	65	1	25	20	1.2	
29/68-9 bb	8/10/77	58	2	16	10	1.6	
29/68-22 bd	8/7/76	106	2	7	30	0.23	
29/68-22 cc	3/2/77	125	24	20	1	20.	
29/69-33 ac	2/-/65	155	½	15	-	-	pumped dry
29/69-33 ac	5/15/69	60	1	50	10	5.0	
29/70-26 ba	5/31/73	158	1	16	10	1.6	
30/68-29 da	9/-/57	70	4	20	12	1.7	

Source: Data from Wyoming State Engineer's Office permit files unless otherwise specified under "Remarks."

Reported transmissivities for the Arikaree aquifer east of Lusk range from 8,000 to 77,000 gpd/ft (Whitcomb, 1965), although all four wells tested only partially penetrate the aquifer. Specific capacity based transmissivity estimates indicate a range from 100 to 500,000 gpd/ft, with most wells between 500 and 10,000 gpd/ft.

In general, the Middle Tertiary aquifers are water table aquifers but well-cemented concretionary sandstones are local confining beds (Whitcomb, 1965), and the complex nature of channel deposits within the White River Formation often causes local hydrologic complexity. Springs which issue from the base of the Arikaree aquifer indicate the underlying White River Formation acts regionally as a partial flow barrier.

QUATERNARY AQUIFERS

Quaternary alluvium is present in most stream valleys of the Powder River basin, both as flood plain and terrace deposits. Extensive Quaternary aeolian deposits are present northeast of Casper.

In the western and southern basin the alluvium is near population centers (Sheridan and Casper) and has been extensively exploited for domestic, community, and occasionally irrigation supplies.

Typically, the younger valley floor deposits are clay-rich Holocene sandy silts with sand and gravel lenses, and the older terrace deposits are Pleistocene sands and gravels, often iron-stained. Both deposits become coarser and more extensive near the mountain uplifts; thickness varies greatly and can exceed 100 feet. The aeolian deposits are fine-grained sand and silt which locally exceed 100 feet in thickness.

Well yields of over 1,000 gpm can be obtained from Quaternary alluvial aquifers (Crist and Lowry, 1972). Specific capacities vary widely, ranging from 0.3 up to 18 gpm/ft of drawdown (Lowry and Cummings, 1966; Whitcomb and Morris, 1964). In some areas yield is limited by minimal saturated thicknesses (Lowry and Cummings, 1966).

Hydrologic properties of the alluvium vary with sediment size. Measured porosities range from 28 to 45 percent (Whitcomb and Morris, 1964). Permeabilities of clay- and silt-rich alluvium range from 0.1 to 2 gpd/ft^2, coarser deposits generally have permeabilities of 15 to 180 gpd/ft^2, and values of over 600 gpd/ft^2 have been reported (Whitcomb and Morris, 1964; Lowry and Cummings, 1966; Whitcomb, 1965). Transmissivities vary from 15 to 350 gpd/ft (Davis and Rechard, 1977; Whitcomb and Morris, 1964) and range up to 64,000 gpd/ft (Crist and Lowry, 1972); saturated thickness is a significant factor affecting transmissivity values.

The Quaternary alluvial aquifers are in hydraulic connection with all bedrock aquifers in outcrop areas, and also with surface waters. In larger valleys they provide hydraulic interconnection between otherwise hydraulically isolated sandstones of the shallow bedrock aquifer system (Whitcomb, 1965). Induced recharge from surface waters to the alluvium is probable in areas of extensive well development but has not been specifically studied.

V. WATER QUALITY

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Roughly 900 water quality analyses were reviewed for this report. Data sources included: the U.S. Geological Survey WATSTOR data system, the Wyoming Water Resources Research Institute (WRRI) data system (WRDS), a compilation of water well analyses by Hodson (1971b), compilations of oil field water analyses by Crawford (1941) and Crawford and Davis (1962), and analyses conducted for this report. Additionally, analyses of Madison and Minnelusa aquifer waters have been compiled by Hodson (1974) and Wells and others (1979), respectively. All analyses used, except those by WRRI, are published or available elsewhere and therefore are not tabulated in this report. The results of the analyses collected specifically for this study are tabulated in Appendix C.

The first part of this chapter discusses the general water quality of major aquifer systems and other aquifers in terms of dissolved solids content and major ion composition. Total dissolved solids concentrations for the major aquifer systems are shown on Plates 4 through 8. Due to the limited amount of data available for other aquifers in the basin the dissolved solids concentrations are summarized in Table V-3. Where possible, trends in constituents and the mechanism causing them have been identified. The second portion of the chapter addresses water quality related to U.S. Environmental Protection Agency drinking water standards.

GENERAL WATER QUALITY

Madison Aquifer System

Extensive chemical data exist on waters of the Madison aquifer system, although most analyses are of waters from the Madison and Minnelusa aquifers and their equivalents. Varying degrees of hydraulic connection have been postulated between the Madison and Minnelusa aquifers. For this reason, the quality and general chemical character of their waters are discussed separately, and then compared.

Madison Aquifer

In the east half of the Powder River basin the Madison aquifer has a limited outcrop area. Chemical analyses of water from one outcrop well (48/60-4) and one Madison spring (50/61-24) show total dissolved solids (TDS) contents of 248 mg/l and 558 mg/l, respectively. Near-outcrop wells in the east half of Niobrara, Crook, and Weston counties produce waters with less than 500 mg/l TDS (Plate 4). Several analyses from western Crook County and Campbell County show that TDS levels increase rapidly across the Black Hills monocline, with the 3,000 mg/l dissolved solids iso-line roughly paralleling this structure.

Basinward increases in TDS coincide with changes in major ion composition (Figure V-1). Waters containing less than 500 mg/l TDS are primarily calcium-magnesium bicarbonate, while those with 500 mg/l to 1,000 mg/l dissolved solids are calcium-magnesium sulfate in character. More saline waters are predominantly sodium sulfate or sodium sulfate-chloride.

Similar downgradient trends are seen in the west half of the basin. Springs from Madison outcrops generally yield calcium bicarbonate

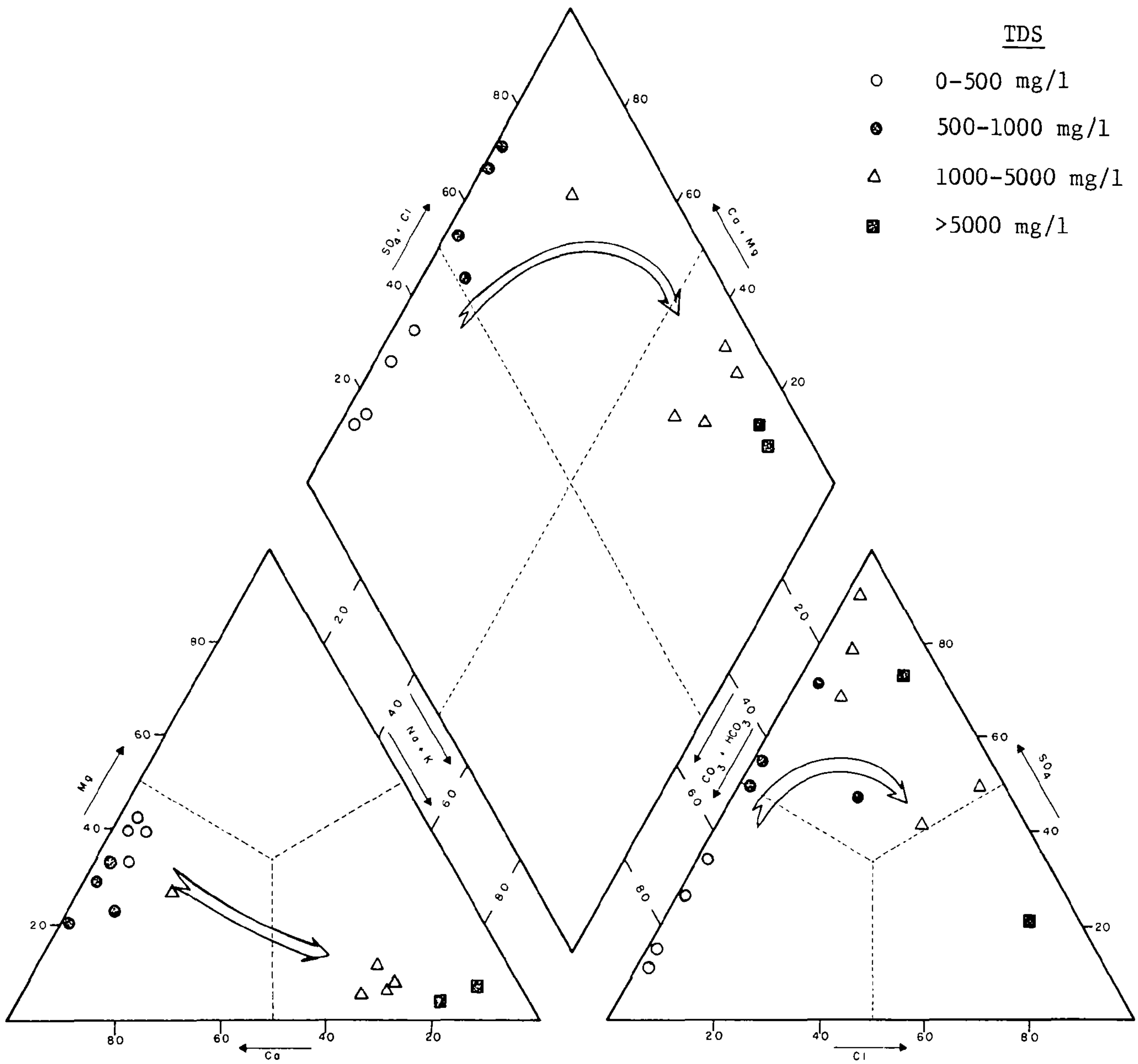

Figure V-1. Trilinear plot of representative Madison aquifer waters, eastern Powder River basin, Wyoming. Numbers plotted are percent of total milliequivalents per liter. Arrows indicate general basinward trends of TDS concentration and major ion composition.

waters, containing less than 500 mg/l dissolved solids (Plate 4, Figure V-2). Away from outcrop, available data indicate that TDS concentrations increase to greater than 3,000 mg/l, with the waters progressively enriched in dissolved sulfate, sodium, and chloride. The most rapid change in dissolved solids content and major ion composition occurs in western Converse County, and is probably related to the structurally complex nature of the northern flank of the Laramie Mountains.

Minnelusa Aquifer

Minnelusa aquifer water quality in the east half of the basin is more variable than Madison aquifer water quality. Outcrop and near-outcrop wells produce waters containing from 200 mg/l to over 3,000 mg/l TDS (Plate 5). Many waters with low TDS originate in the lower Minnelusa Formation (see "Comparison of Madison and Minnelusa Waters," below). Dilute waters (less than 500 mg/l TDS) are calcium-magnesium bicarbonate in character (Figure V-3), whereas an increase to 1,000 mg/l TDS shows an associated increase in dissolved sulfate. Waters from 1,000 mg/l to about 3,000 mg/l contain predominantly calcium and sulfate ions from solution of gypsum beds in the upper Minnelusa.

Away from outcrop but east of the Black Hills monocline, TDS concentration is generally greater than 3,000 mg/l, with dissolved calcium, sodium, and sulfate the major ions in solution. West of the monocline, data from oil field tests indicate that upper Minnelusa waters become highly saline, with TDS exceeding 100,000 mg/l in places, and dissolved sodium and chloride the dominant ions. As the majority of Minnelusa oil traps are stratigraphic (Strickland, 1958) these waters may represent trapped formation water.

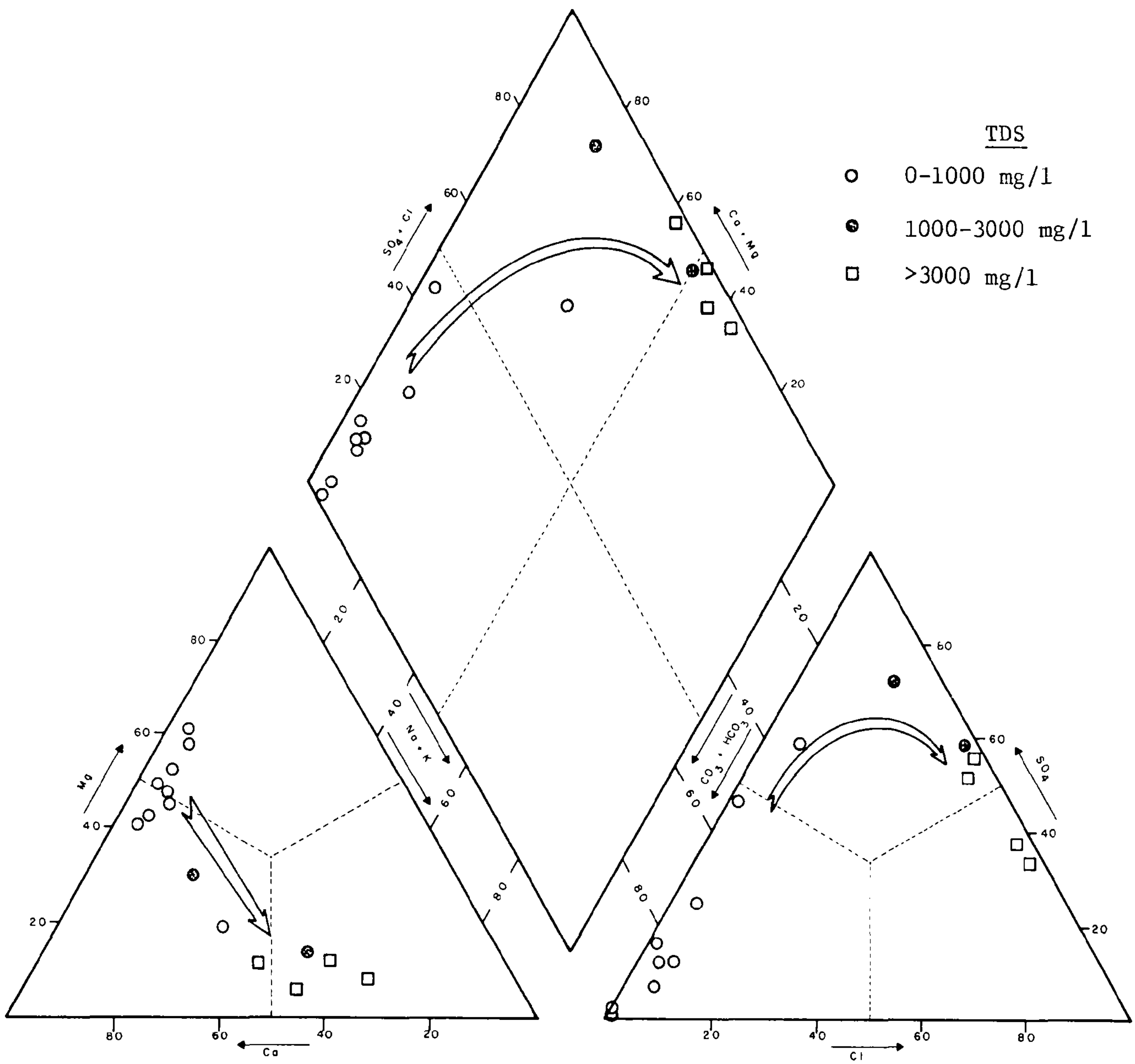

Figure V-2. Trilinear plot of representative Madison aquifer waters, western Powder River basin, Wyoming. Numbers plotted are percent of total milliequivalents per liter. Arrows indicate general basinward trends of TDS concentration and major ion composition.

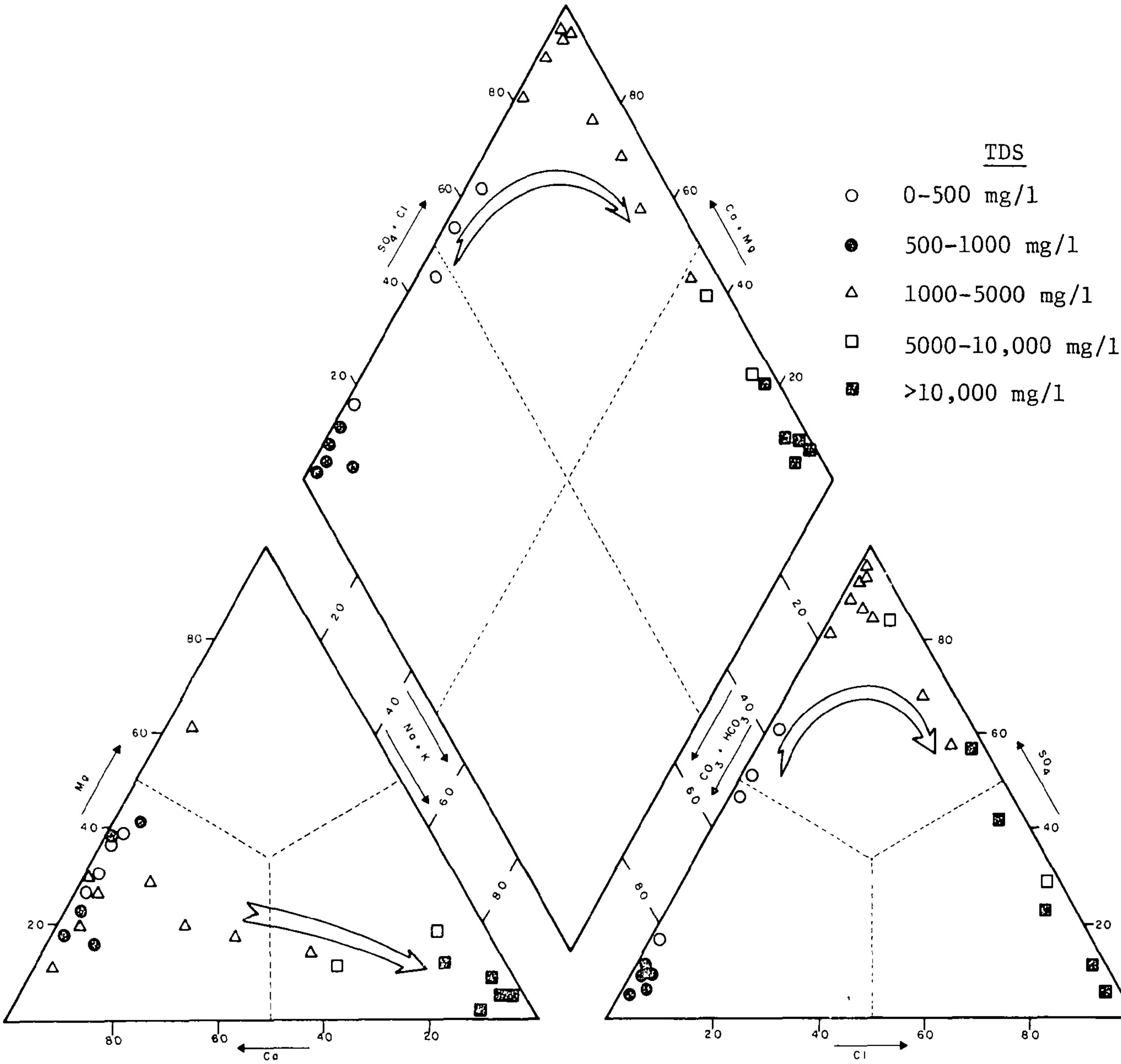

Figure V-3. Trilinear plot of representative Minnelusa aquifer waters, eastern Powder River basin, Wyoming. Numbers plotted are percent of total milliequivalents per liter. Arrows indicate general basinward trends of TDS concentration and major ion composition.

In the west half of the basin, Tensleep aquifer (Minnelusa equivalent) outcrop waters characteristically contain under 500 mg/l dissolved solids (Plate 5). Available data indicate a generally eastward (basinward) increase in TDS. High TDS waters, present in the deep parts of the aquifer in the east half of the basin, are not found in the western part.

Low TDS (less than 500 mg/l) Tensleep aquifer outcrop waters are primarily magnesium-calcium bicarbonate in character (Figure V-4). One analysis of Tensleep waters with a dissolved solids content of approximately 600 mg/l is enriched in calcium sulfate. Increasing TDS is generally associated with higher sodium sulfate or sodium sulfate-chloride levels.

Comparison of Madison and Minnelusa Waters

Madison and Minnelusa waters in the east half of the basin show several similarities as a result of similar hydrogeologic controls. Dilute (less than 500 mg/l TDS) Minnelusa outcrop waters are of the same chemical character (calcium-magnesium bicarbonate) as dilute Madison waters and compositionally controlled by carbonate dissolution. With increased TDS, waters from wells close to formation outcrops have increased sulfate content, due to gypsum and anhydrite dissolution. Waters of both aquifers show significant increase in TDS and sodium chloride enrichment across the Black Hills monocline. These increases may be due to restricted circulation into the deeper parts of the aquifer, or to fracturing along the monocline, allowing for interformational mixing of Madison and Minnelusa waters with higher TDS sodium chloride waters.

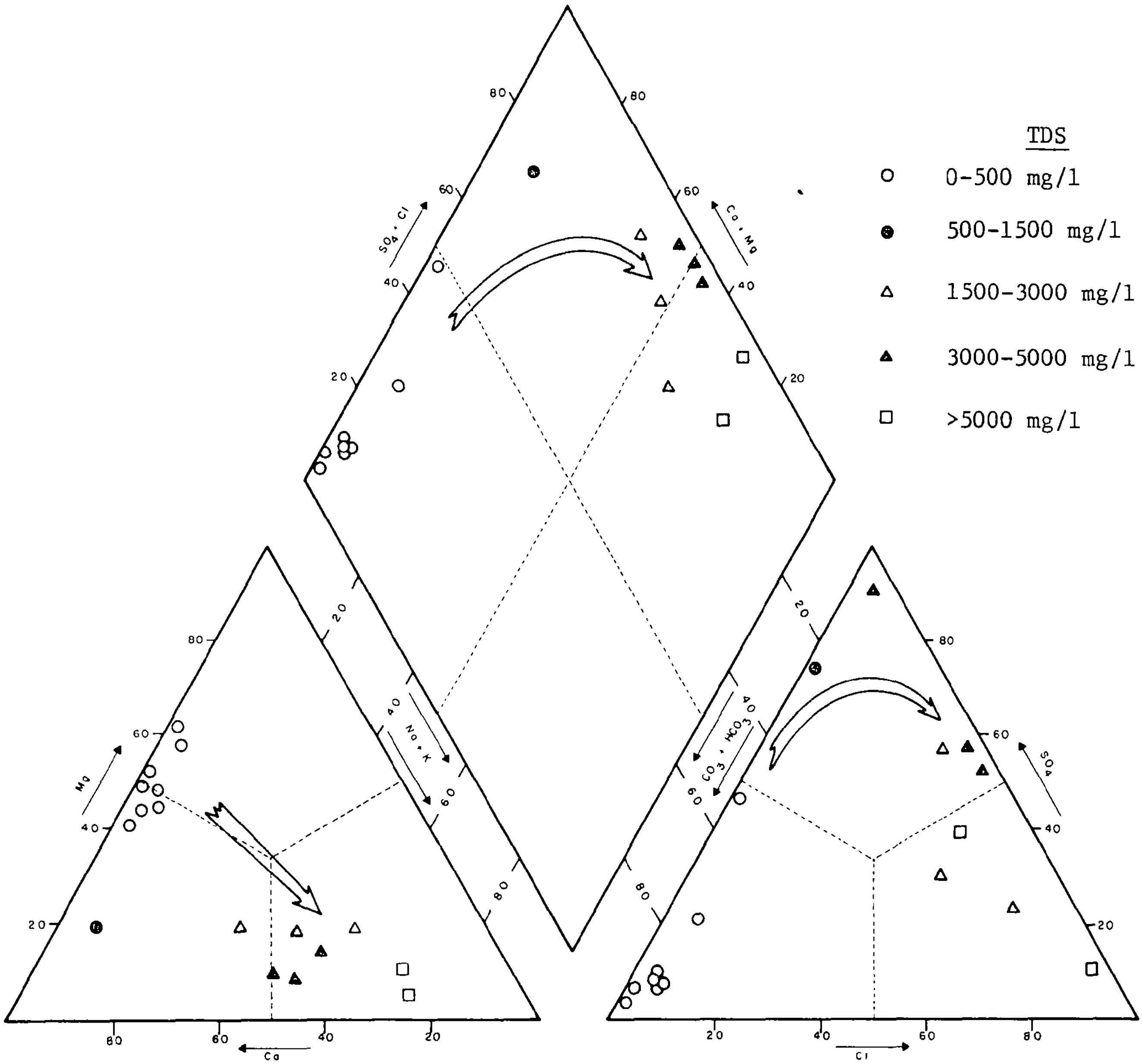

Figure V-4. Trilinear plot of representative Tensleep (Minnelusa) aquifer waters, western Powder River basin, Wyoming. Numbers plotted are percent of total milliequivalents per liter. Arrows indicate general basinward trends of TDS concentration and major ion composition.

Stratigraphic controls on the composition of Madison aquifer system waters in the eastern part of the Powder River basin are apparent. Eisen and others (1981) found that lower Minnelusa and Madison water chemistries in the eastern part of the basin are very similar, although upper Madison water has slightly higher TDS and sulfate concentrations, attributable to anhydrite which is commonly present (Andrichuk, 1955). They also identified TDS and dissolved sulfate differences between basal Minnelusa/Madison waters and upper/middle Minnelusa waters. They concluded that the basal Minnelusa and Madison are hydraulically connected and the middle Minnelusa Formation is a hydraulic barrier.

Comparison of Figures V-2 and V-4 shows a strong resemblance in major ion composition between Madison and Tensleep aquifer waters in the west half of the basin. Dissolved solids increase more quickly downgradient in Tensleep waters than in Madison waters. Salinity differences are not great, however, and may represent incomplete mixing of the respective waters, as opposed to a lack of hydraulic connection between the formations.

Permo-Triassic Aquifers

Few analyses of water from Permo-Triassic aquifers of the Powder River basin are available. Two analyses of Minnekahta aquifer water from Crook County have mixed ion composition and 650 and 1,800 mg/1 TDS. Most Chugwater/Spearfish water wells within the basin for which water analyses are available produce calcium sulfate waters, with between 2,240 and 3,420 mg/1 TDS, as a result of gypsum dissolution. Some variability of Spearfish water is noticeable, even with the limited data base. One well (53/61-5 ad) in the outcrop produces calcium-magnesium bicarbonate water with a TDS concentration of 414 mg/l; conversely, one spring (46/61-98 d) issuing from the formation has sodium chloride water with 30,000 mg/l TDS. In Natrona County one Chugwater well (39/83-7 aab) produces mixed cation sulfate water with 1,330 mg/l TDS.

Sundance Aquifer

The few available water well data indicate much variability in Sundance water composition. In the northeastern part of the basin TDS concentrations range from 894 to 1,870 mg/l. Crook County Sundance waters are sodium sulfate dominated, while to the south Weston County Sundance waters are mixed ion in character. Two analyses from the west side of the basin suggest a similar north-south compositional zonation.

Away from outcrops, Sundance Formation waters from oil fields on the southern margins of the basin range from 4,044 to 15,568 mg/l in TDS, but only exceed 10,000 mg/l TDS in northeastern Natrona and southeastern Johnson counties. At Lance Creek in Niobrara County Sundance water is sodium sulfate in composition, while in the southwest part of the basin it is predominantly sodium chloride, although some analyses have codominant sulfate. The source of sulfate in Sundance water is unknown as the formation is not reported to be gypsiferous.

Dakota Aquifer System

The general chemical character of Dakota system waters is highly variable, due to rapid vertical and horizontal lithologic changes within individual water-bearing units, and lithologic differences between the individual aquifers themselves. However, existing analyses of Dakota waters show a systematic spatial distribution of gross water types and total dissolved solids range.

In the east half of the basin, waters from Dakota outcrops contain 350 to 3,300 mg/l dissolved solids, and are calcium-magnesium sulfate in character. Total dissolved solids increase away from outcrop, with the most rapid increases occurring to the west and southwest where TDS iso-lines roughly parallel the Black Hills monocline (compare Plates 1 and 6).

Between outcrop areas and the monocline, Dakota waters generally contain less than 3,000 mg/l TDS, and show a basinward change in chemical character from calcium-magnesium sulfate at the outcrop to sodium sulfate to sodium bicarbonate (Figure V-5). Bowles (1968) noted a similar evolution of Dakota waters in southwest South Dakota, and suggested the change in ionic composition was due to exchange of dissolved calcium and magnesium for sodium, followed by bacterial reduction of sulfate and the resulting production of bicarbonate. In the analyses used for this report, these changes in chemical character are not accompanied by significant changes in the dissolved solids content, implying that exchange-type reactions are responsible for the observed downgradient evolutions of Dakota waters.

Across the Black Hills monocline, TDS increases rapidly from less than 3,000 mg/l to greater than 10,000 mg/l, with sodium chloride dominating the ions in solution. The sudden change in Dakota water chemistry at the monocline suggests that the structure either acts to restrict ground-water movement into the deeper parts of the aquifer,

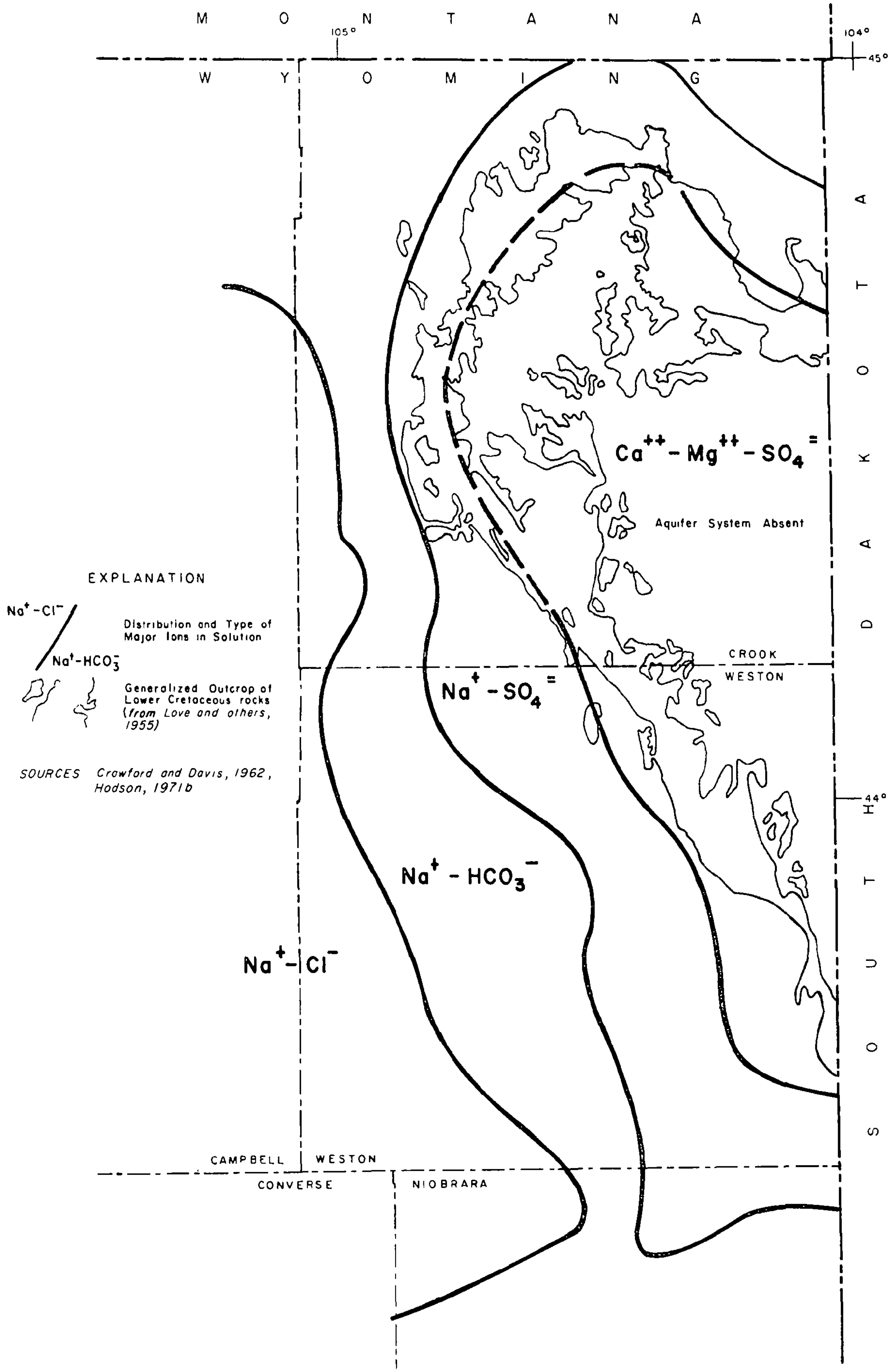

Figure V-5. Major ion composition of Dakota aquifer system water, eastern Powder River basin, Wyoming.

or that fracturing along the monocline allows for interformational mixing of Dakota water with more saline waters from stratigraphically adjacent shales.

In the southwest part of the basin, the limited amount of data available indicate that near-outcrop wells generally contain less than 1,500 mg/l TDS and are sodium bicarbonate in character. Dissolved solids increase rapidly to the north and east as the Dakota system dips steeply basinward. Available data indicate that dissolved sodium and chloride are dominant in waters with more than 3,000 mg/l TDS.

Data from "Muddy" sandstone waters are limited to analyses of oil field waters. In the western part of the basin the "Muddy" produces sodium chloride waters with TDS concentrations from 9,786 to 17,419 mg/l. In the eastern part of the basin TDS ranges from 3,241 to 33,624 and most water compositions are sodium chloride. Bicarbonate is often also significantly present, and may dominate in the Newcastle area. Muddy waters south of T. 37 N. on the east side of the basin are more dilute than those to the north (Crawford and Davis, 1962).

Upper Cretaceous Aquifers

Frontier Aquifer

Water wells completed in the Frontier aquifer produce waters ranging from sodium bicarbonate to sodium sulfate in composition and from 812 to 3,030 mg/l in TDS, on the basis of available data. Sulfate is more prominent in the waters with higher TDS concentrations.

Crawford and Davis (1962) report oil field Frontier waters have little sulfate, are sodium bicarbonate to sodium chloride in composition, and range from 1,417 to 24,950 in TDS concentration. They associated sulfate found in a few samples with surface water infiltration; and TDS and high chloride concentrations with low sand permeability, lenticularity, and increased distance from outcrop.

Shannon Aquifer

Four analyses of water from wells completed in the Cody Shale are reported (Hodson, 1971b) but the Shannon aquifer was not identified as a specific source. Three samples were sodium sulfate water ranging from 2,180 to 12,580 mg/l TDS; the fourth, from a well 285 feet deep (43/81-5 b), was calcium-magnesium sulfate water with 780 mg/l TDS.

Shannon waters from oil fields are of several types. Water from fields north of Casper is sodium sulfate in character, often also has significiant amounts of calcium and magnesium, and ranges in TDS concentration from 2,874 to 5,937 mg/l. Oil fields east of Casper have sodium chloride waters with over 9,000 mg/l TDS. The Billy Creek Oil Field (T. 48 N., R. 82 W.) has waters with from 2,132 to 3,269 mg/l TDS which are sodium bicarbonate-chloride in composition.

Crawford (1940) felt exchange reactions controlled cation species, and composition of surface waters at outcrops controlled anion composition. He associated sulfate waters with nearby outcrops in contact with sulfate surface water, and chloride-bicarbonate waters with deeply buried oil fields "fed only by a fresh water source" in the mountains. For the chloride-bicarbonate waters changes in TDS levels are associated with chloride concentration.

Mesaverde Aquifer

Little data on Mesaverde aquifer water are available. Water wells produce either dilute (less than 600 mg/l TDS) waters of calcium or sodium bicarbonate composition or sodium sulfate waters with TDS concentrations ranging from 1,360 to 3,980 mg/l.

Fox Hills/Lance Aquifer System

Chemical data for Fox Hills/Lance aquifer system waters are sparse and largely limited to outcrop areas. No significant differences in dissolved solids concentrations or distribution of major ions are seen between Fox Hills and Lance waters.

North of Niobrara County, in the east half of the basin, Fox Hills/Lance waters from outcrop areas have a TDS content ranging from 600 to 1,500 mg/l (Plate 7). These waters are primarily sodium bicarbonate-sulfate in character, although three analyses from Weston County, with less than 700 mg/l TDS, were calcium and magnesium enriched.

Fox Hills/Lance waters from outcrop areas in Niobrara County are similar in character to those found in the north but contain higher concentrations of dissolved solids, varying from 1,000 mg/l to 3,300 mg/l. Existing data are insufficient to explain the elevated levels of dissolved solids in this area; however, potentiometric data indicate a separate flow system exists (see Chapter IV).

Outcrop wells in the west half of the basin yield waters containing between 450 and 4,060 mg/l TDS (Plate 7). The chemical character of these waters varies from calcium bicarbonate to calcium sulfate to sodium sulfate to sodium bicarbonate. There is no apparent correlation between chemical character and TDS, and except for a band of primarily calcium sulfate waters extending from T. 43 N. to T. 52 N., no spatial distribution of water types is evident.

Local lithologic variation likely controls anion composition, through dissolution of carbonate, gypsum, or pyrite, and exchange reactions influence cation composition, favoring sodium replacement of calcium (Thorstenson and others, 1979).

Analyses of Fox Hills/Lance waters away from outcrop areas show a TDS range of 288 mg/l (well 45/71-36 bd, Appendix C) to 3,530 mg/l (well 49/75-32) and are sodium bicarbonate or sodium bicarbonate-sulfate in character. In an extensive study of the aquifer in North Dakota (Thorstenson and others, 1979) lignite was found to cause down-gradient sulfate reduction which, in conjunction with cation exchange, resulted in dominantly sodium bicarbonate waters away from recharge zones. Similar evolution of Fox Hills/Lance waters is likely in the Powder River basin, paralleling that of the Dakota system.

Wasatch/Fort Union Aquifer System

The Wasatch/Fort Union aquifer system is exposed over a large portion of the central basin, and extensive chemical data exist on its waters. The discontinuous, lenticular nature of the water-bearing sandstones comprising the system results in significant water quality differences over short geographic distances. Several generalizations can be made, however, with respect to the overall chemical character of Wasatch/Fort Union waters.

Dissolved solids content varies from less than 250 mg/l to over 6,500 mg/l. Generally there is little correlation between TDS and well depth, although a decrease in dissolved solids with increasing depth has been suggested for some parts of the aquifer (Whitcomb and others, 1966; Davis, 1976). An apparent though unsystematic geographic zonation of dissolved solids content is present (Plate 8). An area of relatively dilute (less than 1,000 mg/l TDS) water runs northwest-southwest through the east-central part of the basin, while wells in several sporadically located zones produce waters containing greater than 3,000 mg/l dissolved solids.

Wasatch/Fort Union waters from relatively shallow wells have a widely variable major ion composition. Most analyses show either a mixed cation content or sodium enrichment (Figure V-6). Waters containing less than 500 mg/l dissolved solids are enriched in bicarbonate, while more saline waters are characteristically high in dissolved sulfate.

Major ion composition has a relationship to well depth. Figure V-7 shows a relative increase in dissolved sodium and bicarbonate with depth. The increase in sodium has been ascribed to cation exchange of sodium for dissolved calcium and magnesium. The presence of hydrogen sulfide in some Wasatch/Fort Union waters implies that bacterial reduction of sulfate results in the observed change in anion composition (Whitcomb and others, 1966; Lowry and Cumming, 1966). It is probable that these variations result from horizontal flow within hydrologically isolated sand bodies, and that depth is only an indicator of relative distance from outcrop recharge zones, rather than a large component of vertical downward flow through the system.

Wells penetrating coal seams or other carbonaceous deposits often yield both water and gas. The discharged gas is mainly methane and is associated with smaller quantities of nitrogen and oxygen (Whitcomb and others, 1966; Lowry and Cummings, 1966). Gas-to-water ratios

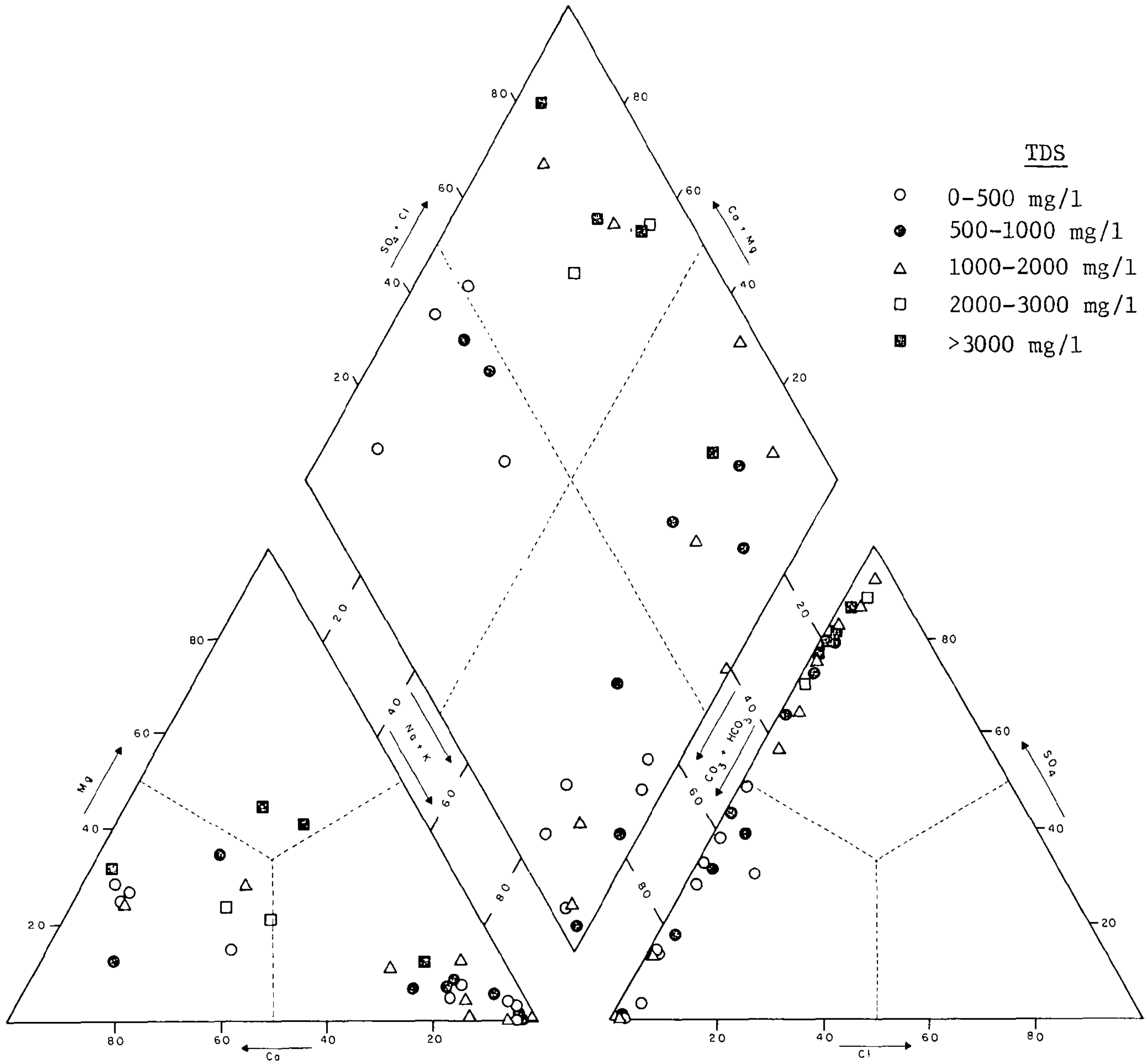

Figure V-6. Trilinear plot of representative Wasatch/Fort Union aquifer system waters, Powder River basin, Wyoming. Numbers plotted are percent of total milliequivalents per liter.

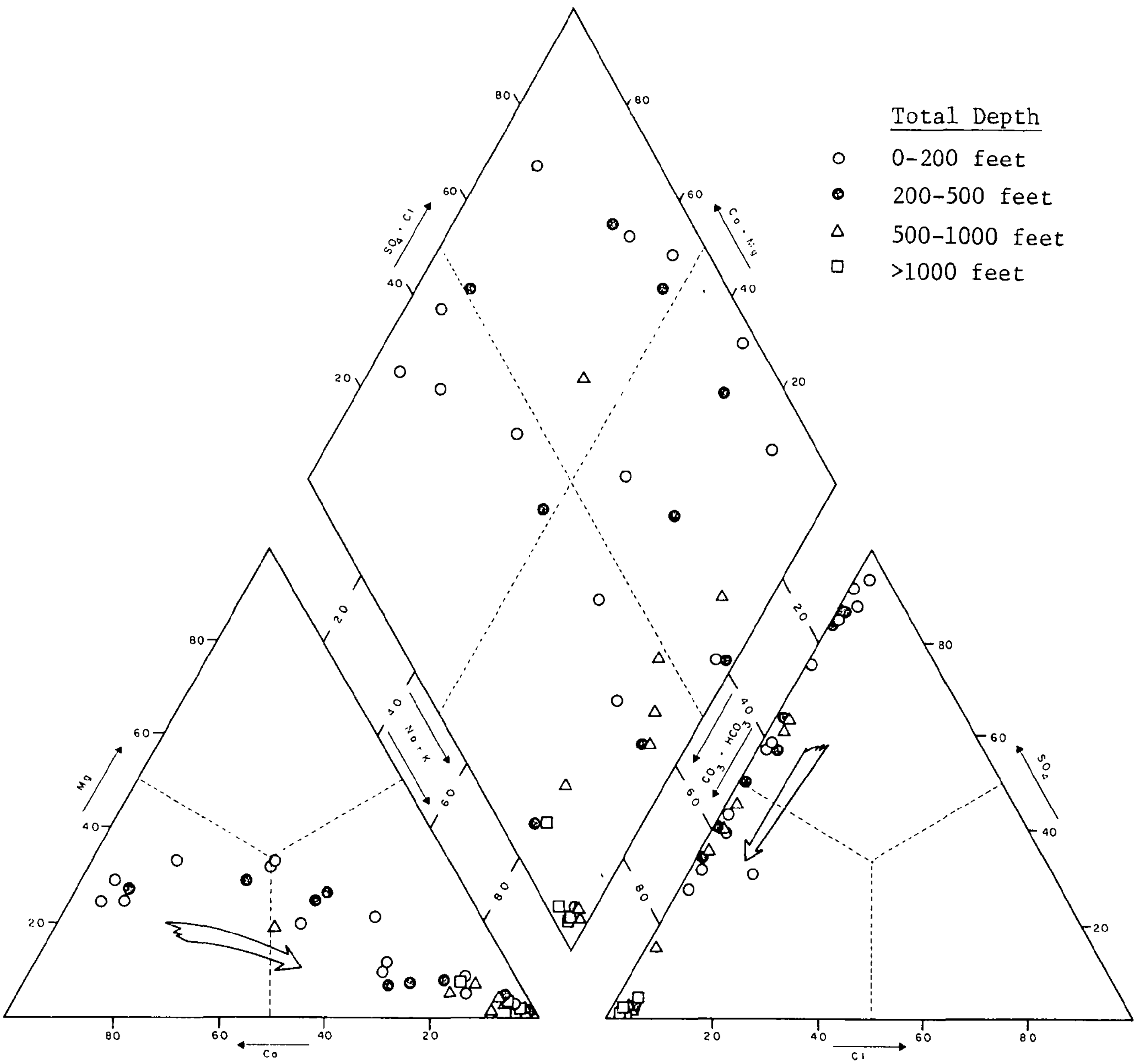

Figure V-7. Trilinear plot of representative Wasatch/Fort Union aquifer system waters, Powder River basin, Wyoming. Numbers plotted are percent of total milliequivalents per liter. Arrows indicate general trend of composition with depth.

as large as 2.2 have been measured at certain wells in Johnson County (Whitcomb and others, 1966).

Middle Tertiary Aquifers

Limited water quality data are available for the Middle Tertiary White River and Arikaree aquifers in the southeastern part of the Powder River basin. Typically water from these aquifers contains less than 1,000 mg/l TDS and is sodium bicarbonate in character, but one area 12 miles west of Douglas (33/73-27 and 34) has sodium sulfate dominated waters with about 4,500 mg/l TDS. Existing data are insufficient to explain the observed conditions.

Quaternary Aquifers

Available analyses of waters from Quaternary aquifers show a TDS concentration range of 106 to 9,300 mg/l. Cation composition ranges from calcium to sodium and anion composition ranges from bicarbonate to sulfate. Carbonate or gypsum dissolution in conjunction with cation exchange on the fine-grained component of the alluvial deposits are probable controls on the composition.

DRINKING WATER STANDARDS

Primary Standards

Existing chemical analyses identify two of the ten inorganic species with primary drinking water standards (Table V-1) as having relatively high concentrations in Powder River basin ground waters: selenium and fluoride.

Few analyses for the other eight inorganic constituents with established primary drinking water standards are available, and even

Table V-1. Drinking water quality standards.

Constituent	Primary Drinking Water Standard[a]	Secondary Drinking Water Standard[a]
Arsenic	0.05	
Barium	1.	
Cadmium	0.01	
Chloride		250
Chormium	0.05	
Coliform Bacteria	1 colony/100 ml[b]	
Color		15 color units
Copper		1.
Corrosivity		Noncorrosive[c]
Fluoride	2.0[d]	
Foaming Agents		0.5
Iron		0.3
Lead	0.05	
Manganese		0.05
Mercury	0.002	
Nitrate (as N)	10.	
Odor		3 threshold odor units
Organic Chemicals-Herbicides		
2,4-D	0.1	
2,4,5-TP	0.01	
Organic Chemicals-Pesticides		
Endrin	0.0002	
Lindane	0.004	
Methoxychlor	0.1	
Toxaphene	0.005	
pH		6.5-8.5 units
Radioactivity		
Ra-226 + Ra-228	5pCi/1	
Gross Alpha Activity	15 pCi/1[e]	
Tritium	20,000 pCi/1	
Sr-90	8 pCi/1	
Selenium	0.01	
Silver	0.05	
Sodium		f
Sulfate		250
Total Dissolved Solids		500

Table V-1. (continued)

Constituent	Primary Drinking Water standard[a]	Secondary Drinking Water Standard[a]
Turbidity	1 turbidity unit[g]	
Zinc		5.

[a]All concentrations in mg/l unless otherwise noted.

[b]The standard is a monthly arithmetic mean. A concentration of 4 colonies/100 ml is allowed in one sample per month if less than 20 samples are analyzed or in 20 percent of the samples per month if more than 20 samples are analyzed.

[c]The corrosion index is to be chosen by the State.

[d]The fluoride standard is temperature-dependent. This standard applies to locations where the annual average of the maximum daily air temperature is 58.4°F to 63.8°F.

[e]The standard includes radiation from Ra-226 but not radon or uranium.

[f]No standard has been set, but monitoring of sodium is recommended.

[g]Up to five turbidity units may be allowed if the supplier of water can demonstrate to the State that higher turbidities do not interfere with disinfection.

Source: U.S. Environmental Protection Agency, 1976.

fewer exceedences are reported: uranium mine monitoring wells in the Wasatch aquifer (38/73-10, 11, 15) produce waters with varying concentrations of lead and mercury, ranging up to 0.1 and 0.01 mg/l, respectively; also, a Wasatch(?) spring (36/72-33) has 0.24 mg/l of mercury. Exceedences of the nitrate standard are reported at a few shallow wells. The tap water at Osage contains 0.09 mg/l silver; however, the Madison aquifer supply well produces water with less than 0.01 mg/l silver.

Selenium

Generally, high selenium waters (greater than 0.01 mg/l) are limited geographically to the extreme southwest part of the basin (Figure V-8) and stratigraphically to wells completed in the upper Cretaceous sandstone aquifers or in nearby Quaternary terrace and alluvial aquifers. Existing data show that 17 wells completed in the Mesaverde Formation, Cody Shale, or Frontier Formation produce waters which exceed the primary drinking water standard. Seven of these wells, all in the Cody Shale, produce waters with selenium concentrations exceeding 0.1 mg/l and ranging up to 6.5 mg/l. Of the 49 wells completed in Quaternary aquifers which have reported exceedences of the selenium standard, 24 have waters with over 0.1 mg/l selenium, and all these wells receive recharge from nearby irrigation. The highest recorded concentration in Quaternary aquifer waters is 1.8 mg/l. Large fluctuations in the selenium level with time at any one site are common; whether the observed fluctuation is the result of a natural process or analytical errors cannot be determined. Crist (1974) found conflicting trends when he related selenium levels to

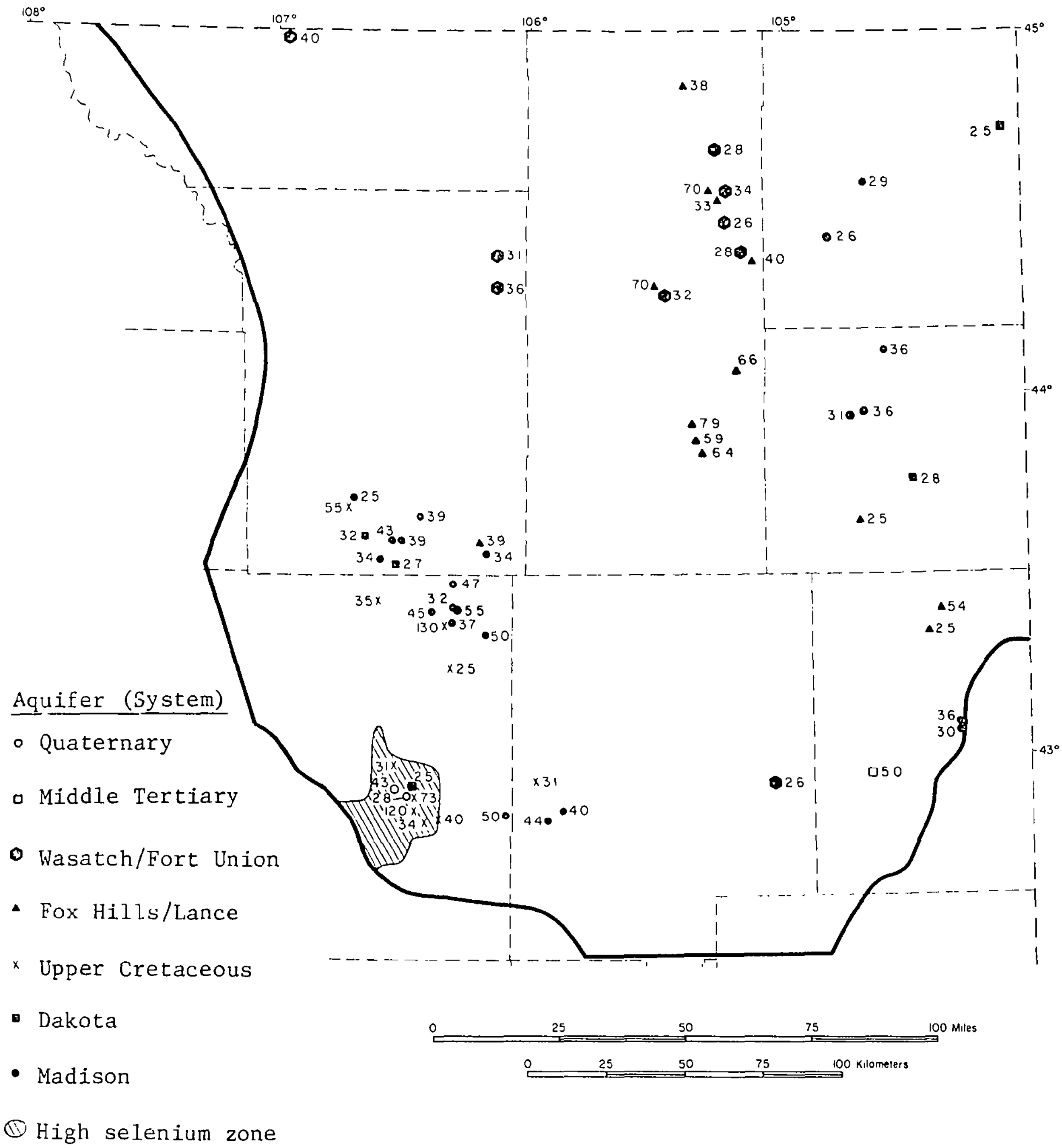

Figure V-8. Location of reported high selenium and fluoride in Powder River basin ground waters. Points indicate fluoride concentrations in excess of 2.4 mg/l, by source. All analyses of waters from Upper Cretaceous or Quaternary aquifers with greater than 0.01 mg/l selenium are found within the shaded area.

aquifer recharge by surface waters of the Kendrick Irrigation Project, but he did conclude that irrigation "has accelerated movement of selenium within and from the irrigated areas."

Only three wells within the study area which tap aquifers other than those noted above show excessive selenium concentrations on the basis of available analyses. One well (40/78-26 cba) is developed in the Fox Hills Formation, another (32/81-21 aca) taps the Lance Formation, and the third (55/61-26 da) produces from the Fall River aquifer of the Dakota aquifer system. These wells produce waters containing 0.02 to 0.04 mg/l selenium.

Fluoride

High concentrations of fluoride (greater than 2.4 mg/l) in Powder River basin ground waters are widely distributed, both spatially and stratigraphically (Figure V-8). Fluoride enrichment is characteristic of Madison system waters throughout much of the basin, and of Fox Hills/Lance waters in the eastern basin. Only five analyses of Dakota waters show fluoride to exceed 2.4 mg/l, while high concentrations in Wasatch/Fort Union waters are sporadically scattered and probably due to local lithologic variations. Waters from Upper Cretaceous aquifers also show fluoride enrichment.

Secondary Standards

Major Aquifer Systems

The secondary drinking water standards for which water analyses in the Powder River basin are widely available include sulfate, chloride, iron, and total dissolved solids. Total dissolved solids ranges for all major aquifer systems are spatially displayed on Plates 4 to 8.

Table V-2 summarizes sulfate, chloride, and iron concentrations for each major aquifer system by county. The waters from each aquifer system show a wide range in the concentrations of these constituents in a given geographic area, although some spatial and stratigraphic distribution of concentration ranges does exist.

Existing data show sulfate concentrations consistently exceed the recommended maximum (250 mg/l) in Madison aquifer waters from Campbell and Natrona counties, in Minnelusa aquifer waters from Converse County, in Fox Hills/Lance waters from Natrona County, and in Wasatch/Fort Union waters from Crook and Niobrara counties.

Chloride concentrations consistently exceed the recommended maximum (250 mg/l) in Madison system and Dakota system waters on the west side of the Black Hills monocline as well as in Dakota waters from Converse, Natrona, and Niobrara counties.

High iron concentrations occur sporadically in waters from all major aquifer systems.

Minor and Local Aquifers

Table V-3 summarizes the ranges of total dissolved solids, sulfate, chloride, and iron for waters from minor and local aquifers within the Powder River basin, on the basis of available analyses. The secondary TDS standard of 500 mg/l is often exceeded even in outcrop recharge areas, while in the more central oil-producing parts of the basin TDS concentration of bedrock aquifer waters usually exceeds 3,000 mg/l. In outcrop areas exceedences of the sulfate standard are typical, while most oil field waters exceed chloride standards. Water from Quaternary alluvial aquifers often exceeds standards for TDS and sulfate.

Table V-2. Concentration ranges of sulfate, chloride, and iron in waters of major aquifer systems, Powder River basin, by county (concentrations expressed as milligrams per liter).

Aquifer System	Aquifer	County	Sulfate	Chloride	Iron
Madison	Madison	Campbell	858-2403	32-560	-
		Converse	192-3229	18-3140	-
		Crook	7-1315	2-1100	0.1-0.25
		Johnson	1-1100	1-696	-
		Natrona	313-2025	82-1050	0.2-4.8
		Niobrara	12-1263	7-2900	-
		Sheridan	5-1419	0-52	-
		Weston	5-459	0-95	0.01-0.31
Madison	Minnelusa	Campbell	200-5900	38-120000	0-0.88
		Converse	1200-2400	110-1100	-
		Crook	6-8800	0-82000	0-4.2
		Johnson	2-1200	0.2-8500	0-1.1
		Natrona	130-2600	2-730	0-0.29
		Niobrara	2-10000	19-110000	-
		Sheridan	5-4700	0-33000	0-0.58
		Weston	12-18000	1-20000	0-0.62
Dakota	(Newcastle/ Muddy is excluded)	Campbell	156-984	35-9100	-
		Converse	0-7901	25-10000	-
		Crook	0-4156	2-5700	0.23-5.5
		Johnson	0-565	117-1080	0.02-110
		Natrona	12-1321	3-8200	0.05-120
		Niobrara	0-714	3-4360	0.01-0.03
		Sheridan	-	-	-
		Weston	80-2000	4-5940	0.06-54
Fox Hills/ Lance	-	Campbell	1-600	2-720	0.01-0.18
		Converse	-	-	-
		Crook	212-365	2-10	0.2-0.69
		Johnson	33-2320	1-157	0.5-6.3
		Natrona	456-1070	1-37	0-1.0
		Niobrara	0.3-1970	7-110	0-8.6
		Sheridan	157-493	8-42	0.02-0.13
		Weston	92-705	2-13	0.03-4.9
Wasatch/ Fort Union	-	Campbell	0-5940	1-50	0-14.6
		Converse	4-1830	2-52	0.01-1.2
		Crook	510-562	7-85	0.09-0.18
		Johnson	0-3020	1-42	0.03-19
		Natrona	-	-	-
		Niobrara	558-775	4-20	0.13-6.9
		Sheridan	0-4080	0-53	0.01-25
		Weston	33-1240	27-30	0.04-0.17

Sources: Hodson, 1971b, 1974; Wells and others, 1979; Crawford, 1940; Crawford and Davis, 1962; Water Resources Research Institute, WRDS Data System.

Table V-3. Ranges of total dissolved solids, sulfate, chloride, and iron concentrations in waters from minor aquifers, Powder River basin, Wyoming (concentrations expressed as milligrams per liter).

Aquifer(s)	Vicinity	TDS	Sulfate	Chloride	Iron
Minnikahata	Crook Co.	650-1800	261-1050	3-38	0-0.03
Chugwater/ Spearfish	Northeast	414-30000	84-3190	3-15600	0.02-1.9
	Southwest	1330-2410	789-1460	6-8	0.01-0.06
Sundance	Northeast	894-1870	475-1080	3-14	0.31-1.4
	Southwest	416-4100	156-2750	5-18	0.07-5
	Oil fields	4044-15568	0-5879	145-7409	-
Frontier	Northwest	390-2020	13-1250	2-122	0-2.9
	Natrona Co.	812-3030	0-1620	5-243	0.03-1.9
	Oil fields	1417-24950	0-3477	72-13800	-
Cody Shale Sands	Southwest	780-12580	465-7830	8-227	0.08-0.43
	Oil fields	2132-14694	32-3713	0-8558	-
Mesaverde	Northwest	550-2340	186-1430	2-36	0.22-12
	Natrona Co.	370-3980	89-2040	4-73	0.11-20
	Converse Co.	1780	515	52	0.08
Middle Tertiary	Converse Co.	718-4530	105-2750	26-41	-
	Niobrara Co.	263-479	2.0-44	4.0-57	0.01-5.7
Quaternary Alluvium	Campbell Co.	474-3560	7-1980	1-25	0.02-0.99
	Converse Co.	1530	700	31	-
	Crook Co.	1020-3340	295-1950	4-12	0.21-11
	Johnson Co.	106-4490	10-2540	0-242	0.05-7.2
	Natrona Co.	506-9300	206-5320	16-200	0.04-0.2
	Niobrara Co.	922-1920	348-1080	11-21	0.3-3.1
	Sheridan Co.	272-2060	8-1020	0-12	0.01-4.3

Sources: Crawford, 1940; Crawford and Davis, 1962; Hodson, 1971b.

Almost all minor aquifers show sporadic exceedences of the iron standard.

Radionuclear Species

Existing data on radionuclear species in Powder River basin ground waters generally include determinations for gross alpha, gross beta, dissolved uranium, and radium-226, a decay product of uranium-238. Primary drinking water standards have been established for radium-226 and gross alpha radiation (Table V-1).

Analysis for radium-226, gross alpha, and gross beta contain an error limit that generally indicates the 95 percent confidence interval of the analysis. Variance in measured concentrations is usually due to either (1) instrument insensitivity at low concentrations or (2) particle absorption in samples containing high dissolved solids. Where the confidence interval is large relative to the given absolute value, interpretation of results is difficult.

Pre-Tertiary Strata

Available data on radionuclide concentrations in ground water from pre-Tertiary strata include 10 analyses from the Madison aquifer system, six analyses from the Dakota system, and seven analyses from the Fox Hills/Lance (Table V-4). In general, existing data on the pre-Tertiary formations of the basin are too sparse to allow for interpretation.

Two analyses of Madison aquifer water exceed both the 5 pCi/l primary standard for radium-226 and 15 pCi/l standard for gross alpha radiation. One of these Madison water analyses shows extremely high levels of the above parameters: 476.3 ± 6.2 pCi/l of radium-226, and

Table V-4. Radionuclear analyses of ground waters, Powder River basin, Wyoming.

Geologic Formation	Location (T/R-Sec-¼-¼)	U (μg/l)	Radium-226 (pCi/l)	Gross Alpha (pCi/l)	Gross Beta (pCi/l)	Remarks	Data Source
Quaternary Alluvium	33/79-7		0.0±0.2	6.9±2.6		Vista West Water Company, Casper	1
	33/79-7, 18		0.0±0.4	15±4		Composite of 4 samples from City of Casper water plant	1
Wasatch	36/72	High: 7,000	173	81.4	70.3	Mine monitor well analyses	2
		Low: 1	0.2	1.6	0		
		N[b]: 19	19	4	4		
	38/73	High: 1,800	145	880	420	Mine monitor well analyses	2
		Low: 5	0.8	5.1	0		
		N: 13	13	13	13		
	43/73	High: 334				Mine monitor well analyses	2
		Low: 0.5					
		N: 16					
	45/77	High: 10,113	51	4,691	835	Mine monitor well analyses	2
		Low: 17	0.2	1.4	0		
		N: 48	48	48	48		
	48/75-14 bd	0.4	<0.1		2.1[a]		3
	49/75-34 ca	<0.1	<0.1		<1.9[a]		3
	50/72-21			0.0±5.2		City of Gillette well H-16	1
	50/72-28 ab	0.6	0.1		<0.8[a]		3
	53/76-22 ab	<0.1	0.8		8.9[a]		3
	54/76-27 bc	0.4	0.1		6.0[a]		3
Fort Union	32/72	High: 240	180			Mine monitor well analyses	2
		Low: 160	3.7				
		N: 2	2				
	34/74	High: 3,550	954			Mine monitor well analyses	2
		Low: 5	10.2				
		N: 19	19				
	35/72	High: 410	76			Mine monitor well analyses	2
		Low: 5	0.4				
		N: 10	10				
	52/74-1 ba	0.3	0.3		12[a]		3
	53/73-20 bd	0.4	0.5		6.1[a]		3
	53/74-35 ab	14	0.3		11[a]		3
	56/85-31 bd	0.1	0.4		7.9[a]		3
	57/70-19 ba	0.2	<0.1		<2.4[a]		3
Lance	45/71-36 bb	9.3	2.4±0.65	329±41	50±22		4
	50/68-14 cd	37.4	0.48±0.26	39±29	0±21		4

Table V-4. (continued)

Geologic Formation	Location (T/R-Sec-¼-¼)	U (μg/l)	Radium-226 (pCi/l)	Gross Alpha (pCi/l)	Gross Beta (pCi/l)	Remarks	Data Source
Fox Hills	36/77-5 bb	0.85	0.53±0.25	0±33	0±31		[illegible]
	37/63-13 cb	17	0.24±0.19	0±31	20±35		[illegible]
	40/78-26 cb	17.9	1.44±0.38	0±45	0±34		[illegible]
	42/62-30 aa	0	0±3.6	0±17	0±19		[illegible]
	50/72-21			0±2.4		Composite of City of Gillette Fox Hills wells	[illegible]
Lakota	48/65-21 bb	12.8	0±0.24	0±16	0±26		[illegible]
	53/66-4 bb	38.3	0.64±0.31	49±29	1±30		[illegible]
	55/66-1 bb	8.5	2.7±0.56	48±33	23±33		[illegible]
Fall River	48/64-18 bd	16.2	0.31±0.42	0±17	6±18		[illegible]
	55/61-26 dc	19.6	0.84±0.26	0±13	4±13		[illegible]
	57/61-27 bd	5.1	0.63±0.35	0±21	0±19		[illegible]
Minnelusa	56/63-25 dc			1.7±1.1		City of Sundance well #3	1
Madison	33/75-8 bd	10.2	476±6.2	342±193	50±137		[illegible]
	39/78-2 bcdc		3.4		93[a]		[illegible]
	40/79-26 ca	6.8	23.5±1.6	56±125	81±117		[illegible]
	40/79-31 bca		1.8		69[a]		[illegible]
	45/61-33 ab				54[a]		
	56/62-18 bdc				2.1[a]		[illegible]
	52/63-25 dc			1.6±1.1		City of Sundance Well #3A	1
	57/65-15 da	6.3	0.7		15		[illegible]
Flathead	57/65-15 da	<0.4	14		19[a]		[illegible]

[a]Gross beta as Cs-137, pCi/l.

[b]N refers to the number of analyses available.

Data Sources: 1 - U.S. Environmental Protection Agency, unpublished data
2 - Wyoming Department of Environmental Quality data files
3 - U.S. Geological Survey data
4 - WRRI samples analyzed for this report

342 ± 193 pCi/l of gross alpha radiation. These values are far greater than others reported for Madison waters (Table V-3; Eisen and others, 1980), though the dissolved uranium concentration in this analysis is 10.2 μg/l, only slightly above the normal uranium content of ground waters, which is 0 μg/l to 10 μg/l (Hem, 1970; Davis and DeWiest, 1966).

The anomalously high radioactivity of the above analysis cannot be readily explained. Deposition of carbonate rocks such as the Madison takes place only from waters saturated with respect to calcite and/or dolomite. The mobility of uranium in such a solution is high due to the formation of soluble uranyl-carbonate complexes (Patten and Bennett, 1963). Consequently, carbonate rocks are rarely enriched in uranium or its decay product, radium-226. Similarly, gypsum and anhydrite deposits, often associated with carbonates, are characteristically low in uranium and radium-226 due to the formation of soluble uranyl-sulfate complex during deposition (Davis and DeWiest, 1966). Radioactivity in ground waters from carbonate rocks may originate from interbeds of clay and shale, or upward movement from underlying sandstones or crystalline rocks.

The two available analyses of Lance aquifer water both exceed the gross alpha standard, while all analyses of Fox Hills water show low alpha radiation (Table V-4). Two analyses of Lakota aquifer water also exceed the gross alpha standard, while Fall River aquifer waters are characteristically low in gross alpha radiation. Available data are insufficient to determine whether these apparent differences are local or basinwide in nature.

Dissolved uranium concentrations in pre-Tertiary ground waters show a fairly well distributed range, from less than 0.1 μg/l to 38 μg/l, which is somewhat higher than normal ground-water uranium levels (Hem, 1970; Davis and DeWiest, 1966).

Wasatch/Fort Union Aquifer System

Numerous radionuclear analyses of Wasatch/Fort Union waters exist, due mainly to the presence of economic uranium deposits. Available data show a wide range in concentrations (Table V-4). Radium-226 ranges from less than 0.1 pCi/l to over 950 pCi/l. Gross alpha and beta radiation vary from 0 pCi/l to 4,691 pCi/l and 835 pCi/l, respectively. Dissolved uranium concentrations of over 10,000 μg/l are reported, approaching the highest known ground-water uranium content in the United States, which is 18,000 μg/l (Davis and DeWiest, 1966). High concentrations of radionuclides are geographically and stratigraphically restricted to areas adjacent to uranium ore zones. Mobilization of uranium likely takes place through the action of shallow oxidizing ground water on reduced uranium minerals, and the formation of soluble uranyl-carbonate complexes (Barker and Scott, 1958).

Existing analyses from non-mining areas show no exceedences of the radium-226 or gross alpha standards, contain less than 1 μg/l dissolved uranium, and show gross beta levels below 15 pCi/l.

VI. R E F E R E N C E S

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APPENDIX A

GROUND-WATER USE FOR COMMUNITY DRINKING WATER SUPPLY AND BY INDUSTRY IN THE POWDER RIVER BASIN, WYOMING

Table A-1. Primary and secondary water sources for incorporated municipalities within the Powder River basin.

County	Municipality EPA PWS ID #	Primary Source: Source Type	Primary Source: Source	Secondary Source: Source Type	Secondary Source: Source	Average Production gal/day*	Average Production AF/yr*	Population* Served	Average gal/cap/day Production	Supplementary Info.
Campbell										
	Gillette 5600019	ground	Wasatch/ Fort Union aquifer system	ground	Fox Hills/ Lance aquifer system	1,200,000	1,345	12,000	100	The city of Gillette is presently developing additional ground-water supplies from the Madison aquifer, in Crook County, to be used as an additional water source starting 1981.
Converse										
	Douglas 5600137	ground	Box Elder spring	surface	N. Platte R.	1,600,000	1,793	7,500	213	Box Elder spring is likely Madison aquifer system water.
	Glenrock 5600199	ground	Quaternary alluvial aquifer and Fox Hills/ Lance aquifer system	surface	Deer Creek	420,000	471	2,800	150	
Crook										
	Hulett 5600026	ground	Minnelusa aquifer			48,000	53	320	150	
	Moorcroft 5600036	ground	Fox Hills/ Lance aquifer system			150,000	168	1,200	125	Town of Moorcroft may purchase future additional water from Gillette Madison well field
	Sundance 5600055	ground	Madison, Minnelusa, Minnekahta, and Spearfish aquifers.			200,000	224	1,200	167	
Johnson										
	Buffalo 5600005	surface	Clear Creek			500,000	560	4,500	111	System base demand is collected through infiltration galleries.
	Kaycee 5600196	surface	Powder River	ground	Quaternary alluvial aquifer	85,000	95	350	243	

Table A-1. (continued)

County	Municipality EPA PWS ID #	Primary Source: Source Type	Primary Source: Source	Secondary Source: Source Type	Secondary Source: Source	Average Production gal/day*	Average Production AF/yr*	Population* Served	Average gal/cap/day Production	Supplementary Info.
Natrona										
	Casper 5600009	ground	Quaternary alluvial aquifers along N. Platte R.	surface	N. Platte R.	10,000,000	11,209	45,000	222	
	Edgergon 5600017	ground	Fox Hills/ Lance aquifer system			80,000	90	650	123	
	Evansville 5600018	surface	N. Platte R.	ground	Quaternary alluvial aquifer	250,000	280	2,500	100	
	Midwest 5600201	surface	N. Platte R.			45,000	50	600	75	
	Mills 5600036	ground	Quaternary alluvial aquifer	surface	N. Platte R.	500,000	560	2,000	250	
Niobrara										
	Manville 5600100	ground	Middle Tertiary aquifers			38,700	43	104	372	
Platte										
	Glendo 5600023	ground	Hartville aquifer			20,000	22	450	44	Hartville aquifer is a Minnelusa equivalent.
Sheridan										
	Clearmont 5600013	ground	Wasatch/ Fort Union aquifer system			15,000	17	153	98	
	Dayton 5600202	surface	Tongue River			180,000	202	650	276	

Table A-1. (continued)

County	Municipality EPA PWS ID #	Primary Source: Source Type	Primary Source: Source	Secondary Source: Source Type	Secondary Source: Source	Average Production gal/day*	Average Production AF/yr*	Population* Served	Average gal/cap/day Production	Supplementary Info.
	Ranchester 5600044	surface	Tongue River			117,380	132	750	156	
	Sheridan 5600052	surface	Big Goose Creek			5,000,000	5,605	13,000	385	
Weston										
	Newcastle 5600256	ground	Madison aquifer			600,000	673	5,000	120	
	Upton 5600140	ground	Madison aquifer & Dakota aquifer system			100,000	112	1,100	91	
					TOTAL:	21,149,080	23,704	101,827	208	

*U.S. Environmental Protection Agency, 1979.

Table A-2. Permitted municipal wells within the Powder River basin (data from Wyoming State Engineer's Permit Files, February, 1980).

County	Municipality	Facility	Location of Facility	State Permit Number	Aquifer	Total Depth (ft)	Static Water El. (ft)	Reported Yield (gal/min)	Completion Date	Chemical Analysis	Well Status	Supplementary Information
Campbell												
	City of Gillette											
		M-1	51N 66W Sec. 6	P56867W	Madison						I	Gillette Madison well field supplies municipalities of Gillette and Moorcroft, as well as local ranchers and industry. Total permitted production is 7000 AF/y with a peak limit of 6000 gpm Well completion statements not filed with St. Engineer as of 6/81.
		M-2	51N 66W Sec. 6	P56868W	Madison						I	
		M-3	51N 66W Sec. 6	P56869W	Madison						I	
		M-4	51N 66W Sec. 6	P56870W	Madison						I	
		M-5	51N 66W Sec. 6	P56871W	Madison						I	
		M-6	51N 66W Sec. 6	P56872W	Madison						I	
		M-7	51N 66W Sec. 6	P56873W	Madison						I	
		M-8	51N 66W Sec. 6	P56874W	Madison						I	
		M-9	51N 66W Sec. 6	P56875W	Madison						I	
		M-10	51N 66W Sec. 6	P56876W	Madison						I	
		S-20	50N 72W Sec. 19	P42985W	Ft. Union (upper & lower)	2429	669	160	7-11-78	Yes	P	
		H-1	50N 72W Sec. 21	P1211W	Wasatch	200±	90±	60	before 6/65	yes	Abd 76	
		H-2	50N 72W Sec. 21	P1212W	Wasatch	200±	90±	60	before 6/65	yes	Abd 72	
		H-3	50N 72W Sec. 21	P1213W	Wasatch	200±	90±	50	before 6/65	Unk	Abd 72	
		H-4	50N 72W Sec. 21	P1214W	Wasatch	200±	90±	60	before 6/65	Yes	Abd 71	
		H-5	50N 72W Sec. 21	P1215W	Wasatch	200±	90±	90	before 6/65	Yes	Abd 72	
		H-6	50N 72W Sec. 21	P1216W	Wasatch	200±	90±	60	before 6/65	Yes	Abd 72	
		H-7	50N 72W Sec. 21	P1217W	Wasatch	200±	90±	50	before 6/65	Yes	Abd 12/78	
		H-8	50N 72W Sec. 21	P1218W	Wasatch	200±	90±	60	before 6/65	Yes	Abd 12/76	
		H-9	50N 72W Sec. 21	P1219W	Wasatch	200±	90±	60	before 6/65	Yes	Abd 70	
		H-10	50N 72W Sec. 21	P41987W	Wasatch	175?	85	40	1960's	Yes	P	

Table A-2. (continued)

County	Municipality	Facility	Location of Facility	State Permit Number	Aquifer	Total Depth (ft)	Static Water El. (ft)	Reported Yield (gal/min)	Completion Date	Chemical Analysis	Well Status	Supplementary Information
	City of Gillette (cont.)											
		H-12	50N 72W Sec. 21	P41988W	Wasatch	230	93	75	1965	Yes	P	
		H-13	50N 72W Sec. 21	P41989W	Wasatch	320	107	110	11-21-69	Yes	P	
		H-14	50N 72W Sec. 21	P41990W	Wasatch	320	112	70	12-1-69	Yes	Abd 9/78	
		H-15	50N 72W Sec. 21	P41991W	Wasatch	222	71	94	3-9-70	Yes	P	
		H-16	50N 72W Sec. 21	P41992W	Wasatch	222	70	52	2-6-70	Yes	P	
		H-22	50N 72W Sec. 21	P41998W	Wasatch	222	65	55	2-9-70	Yes	Abd 8/77	
		H-26	50N 72W Sec. 21	P42002S	Wasatch	301	121	83	3-3-70	Yes	P	
		H-3	50N 72W Sec. 21	P1229W	-	1060	475±	60	before 6/65	Yes	P	Originally completed in Ft. Union (#S-3), subsequently in Wasatch.
		S-2	50N 72W Sec. 21	P1223W	Upper Ft. Union	982	400±	65	before 6/65	Yes	Abd 6/79	
		S-4	50N 72W Sec. 21	P1234W	Upper Ft. Union	1215	350±	150	before 6/65	No	Abd 8/77	
		S-5	50N 72W Sec. 21	P1233W	Upper Ft. Union	1143	350±	125	before 6/65	Yes	P	
		S-6	50N 72W Sec. 21	P1222W	-	930	350	60	before 6/65	Yes	Unk	Originally completed in Ft. Union, subsequently in Wasatch.
		S-7	50N 72W Sec. 21	P1230W	-	1130	400±	60	before 6/65	Yes	Abd 8/78	Originally completed in Ft. Union, Subsequently in Wasatch.
		S-8	50N 72W Sec. 21	P1224W	Ft. Union	818	400±	55	before 6/65	Yes	Abd 76	
		S-9	50N 72W Sec. 21	P42004W	Upper Ft. Union	1208	431	110	8-13-76	No	P	Converted oil test hole.
		S-10	50N 72W Sec. 21	P42005W	Upper Ft. Union	2350	571	170	8-4-76	No	P	Converted oil test hole.
		Fox Hills #1	50N 72W Sec. 21	P1232W	-	3479	450±	125	before 6/65	Unk	P	Originally completed in Fox Hills/Lance system, plugged back to Ft. Union.

Table A-2. (continued)

County	Municipality	Facility	Location of Facility	State Permit Number	Aquifer	Total Depth (ft)	Static Water El. (ft)	Reported Yield (gal/min)	Completion Date	Chemical Analysis	Well Status	Supplementary Information
	City of Gillette (cont.)											
		Fox Hills #3	50N 72W Sec. 21	P30005W	Fox Hills/ Lance System	4436	824	340	12-74	Yes	P	High levels of fluoride and gas.
		H-17	50N 72W Sec. 22	P41993W	Wasatch	283	67	56	12-5-69	Yes	P	
		H-18	50N 72W Sec. 22	P41994W	Wasatch	222	56	75	3-5-70	Yes	Unk	
		H-19	50N 72W Sec. 22	P41995W	Wasatch	284	58	49	12-29-69	Yes	P	
		H-20	50N 72W Sec. 22	P41996W	Wasatch	283	68	55	12-11-69	Yes	Abd 6/78	
		H-21	50N 72W Sec. 22	P41997W	Wasatch	282	58	62	2-2-70	Yes	P	
		H-23	50N 72W Sec. 22	P41999W	Wasatch	303	89	50	1-28-70	Yes	P	
		H-24	50N 72W Sec. 22	P42000W	Wasatch	243	62	110	1-22-70	Yes	P	
		H-25	50N 72W Sec. 22	P42001W	Wasatch	283	74	100	12-18-69	Yes	P	
		S-8	50N 72W Sec. 22	P1226W	Upper Ft. Union	826	484±	60	before 6/65	Yes	Abd 10/78	
		S-17	50N 72W Sec. 22	P42010W	Ft. Union (upper & lower)	2297	500	220	6-13-78	Yes	P	
		Fox Hills #2	50N 72W Sec. 22	P25111W	-	8509	600	200	11-73	Yes	P	Originally completed in Fox Hills/Lance system, plugged back to Fort Union.
		P-1	50N 72W Sec. 27	P1220W	Wasatch	500	100	90	before 6/65	Yes	Unk	
		P-2	50N 72W Sec. 27	P1221W	Wasatch	500	100	80	before 6/65	Yes	Unk	
		C	50N 72W Sec. 27	P1225W	Upper Ft. Union	814	400	60	before 6/65	Yes	Abd 77	
		S-13	50N 72W Sec. 27	P1228W	Upper Ft. Union	855	350	60	before 6/65	Yes	Abd 11/78	
		H-27	50N 72W Sec. 28	P52003W	Wasatch	382	189	80	2-24-70	Yes	P	
		D	50N 72W Sec. 28	P1231W	Upper Ft. Union	1015	400	65	before 6/65	No	Abd 77	

Table A-2. (continued)

County	Municipality	Facility	Location of Facility	State Permit Number	Aquifer	Total Depth (ft)	Static Water El. (ft)	Reported Yield (gal/min)	Completion Date	Chemical Analysis	Well Status	Supplementary Information
	City of Gillette (cont.)											
		S-14	50N 72W Sec. 28	P1227W	Upper Ft. Union	980	450	60	before 6/65	No	Abd 8/78	
		S-18	50N 72W Sec. 33	P41830W	Ft. Union	1732	520	140	9-6-78	Yes	P	
		S-19	50N 72W Sec. 33	P41831W	Ft. Union	1720	750	130	8-11-80	Yes	P	
		S-11	50N 72W Sec. 34	P42006W	Ft. Union	2323	520	125	2-77	Yes	P	Plugged at 1800.
		S-12	50N 72W Sec. 34	P42007W	Ft. Union	2295	463	125	6-17-77	Yes	P	Plugged at 1800.
Converse												
	Glenrock											
		Fox Hills #2	33N 75 W Sec. 4 NE NE	P44855W	Fox Hills	706	0	240	5-1-80	Unk	Unk	Flowing Well
		Fox Hills #1	33N 75W Sec. 4 NW NE	P44473W	Fox Hills	508	20	125	5-1-80	Yes	Unk	
		Glenrock #1	33N 75W Sec. 4 NW SW	P17439W	alluvium	35	5	150	3-31-73	No	Unk	
		Glenrock #3	33N 75W Sec. 4 NW SW	P17441W	alluvium	33	5	70	3-31-73	No	Unk	
		Glenrock #4	33N 75W Sec. 4 NW NW	P17442W	alluvium	31	5	80	4-17-73	No	Unk	
		Glenrock #2	33N 75W Sec. 4 SW NW	P17440W	alluvium	35	5	120	3-31-73	No	Unk	
Crook												
	Sundance											
		Cole #3	52N 63W Sec. 25 SE SW	P1544W	Minnelusa	517	471	240	9-10-65	No	Unk	
		Cole #3A	52N 63W Sec. 25 SE SW	P8377W	Madison	1123	432	300	8-15-71	Yes	P	
		Cole #3B	52N 63W Sec. 25 SE SE	P50484W	Madison	1236	429	260	7-80	No	P	
		Loydcole #4	51N 63W Se. 11 SE NE	P2522W	Minnekahta	110	23	22	3-57	Unk	Unk	
		Hard water well #5	51N 63W Sec. 23	P2523W	Minnelusa	440	120	200	9-54	Yes	Unk	Yield enlarged 200 gpm by permit #2580.

Table A-2. (continued)

County	Municipality	Facility	Location of Facility	State Permit Number	Aquifer	Total Depth (ft)	Static Water El. (ft)	Reported Yield (gal/min)	Completion Date	Chemical Analysis	Well Status	Supplementary Information
	Sundance (cont.)											
		Loafman well #1	51N 63W Sec. 24	P2520W	Spearfish	140	16	8	7-34	Unk	Unk	
		Loafman well #2	51N 63W Sec. 27	P2521W	Spearfish	115	5	15	6-58	Unk	Unk	
	Hulett	Hulett Artesian well #1	54N 64W Sec. 7	P31C	Minnelusa	620	0	480	9-15-34	Unk	P	Flowing well.
		Hulett Artesian well #2	54N 64W Sec. 7	P118G	Minnelusa	690	0	250	9-1-51	Unk	P	Flowing well.
		Hulett Artesian well #3	54N 64W Sec. 7	P56489W	(Madison)	N.R.	N.R.	N.R.	N.R.	Unk	I	Pending permit, 6/81: anticipated depth 1,500 feet, anticipated yield 500 gpm.
	Moorcroft											
		Moorcroft #4	50N 67W Sec. 31	P993W	Fox Hills /Lance	485	90	60	6-4-74	Unk	Unk	
		Moorcroft #5	50N 67W Sec. 31	P33968W	Fox Hills /Lance	485	310	30	8-76	Yes	Unk	Yield enlarged 25 gpm by permit # 42845
		Moorcroft #1	50N 67W Sec. 31	P990W	Fox Hills /Lance	500	150	30	4-22-64	Unk	Unk	
		Moorcroft #2	50N 67W Sec. 31	P991W	Fox Hills /Lance	400	150	50	5-1-64	Unk	Unk	
		Moorcroft #3	49N 67W Sec. 6	P992W	Fox Hills /Lance	385	125	30	5-15-64	Unk	Unk	
		Moorcroft #6	50N 68W Sec. 36	P43549W	Fox Hills /Lance	760	89	100	2-21-79	Unk	Unk	
Johnson												
	Kaycee											
		Kaycee Well #2	43N 82N Sec. 12 NE SW	P11W	alluvium	20	12	347	10-1-58	Unk	Unk	
		Kaycee Well #3	48N 82W Sec. 12 NE SW	P4327W	(alluvium)	N.R.	N.R.	N.R.	N.R.	Unk	I	Pending permit, 6/81 anticipated depth 40 ft.; anticipated yield 70 gpm.

Table A-2. (continued)

County	Municipality	Facility	Location of Facility	State Permit Number	Aquifer	Total Depth (ft)	Static Water El. (ft)	Reported Yield (gal/min)	Completion Date	Chemical Analysis	Well Status	Supplementary Information
	Buffalo											
		Buffalo Underground Water Supply No. 1	50N 82W Sec. 6	P1G	alluvium	18	11	990	10-30-47	Unk	Unk	Infiltration gallery.
		Clear Creek #2	50N 82W Sec. 6	P42W	alluvium	25	12	790	7-28-74	No	Unk	Infiltration gallery.
Natrona												
	Casper											
		Park Well #2	34N 79W Sec. 34 SE SW	P575W	alluvium	28	8	920	7-17-61	No	Unk	"Park" wells are principally for park irrigation but are also permitted for municipal use.
		Park Well #3	34N 79W Sec. 34 SE SW	P576W	alluvium	33	8	1000	7-19-71	No	Unk	
		Park Well #4	34N 79W Sec. 34 SE SE	P577W	alluvium	32	7	850	7-2-62	No	Unk	
		Park Well #1	33N 79W Sec. 3 NE NW	P574W	alluvium	29	8	700	6-1-62	No	Unk	
		Casper #14	33N 79W Sec. 7 SW NW	P601G	alluvium	30	8	600	1956	Unk	Unk	
		Casper #15	33N 79W Sec. 7 SW SW	P602G	alluvium	33	8	800	1956	Unk	Unk	
		City of Casper #16	33N 79W Sec. 7 SW SE	P1152W	alluvium	31	12	600	6-10-64	No	Unk	
		City of Casper #17	33N 79W Sec. 7 SE SW	P1153W	alluvium	31	12	500	6-10-64	No	Unk	
		City of Casper #18	33N 79W Sec. 7 SE SW	P1154W	alluvium	34	12	1000	6-10-64	No	Unk	
		Casper #4	33N 79W Sec. 18 NW NE	P594G	alluvium	38	14	700	5-13-53	Unk	Unk	
		Casper #1	33N 79W Sec. 18 NW NE	P615C	alluvium	30	16	500	1920	Unk	Unk	
		Casper #2	33N 79W Sec. 18 NW NE	P616C	alluvium	30	13	500	1920	Unk	Unk	
		Casper #3	33N 79W Sec. 18 NW NE	P617C	alluvium	30	13	500	1920	Unk	Unk	

Table A-2. (continued)

County	Municipality	Facility	Location of Facility	State Permit Number	Aquifer	Total Depth (ft)	Static Water El. (ft)	Reported Yield (gal/min)	Completion Date	Chemical Analysis	Well Status	Supplementary Information
	Casper (cont.)											
		Ranney #1	33N 79W Sec. 18 NW NW	P46W	alluvium	24	5	1400	10-1-58	No	Unk	Cassion
		Ranney #2	33N 79W Sec. 18 NW NW	P47W	alluvium	25	5	1100	10-1-58	No	Unk	Cassion
		Ranney #3	33N 79W Sec. 18 NW NW	P48W	alluvium	25	5	1550	8-15-58	No	Unk	Cassion
		Morad #2	33N 79W Sec. 18 SW NE	P1798W	alluvium	31	8	700	7-16-66	No	Unk	
		Morad #3	33N 79W Sec. 18 SW NE	P1799W	alluvium	32	8	700	7-18-66	No	Unk	
		Morad #1	33N 79W Sec. 18 SW NW	P1797W	alluvium	31	10	450	7-15-66	No	Unk	
		City of Casper #11	33N 80W Sec. 12 SE NE	P49W	alluvium	30	8	750	3-56	No	Unk	
		City of Casper #12	33N 80W Sec. 12 SE NE	P50W	alluvium	30	7	750	3-56	No	Unk	
		Casper #5	33N 80W Sec. 12 SE SE	P595G	alluvium	30	7	700	1953	Unk	Unk	
		Casper #6	33N 80W Sec. 12 SE SE	P596G	alluvium	36	10	700	1953	Unk	Unk	
		Casper #7	33N 80W Sec. 12 SE SE	P597G	alluvium	34	9	700	1953	Unk	Unk	
		Casper #8	33N 80W Sec. 12 SE SE	P598G	alluvium	32	8	600	1953	Unk	Unk	
		Casper #9	33N 80W Sec. 12 SE SE	P599G	alluvium	30	5	700	1953	Unk	Unk	
		Casper #10	33N 80W Sec. 12 SE SE	P600G	alluvium	28	8	600	1953	Unk	Unk	

Table A-2. (continued)

County	Municipality	Facility	Location of Facility	State Permit Number	Aquifer	Total Depth (ft)	Static Water El. (ft)	Reported Yield (gal/min)	Completion Date	Chemical Analysis	Well Status	Supplementary Information
Natrona												
	Edgerton											
		Edgerton #7	41N 78W Sec. 36	P53598W	(Fox Hills)	N.R.	N.R.	N.R.	N.R.	Unk	1	Pending permit, 6/81: anticipated depth 1900 ft, anticipated yield 200 gpm.
		Edgerton Water Well #5	41N 78W Sec. 36	P6319W	Fox Hills	2000	N.R.	60	10-9-70	No	Unk	
		Edgerton #6	40N 78W Sec. 1 NW NW	P44002W	Fox Hills	2120	290	55	9-5-78	Yes	Unk	
		Edgerton Well #3	40N 78W Sec. 11 NE NW	P1652W	Fox Hills /Lance	910	330	34	10-4-66	No	Abd 10/79	Deepened 8/75, 2/76.
		Edgerton Water Well #1	40N 78W Sec. 11 SE NW	P1002W	Fox Hills /Lance	976	800	30	N.R.	Unk	Abd 4/61	
		Edgerton Well #1a	40N 78W Sec. 11 SE NW	P1653W	Fox Hills /Lance	735	225	30	10-4-66	No	Unk	Deepend 8/75.
		Edgerton Parsons #1	40N 78W Sec. 15 NE NW	P508C	Fox Hills	130	80	11	6-38	Unk	Unk	
	Evansville											
		Evansville #6	34N 79W Sec. 36 SE NW	P585W	alluvium	37	9	250	8-19-61	No	Unk	
	Mills											
		Mills Well #4	33N 79W Sec. 7 NE SW	P2722W	alluvium	31	9	N.R.	N.R.	Unk	Abd 1/70	
		Mills Well #5	33N 79W Sec. 7 NW NW	P4588W	alluvium	30	11	500	9-15-70	Yes	Unk	
		Mills #1	33N 79W Sec. 7 SW NW	P1252W	alluvium	30	6	300	10-1-48	Yes	Unk	
		Mills #2	33N 79W Sec. 7 SW NW	P1253W	alluvium	30	6	300	10-1-45	Yes	Unk	
		Mills #3	33N 79W Sec. 7 SW NW	P1254W	alluvium	30	6	500	6-16-61	Yes	Unk	
		Mills #6	33N 79W Sec. 7 SW NW	P50607W	alluvium	34	9	600	12-19-80	Unk	Unk	

Table A-2. (continued)

County	Municipality	Facility	Location of Facility	State Permit Number	Aquifer	Total Depth (ft)	Static Water El. (ft)	Reported Yield (gal/min)	Completion Date	Chemical Analysis	Well Status	Supplementary Information
Niobrara												
	Manville											
		Manville Well #1	32N 65W Sec. 1 SW NE	P594C	Middle Tertiary	185	30	150	1913	Unk	Unk	
		Manville Well #2	32N 65W Sec. 1 SW NE	P595C	Middle Tertiary	185	40	100	1913	Unk	Unk	
Platte												
	Glendo											
		Cemetary Well #1	29N 68W Sec. 19	P548G	alluvium	72	41	1000	8-15-56	Unk	Unk	Originally drilled in 1905. Also permitted for industrial and cemetary use.
		Downey Well #1	29N 68W Sec. 20	P433C	Hartville	410	0	225	11-16-41	Unk	Unk	Flowing well. Hartville is a Minnelusa equivalent.
Sheridan												
	Clearmont											
		Clearmont #1	54N 79W Sec. 16	P37666W	Wasatch	522	110	30	May 1978	Unk	P	
		Clearmont #2	54N 79W Sec. 16	P45802W	(Ft. Union)	N.R.	N.R.	N.R.	N.R.	Unk	I	Pending permit, 6/81: anticipated depth 1400 feet; anticipated yield 200 gpm.
		Clearmont Water Well #1	54N 79W Sec. 21	P1665W	Wasatch	130	90	7	7-31-23	Yes	Abd	Well is currently pumping large quantities of sand-completion statement has not been filed.
		Clearmont Water Well #2	54N 79W Sec. 21	P1666W	Wasatch	172	90	35	6-17-58	Yes	P	
Weston												
	Upton											
		Town of Upton Well #1	48N 65W Sec. 25 NW SW	P28334W	Dakota System	547	440	38	5-1957	No	P	

Table A-2. (continued)

County	Municipality	Facility	Location of Facility	State Permit Number	Aquifer	Total Depth (ft)	Static Water El. (ft)	Reported Yield (gal/min)	Completion Date	Chemical Analysis	Well Status	Supplementary Information
	Upton (cont.)											
		Town of Upton Well #2	48N 65W Sec. 25 SW NW	P28335W	Madison	3162	0	205	10-19-49	Yes	P	
		Town of Upton Well #3	48N 65W Sec. 35 SW NE	P28336W	Dakota System	804	200	35	3-1959	Yes	P	
		Town of Upton Well #4	48N 65W Sec. 35 SW SW	P28337W	Madison	3193	N.R.	205	4-1963	Yes	P	
		Town of Upton #5	48N 65W Sec. 35 SW SW	P28338W	Dakota System	545	120	35	10-56	Yes	P	
	Newcastle											
		Newcastle Artesian Well #1	45N 61W Sec. 20 SE SW	P38G	Madison	2638	0	1600	2-14-49	Yes	P	Flowing well.
		Newcastle #4	45N 61W Sec. 20 SE SW	P39352W	Madison	3245	0	640	6-25-78	Yes	P	Flowing well.
		Municipal Well #3	45N 61W Sec. 21 SW NW	P1317W	Madison	2872	0	463	9-10-65	Yes	P	Flowing well.
		Newcastle #2	45N 61W Sec. 28 NE NW	P389W	Madison	3028	28	650	6-30-61	Yes	P	

Abreviations:
I - Incomplete
P - Producing
Abd - Abandoned
N.R. - None Reported
Unk - Unknown

Table A-3. Non-municipal community water supply systems within the Powder River basin, Wyoming.[a]

Facility Name and Location	EPA PWS ID #	Owner Type[b]	Population Served	Average Production (gal/day)	Water Source	Source Location	SEO Permit #	Total Depth (ft)	Aquifer	Reported Yield (gpm)	Completion Date	Supplementary Information
CAMPBELL COUNTY												
Anderson Subdivision Homeowners Assn., 1 mi E of Gillette	5600193	A	220	22,000	Anderson #1	50/72-23 ba	20855	1,050	Fort Union	25	12/10/73	
					1st Enl. #1	50/72-23 ba	27231	1,050	Fort Union	50	N.A.	
					2nd Enl. #1	50/72-23 ba	52223	1,050	Fort Union	50	N.A.	
					Anderson #2	50/72-23 ab	27033	1,270	Fort Union	45	7/7/75	
					Enl. #2	50/72-23 ab	52224	1,270	Fort Union	50	N.A.	
Antelope Valley Subdivision, 5 mi SE of Gillette	5600251	A	200	2,500	Antelope Valley #1	49/72-13 cc	37361	(1,400)	(Fort Union)	(100)	--	Permit 37361 pending completion as of 6/81
Big W Trailer Court, Gillette	5600126	I	70	3,500	UNK	UNK	UNK	UNK	UNK	UNK	UNK	EPA data base lists 2 wells
Black Hills Power & Light, Wyodak	5600135	C	570	50,000	Wyodak #1	50/71-27 bc	5538	600	Fort Union	13	11/20/35	All wells supply Wyodak power plant, some also supply the company town. Wells #1, 9, 10, 11, and 12 are only permitted for industrial use. Well #4 is abandoned.
					Wyodak #3	50/71-27 ba	5539	528	Fort Union	23	2/13/54	
					Wyodak #4	50/71-22 cd	5540	575	Fort Union	50	4/14/50	
					Wyodak #5	50/71-27 ba	5541	600	Fort Union	38	3/54	
					Wyodak #6	50/71-22 cd	5542	600	Fort Union	26	4/55	
					Wyodak #7	50/71-22 ca	5543	600	Fort Union	27	1/54	
					Wyodak #8	50/71-27 ab	5293	541	Fort Union	25	7/30/70	
					Wyodak #9	50/71-22 dc	9170	556	Fort Union	15	2/15/72	
					Wyodak #10	50/71-22 dc	15581	3,664	Fox Hills?	1,400	5/4/73	
					Wyodak #11	50/71-27 ab	20832	2,646	Lance?	1,300	6/24/77	
					Wyodak #12	50/71-27 ba	24990	1,180	Fort Union	1,200	12/2/73	
Butler Court, Gillette	5600127	I	35	1,750	UNK	UNK	UNK	UNK	UNK	UNK	UNK	EPA data base lists 1 well
Campbell County Countryside Water Users, 1 mi NE of Gillette	5600192	A	480	54,000	Kenitzer #1	50/71-18 dd	5670	335	Wasatch	30	5/17/71	Permits 5670 & 17453 are cancelled
					Kenitzer #2	50/71-18 bc	41246	320	Wasatch	10.5	-/-/69	
					Kenitzer #3	50/71-18 ca	14345	365	Wasatch	50	8/6/72	
					Countryside Water Users #1	50/71-18 bc	24605	1,190	Fort Union	150	6/17/74	
					Outer Limits #1	50/71-18 da	17453	(330)	(Wasatch)	(20)	--	
Carson Mobile Home Park, 1½ mi S of Gillette	5600117	I	251	5,400	Carson #1	50/72-34 aa	2402	1,112	Fort Union	27	5/18/68	
					Carson #2	50/72-34 aa	2403	1,106	Fort Union	32	8/27/68	
Collins Heights Subdivision, 3 mi E of Gillette	5600129	I	120	15,000	Collins #1	50/71-19 dc	32002	1,234	Fort Union	20	8/-/72	
					Collins #2	50/71-19 dc	32003	1,050	Fort Union	100	7/-/75	
Diamond Mobile Home Park, 2 mi E of Gillette	5600131	I	400	14,500	Sullivan #2	50/72-25 aa	32660	1,040	Fort Union	50	4/30/76	
Fox Park Subdivision, 3 mi SE of Gillette	5600745	I	50	5,000	Drum-Coulter #1	50/71-31 ab	37958	1,775	Fort Union	300	2/20/78	
Green's Trailer Court, S of Gillette	5600122	I	150	15,000	UNK	UNK	UNK	UNK	UNK	UNK	UNK	EPA data base lists 1 well

Table A-3. (continued)

Facility Name and Location	EPA PWS ID #	Owner Type[b]	Population Served	Average Production (gal/day)	Water Source	Source Location	SEO Permit #	Total Depth (ft)	Aquifer	Reported Yield (gpm)	Completion Date	Supplementary Information
CAMPBELL COUNTY (continued)												
Heritage Village Subdivision, 2 mi NE of Gillette	5600249	I	550	55,000	Anderson #3	50/72-14 cd	33293	1,000	Fort Union	50	9/-/76	
					Enl. #3	50/72-14 cd	42641	1,000	Fort Union	100	N.A.	
					Anderson #4	50/72-14 ca	33294	1,002	Fort Union	50	9/25/77	
					Enl. #4	50/72-14 ca	42642	1,002	Fort Union	100	N.A.	
Hidden Valley Home-owners Assn., 4 mi SW of Gillette	5600144	A	120	12,000	Hidden Valley #1	49/72-6 ad	49066	(1,200)	(Fort Union)	(150)	--	Permit 49066 is pending completion as of 6/81 and is a refiling of cancelled permit 30012.
					Hidden Valley #2	49/72-6 ad	49067	1,320	Fort Union	80	10/1/79	
Hitching Post Trailer Court, Gillette	5600119	I	34	82,000	Hitching Post #1 ?	49/72-12 cd	6349	1,108	Fort Union	25	5/8/69	Hitching Post #1 is identified as supply well on EPA data base but permitted for domestic use only. Edwards #3, same owner, is a can-celled permit to supply on 80 space mobile home park.
					Edwards #3 ?	54/74-24 bb	29725	(500)	(Wasatch)	(25)	--	
Hoy Mobile Home Park, Gillette	5600141	UNK	100	6,000	UNK	UNK	UNK	UNK	UNK	UNK	UNK	EPA data base lists 1 well
Imperial Trailer Court, 2½ mi S of Gillette	5600120	I	68	3,400	Acres #1 ?	49/72-2 cd	4975	211	Wasatch	25	4/8/70	Well #1 permitted for domestic use only, EPA data base identified #2 as sole source.
					Enl. ?	49/72-2 cd	26792	211	Wasatch	0	N.A.	
					Acres #2	49/72-2 cd	26795	1,120	Fort Union	25	7/5/74	
					Enl. #2	49/72-2 cd	28320	1,120	Fort Union	25	N.A.	
J and J Mobile Home Park, 2 mi W of Gillette	5600130	I	500	25,000	Dickinson #1	50/72-20 ca	38071	1,255	Fort Union	200	7/17/77	EPA data base lists 2 wells, deep and shallow.
Jones Trailer Court, 3 mi SW of Gillette	5600125	I	90	5,000	Jones #2 ?	49/72-5 ba	30481	399	Wasatch	25	4/12/78	Well permitted for domestic use only.
Knutson's Trailer Park, Gillette	5600124	L	50	3,750	UNK	UNK	UNK	UNK	UNK	UNK	UNK	EPA data base lists 1 well.
Lakeside Properties, Inc., 2 mi S of Gillette	5600118	I	189	9,800	Lakeside #3	50/72-34 ac	6740	1,100	Fort Union	100	10/25/70	EPA data base lists 2 wells, #1 and #2
					Enl. #3	50/72-34 ac	52284	1,100	Fort Union	0	N.A.	
McCulloch Gas Trailer Court, Hilight	5600143	I	50	2,500	McCulloch Water Well #1	45/71-26 cc	5492	831	Fort Union	15?	5/15/70	
Morgan Trailer Court, Gillette	5600142	I	36	1,800	Morgan #10 ?	48/72-25 bd	26012	190	Wasatch	15	7/75	EPA data base lists different mailing address and 2 wells.
Nepstad Trailer Court, 2 mi S of Gillette	5600138	I	50	2,500	Nepstead #1	49/72-3 ac	14694	1,211	Fort Union	100	11/28/72	
Nickelson Farms Water Co., 10 mi SE of Gillette	5600619	A	400	20,000	Nickelson's Little Farms #1	49/71-26 ca	37957	1,300	Fort Union	100	8/15/77	Permit 52304 pending comple-tion as of 6/81
					#2 Nickelson's	49/71-26 ca	52304	(1,500)	(Fort Union)	(250)	--	
Phillips Petroleum, Hilight	5600279	I	29	3,600	Hay Booster Water Well #1	45/71-10 ad	6758	778	Fort Union	5	12/9/70	

Table A-3. (continued)

Facility Name and Location	EPA PWS ID #	Owner Type[b]	Population Served	Average Production (gal/day)	Water Source	Source Location	SEO Permit #	Total Depth (ft)	Aquifer	Reported Yield (gpm)	Completion Date	Supplementary Information
CAMPBELL COUNTY (continued)												
Prairie Trailer Court, Rozet	5600134	I	90	4,500	UNK	UNK	UNK	UNK	UNK	UNK	UNK	EPA data base lists 2 wells, deep and shallow.
Prospector Village - AMAX, 8 mi N of Gillette	5600123	I	400	30,000	Prospector #1	51/72-17 cc	34920	1,100	Fort Union	75	11/3/76	
					Prospector #2	51/72-17 cc	44003	1,130	Fort Union	100	3/1/80	
Rawhide Village, 7 mi N of Gillette	5600128	I	400	40,000	Kontono Well #1	51/72-20 aa	29719	1,020	Fort Union	15	7/15/75	Well #1 serves Rawhide Village I & II, well #2 serves Rawhide Village III. Well #1 completion statement indicates 100 gpm yield but 15 gpm is adjudicated amount.
					Kontono Well #2	51/72-20 aa	49324	1,097	Fort Union	100	11/1/76	
					Enl. #2	51/72-20 aa	50566	1,097	Fort Union	300	N.A.	
Rocky Point Homeowners Assn., 4 mi SW of Gillette	5600259	A	60	9,000	Point #1	49/72-6 c	30208	1,420	Fort Union	100	12/-/76	
Stanley Trailer Court, NE of Gillette	5600121	I	45	2,250	UNK	UNK	UNK	UNK	UNK	UNK	UNK	EPA data base lists 1 well.
Stroup Trailer Court, 2 mi S of Gillette	5600145	I	150	7,500	Stroup #1	49/72-2 dc	29724	(448)	(Wasatch)	(20)	--	Permit pending completion as of 6/81.
Sunburst Water and Sewer District, 2 mi S of Gillette	5600116	A	200	20,000	Sunburst #1	49/72-3 ac	1015	200	Wasatch	15	-/-/59	More than 3 wells may be represented by these permits; 2nd Enl. #2 is for points of use only.
					Enl. #1	49/72-3 ac	41018	1,253?	Fort Union	75?	N.A.	
					Sunburst #2	49/72-3 da	1174	540	Wasatch	25	6/-/66	
					1st Enl. #2	49/72-3 da	29612	~1,200?	Fort Union	75	N.A.	
					2nd Enl. #2	49/72-3 da	41019	~1,200?	Fort Union	0	N.A.	
					Sunburst #3	49/72-3 da	2559	675	Fort Union	30	8/1/69	
Sundog Addition Homeowners Assn., 4 mi SW of Gillette	5600148	A	30	3,000	Sundog I	49/72-7 bb	29916	1,150	Fort Union	35	8/4/75	Well I is backup; well II is primary supply.
					Sundog II	49/72-6 cc	56602	1,520	Fort Union	90	7/20/80	
Tomek Trailer Court, Gillette	5600139	I	45	2,250	Tomek #1	50/72-23 dc	6500	(380)	(Wasatch)	(25)	--	Permit 6500 cancelled.
Westridge Water Users Assn., 2 mi S of Gillette	5600146	A	220	16,500	Ellison #2	50/72-33 cd	14224	1,186	Fort Union	25	8/25/72	
					Enl. #2	50/72-33 cd	46017	1,186	Fort Union	45	N.A.	
					Wenger #1	50/72-33 ca	24603	1,360	Fort Union	109	7/24/73	
					Wenger #2	50/72-32 db	37169	1,250	Fort Union	100	8/17/77	
Wright Water and Sewer District, Wright	5600136	A	800	55,000	RJ #1	44/72-27 dc	46663	643	Wasatch	50	6/25/75	Cancelled permits 27638, 29417, 31916, and 37539 apply to wells #1, 2, 2, and 3, respectively. Permits 48090 and 48091 are pending completion as of 6/81.
					RJ #2	44/72-27 cc	46664	2,660	Fort Union	350	5/17/76	
					RJ #3	44/72-35 bd	46696	2,730	Fort Union	325	11/79	
					RJ #4	44/72-26 bc	48090	(2,800)	(Fort Union)	(600)	--	
					RJ #5	44/72-34 ca	48091	(2,800)	(Fort Union)	(400)	--	

Table A-3. (continued)

Facility Name and Location	EPA PWS ID #	Owner Type[b]	Population Served	Average Production (gal/day)	Water Source	Source Location	SEO Permit #	Total Depth (ft)	Aquifer	Reported Yield (gpm)	Completion Date	Supplementary Information
CONVERSE COUNTY												
Coles Trailer Park, 2 mi S of Douglas	5600270	I	100	5,000	E. Cole #1 ?	32/71-21 bb	14621	90	Middle Tertiary	8	-/-/28	Wells permitted for domestic use only.
					E. Cole #2 ?	32/71-21 bb	29898	200	Middle Tertiary	25	10/20/75	
KOA Kampgrounds, W of Douglas	5600247	I	120	6,000	UNK	UNK	UNK	UNK	UNK	UNK	UNK	EPA data base lists 2 wells.
McClure's Trailer Sales & Service, 1 mi N of Douglas	5600277	I	24	1,200	McClure #1	32/71-4 bd	22223	65	Fort Union	10	UNK	Well #3 replaces well #1, which has sanding problem.
					McClure #2	32/71-4 ba	30584	80	Fort Union	23	9/18/75	
					Enl. #2	32/71-4 ba	53707	80	Fort Union	25	N.A.	
					McClure #3	32/71-4 bd	53708	100	Fort Union	25	5/4/81	
Ridgewater Estates One, 2 mi SW of Douglas	5600285	I	70	11,025	Ridgewater #1	32/72-13 dc	56453	185	Middle Tertiary	40	8/1/78	
					Smith #1	32/72-13 cd	56454	500	Middle Tertiary	50	7/12/80	
Schrandts Mobile Villa, SE of Douglas	5600269	I	70	3,500	UNK	UNK	UNK	UNK	UNK	UNK	UNK	EPA data base lists 2 wells.
Tennessee Ernie's Trailer Acres, Douglas	5600234	I	75	3,750	UNK	UNK	UNK	UNK	UNK	UNK	UNK	EPA data base lists 1 well.
Westland Trailer Park, 2½ mi SW of Douglas	5600274	UNK	90	4,500	Westland Est. #1	32/72-24 bd	28274	127	Middle Tertiary	26	5/18/75	Well #2 permitted for domestic use only.
					Westland Est. #2 ?	32/72-24 ab	28131	71	Middle Tertiary	10	-/-/44	
CROOK COUNTY												
Pine Haven Water Co., 8 mi NE of Moorcroft	5600191	I	55	3,200	Keyhole #1	50/66-5 ba	29613	4,110	Minnelusa & Madison?	150	11/10/77	Permit 29613 cancelled but TFN #12-2-373 is a refiling for same well. EPA data base lists 2 wells
Roberts Trailer Park, 1 mi NE of Hulett	5600377	I	25	1,875	Roberts #1 ?	54/64-6 ca	8113	700	Minnelusa	25	2/28/71	Well permitted for domestic use only.
Vista West Subdivision, N of Sundance?	5600246	A	120	12,000	Ogden Spring	--	--	--	--	--	--	No ground-water permit at St. Engineer's Office.
JOHNSON COUNTY												
Bald Mountain Trailer Court, 2½ mi W of Buffalo	5600258	I	80	8,000	Wilson #1	50/82-5 ba	23207	200	Wasatch	20	6/8/73	EPA data base lists 3 wells.
					Wilson #2	50/82-5 ba	33490	200	Wasatch	30	7/16/76	
Cross C Campground, 2 mi W of Buffalo	5600229	I	50	2,500	UNK	UNK	UNK	UNK	UNK	UNK	UNK	EPA data base lists 1 well.
Linch Utility, Linch	5600241	A	100	33,600	Sussex #5	42/78-23 bc	579G	471	Lance	18	3/5/49	Permits 6539 and 6540 are for same wells as 579G and 580G. All 5 permits are currently (6/81) cancelled.
					Sussex #6	42/78-22 ad	580G	425	Lance	25	11/5/49	
					Sussex #13	42/78-23 ba	587G	1,936	Fox Hills ?	90	9/14/55	

Table A-3. (continued)

Facility Name and Location	EPA PWS ID #	Owner Type[b]	Population Served	Average Production (gal/day)	Water Source	Source Location	SEO Permit #	Total Depth (ft)	Aquifer	Reported Yield (gpm)	Completion Date	Supplementary Information
NATRONA COUNTY												
Air Base Acres, 6 mi NW of Casper	5600080	A	150	12,000	Purchase	--	--	--	--	--	--	Purchased from City of Casper
Alcova Acres Investment Corp., 6 mi SW of Casper	5600071	I	340	54,600	Jade Hills #1	33/80-22 ad	1994	35	Alluvium	75	6/14/67	#1 also has cancelled permit #2161?.
					Jade #2	33/80-27 aa	933	600?	Frontier?	25?	before 11/62	
					Alcova #3	33/80-27 dd	29634	(1,000)	(Dakota Sys?)	(350-500)	--	Permit 29634 cancelled.
					Alcova #4	33/80-27 ac	30903	903	Dakota Sys?	400?	9/75	Well #4 abandoned 9/75.
					Alcova #5	33/80-22 da	32606	(40)	(Alluvium)	(300)	--	Permit 32606 pending
					Enl. #5	33/80-22 da	42904	(40)	(Alluvium)	(75)	N.A.	completion as of 6/81.
Ardon Subdivision Water Users, Casper	5600083	A	18	2,000	Purchase	--	--	--	--	--	--	Purchased from City of Casper.
Brooks Water & Sewer District, W of Casper (Mountain View)	5600070	A	4,000	672,000	N. Platte R.	--	--	--	--	--	--	Surface water.
Hillcrest Development, 6 mi S of Casper	5600074	I	80	10,000	Hillcrest Development #1	32/79-6 bb	4943	51	Cody?	40	11/62	
					Hillcrest Development #2	32/79-6 bb	42673	16	Alluvium?	23	9/1/78	#2 is a developed spring; permit 42674 pending completion 6/81. EPA data base lists a total of 3 springs.
					Hillcrest Development #3	32/79-6 bb	42674	(100)	(Cody?)	(100)	--	
Masek Subdivision Prop. Owners, W. of Casper (Mills)	5600084	I	45	5,000	Purchase	--	--	--	--	--	--	Purchased from City of Casper.
Natrona County International Airport, 8 mi NW of Casper	5600079	UNK	970	80,000	Purchase	--	--	--	--	--	--	Purchased from City of Casper.
					Airport #1	34/80-21 ca	1062	3,100	Lakota	170?	12/26/63	Wells are flowing wells.
					Airport #2	34/80-21 dd	1502	2,821	Lakota	15?	3/15/66	
Paradise Valley Utility Co., 4 mi SW of Casper	5600010	I	3,000	300,000	Voorhies #12	33/80-14 dd	16	45	Alluvium	750	4/58	EPA data base lists existing well names as North, East, and West; permit 7808 cancelled; permits 42416, 43266, and 43267 are pending completion as of 6/81.
					Claire #11	33/80-14 da	17	45	Alluvium	750	4/58	
					Bryan #14	33/80-14 da	18	45	Alluvium	500	4/58	
					Paradise Valley #4	33/80-14 da	7808	(35)	(Alluvium)	(600)	UNK	
					Paradise Valley #5	33/80-14 da	42416	(45)	(Alluvium)	(750)	--	
					Paradise Valley #6	33/80-27 da	43266	(45)	(Alluvium)	(750)	--	
					Paradise Valley #7	33/80-27 da	43267	(45)	(Alluvium)	(750)	--	
Pleasant View Water Co., W. of Casper (Mills)	5600082	A	50	6,000	Purchase	--	--	--	--	--	--	Purchased from City of Casper.
Poison Spider Water Co., 12 mi SW of Casper (Bessemer Bend)	5600073	A	100	20,000	Poison Spider #1	32/81-3	5992	22	Alluvium	32.5	7/6/71	
					N. Platte R.	--	--	--	--	--	--	River water is obtained via infiltration gallery.

Table A-3. (continued)

Facility Name and Location	EPA PWS ID #	Owner Type[b]	Population Served	Average Production (gal/day)	Water Source	Source Location	SEO Permit #	Total Depth (ft)	Aquifer	Reported Yield (gpm)	Completion Date	Supplementary Information
NATRONA COUNTY (continued)												
Red Butte Village, 8 mi SW of Casper	5600075	A	136	10,200	Red Butte Improvement #1	33/80-22 dc	30848	31	Alluvium	400	8/4/77	SEO data indicate Red Butte Improvement #1 is sole source. Permit 934 cancelled.
					Riverside Terrace Well #1	33/80-22 dd	40	27	Alluvium	36?	7/15/60	
					Riverside Terrace Well #2	33/80-22 dc	78	27	Alluvium	(500)	7/15/60	
					Red Butte #4	33/80-22 dc	934	(30)	(Alluvium)	(150)	UNK	
Riverside Trailer Court, 1 mi N of Casper	5600072	I	750	37,500	Riverside #1?	33/79-4 ab	18658	20	Alluvium	25	6/47	Wells permitted for domestic use only (yield corrected by SEO from reported total of 700 gpm).
					Riverside #2?	33/79-4 ba	18659	20	Alluvium	25	-/52	
Vista West Water Co., 6 mi NW of Casper (Air Base Acres)	5600069	I	270	27,000	Purchase	--	--	--	--	--	--	Purchased water from City of Casper; wells are flowing wells; #1 abandoned 9/19/76.
					#1 Deep Water	34/80-28 cc	35838	2,338	Lakota	50?	UNK	
					#2 Deep Water	34/80-33 cb	35871	2,030	Lakota	50	12/16/76	
Wardwell Water & Sewer Dist., 2 mi W of Casper (Mills)	5600067	A	1,870	150,000	Wardwell #1	33/79-7 ba	13699	35	Alluvium	500	5/15/72	
NIOBRARA COUNTY												
Gateway Water, Lance Creek	5600163	I	34	3,400	UNK	UNK	UNK	UNK	UNK	UNK	UNK	EPA data base lists 1 well.
Marathon Oil, Lance Creek	5600109	I	96	22,350	UNK	UNK	UNK	UNK	UNK	UNK	UNK	EPA data base lists 2 wells.
SHERIDAN COUNTY												
Acme Realty, Acme	5600001	I	130	13,000	UNK	UNK	UNK	UNK	UNK	UNK	UNK	EPA data base lists 2 wells.
Home Ranch Subdivision, 3 mi S of Sheridan	5600245	I	45	4,500	PFP #1?	55/84-10 bc	36916	(300)	(Fort Union?)	UNK	--	Wells HR #1-4 serve South Home Ranch 1st addition. Wells PFP #1 & 2, and some surface water, are projected to serve 190 units in a trailer court and South Home Ranch Subdivision Phase II. Permits 36916 & 36917 are pending completion as of 6/81.
					PFP #2?	55/84-10 bc	36917	(20)	(Alluvium)	UNK	--	
					HR #1	55/84-15 bc	55604	570	Fort Union	5	8/15/80	
					HR #2	55/84-15 bc	55605	550	Fort Union	5	8/30/80	
					HR #3	55/84-16 ad	55606	380	Fort Union	5	9/10/80	
					HR #4	55/84-15 bc	55607	586	Fort Union	5	9/10/80	
KOA Mobile Home Park, N of Sheridan	5600242	I	25	2,500	UNK	UNK	UNK	UNK	UNK	UNK	UNK	EPA data base lists 2 wells.
Soldier Creek Water Co., N of Sheridan	5600244	A	400	22,000	Purchase	--	--	--	--	--	--	Purchased from City of Sheridan.

Table A-3. (continued)

Facility Name and Location	EPA PWS ID #	Owner Type[b]	Population Served	Average Production (gal/day)	Water Source	Source Location	SEO Permit #	Total Depth (ft)	Aquifer	Reported Yield (gpm)	Completion Date	Supplementary Information
SHERIDAN COUNTY (continued)												
Sun Village, 2 mi SE of Sheridan	5600250	I	40	2,000	Ohm #1	55/84-2 ca	33472	649	Wasatch/Fort Union System	15	10/8/77	Flowing well.
Trailer Village, S of Sheridan	5600429	I	25	1,250	UNK	UNK	UNK	UNK	UNK	UNK	UNK	EPA data base lists 1 well.
Villa Capri Trailer Court, Sheridan	5600376	I	32	2,400	UNK	UNK	UNK	UNK	UNK	UNK	UNK	EPA data base lists 1 well.
Woodland Park Village, 5 mi S of Sheridan	5600243	I	300	15,000	TML #4?	55/84-23 bb	27233	(450)	(Fort Union?)	(35)	--	Permits pending completion as of 6/81.
					TML #5?	55/84-23 bb	27234	(450)	(Fort Union?)	(35)	--	
					TML #6?	55/84-23 bb	27235	(450)	(Fort Union?)	(35)	--	
					TML #7?	55/84-23 bc	27236	(450)	(Fort Union?)	(35)	--	
WESTON COUNTY												
Black Hills Power & Light, Osage	5600038	I	350	32,000	Osage Town	46/63-9 db	149G	670	Lakota	30	8/1/48	Madison wells are flowing wells. Osage #2 well is principal community water source. Wells also supply cooling water for electrical generation plant at Osage. Permits 4698, 50143, and 50144 pending completion as of 6/81.
					Osage #1	46/63-10 dc	426C	2,592	Madison	530	-/-/42	
					Enl. #1	46/63-10 dc	50132	2,592	Madison	0	N.A.	
					Osage #2	46/63-15 bd	143G	2,991	Madison	500	1/10/51	
					Enl. #2	46/63-15 bd	50133	2,991	Madison	0	N.A.	
					Osage #3	46/63-10 cd	46982	(3,200)	(Madison)	(2,500)	--	
					Osage #4	46/63-15 ad	50143	(3,200)	(Madison)	(2,500)	--	
					Osage #5	46/63-10 da	50144	(3,000)	(Madison)	(2,500)	--	
Salt Creek Water District, E of Newcastle	5600133	A	300	36,000	Purchase	--	--	--	--	--	--	Purchased from Water Unlimited Inc. of Newcastle.
Water Unlimited Inc., E of Newcastle	5600132	I	120	13,200	Carlson #1	45/61-28 ab	607	2,738	Madison	1,200	4/1/62	Flowing well.

[a] Data from U.S. Environmental Protection Agency (EPA), 1979, Public Water Supply Inventory, and Wyoming State Engineer's Office (SEO) Files. Parentheses indicate data were obtained from well permit not well completion statement.

[b] Owner types: A = association
C = corporation
D = individual

Table A-4. Ground water used for secondary and tertiary recovery of oil in the Powder River basin, 1979, by field.[a] Inactive units are not tabulated.

Field	County[b]	Unit	Injected Formation	No. Injectors Active	No. Injectors (Inactive)	Injected Water (1979, bbl)	- Produced water (1979, bbl)	= Calculated Makeup[c] Water (bbl)	Makeup Water Source	Remarks
Ash Creek	SH	Shannon	Shannon	8	(8)	641291	224139	417152	Parkman?	Part of field is in Montana and may not be included in produced water volume.
Barber Creek	CA	Parkman	Parkman	7	(2)	526113	347176	178937	Ft. Union	
Basin, NW	CA	Piney Ranch Minnelusa	Minnelusa	1	(2)	15972	15972	0	Ft. Union	Uses Minnelusa produced water only.
Big Muddy	CO	Wall Creek	Wall Creek	6	(34)	390177			Sundance, Lakota	Also uses Dakota produced water.
		Dakota	Dakota	19	(12)	1698533			Sundance, Lakota	Also uses Wall Creek produced water.
		South Block Wall Creek	Wall Creek	4	(1)	729900			Tensleep, Madison	
		South Block Dakota	Dakota	1	(2)	78094			Dakota	May use only Dakota produced water.
		East	Dakota	2	(10)	310902			Alluvium	
		TOTAL		32	(59)	3207606	3231329	0		
Bishop Ranch, S	CA	Bishop Ranch South	Minnelusa	1	(0)	495202	29514	465688	Minnelusa	Uses Minnelusa produced water only according to Oil & Gas Commission files.
Brooks Ranch	NA	Brooks Ranch	Frontier	1	(0)	17714	17714	0	--	Uses Frontier produced water only.
Burke Ranch	NA	Dakota	Dakota	4	(5)	495690	489480	6210	Parkman	
C-H	CA	Minnelusa	Minnelusa	4	(1)	1920213	1248906	671307	Fox Hills	
Chan	CA	Muddy	Muddy	4	(2)	844270	115735	728535	Fox Hills	
Cole Creek	NA	Dakota "A"	Dakota	4	(1)	1342870	1904501	0	Parkman	
Cole Creek, S	CO	Cole Creek lease	Dakota	5	(18)	238112	--	--	--	Uses Cole Creek South produced water only.
			Shannon	?	--	59712			--	Uses Cole Creek South produced water only.
			Lakota	?	--	460746			--	Uses Cole Creek South produced water only.
			TOTAL	9	(18)	758570	941642	0		
Coyote Creek	CR	Watt "A"	Dakota	3	(0)	469702			Fox Hills	
		Watt "B"	Dakota	3	(0)	1470469			Fox Hills	
		TOTAL		6	(0)	1940171	744129	1196042		
Coyote Creek, S	WE	Boxelder Draw	Turner	3	(0)	129883	413325	0	Lance	
Dead Horse Creek	CA	Caballo	Ferguson	4	(2)	46800			Ft. Union	
		North Block	Parkman	8	(3)	360162			Ft. Union	
		TOTAL		12	(5)	406962	65060	341902		

Table A-4. (continued)

Field	County[b]	Unit	Injected Formation	No. Injectors Active	No. Injectors (Inactive)	Injected Water (1979, bbl) -	Produced Water (1979, bbl) =	Calculated Makeup[c] Water (bbl)	Makeup Water Source	Remarks
Dead Horse Creek, S	CA	Hippus #1A	Parkman	1	(0)	45227	9490	35737	Unknown	
Deadman Creek	CR	Deadman Creek	Minnelusa	1	(0)	86155	23803	62352	Fox Hills	May not use any produced water.
Dewey Dome	WE	Dewey Bradley	Sundance	2	(0)	0?	219	0?	Dakota, Lakota	Injection wells ordered shut-in in 1974.
Dillinger Ranch	CA	Minnelusa	Minnelusa	8	(3)	1290159+	1134921	155238+	Fox Hills	No injection data 1 month.
Donkey Creek	CR	Dakota "A"	Dakota	4	(0)	882855	640753	242102	Minnelusa	Uses Minnelusa produced water from nearby field.
Dugout Creek	JO	Shannon	Shannon	10	(16)	613453	827237	0	Madison	Part of Sussex Field.
Duvall Ranch	CA	Minnelusa	Minnelusa	11	(0)	3760419	374194	3386225	Fox Hills	
Fiddler Creek	WE	East Fiddler Creek	Newcastle	10	(40)	2216616			Madison	
		West Fiddler Creek	Newcastle	10	(64)	1091030			Madison	
		TOTAL		20	(104)	3307646	2576749	730897		
Gas Draw	CA	Gas Draw	Muddy	15	(1)	7547841			Fox Hills, Lance	
		Rogers Muddy Sand	Muddy	3	(0)	1969500			Fox Hills, Lance	
		TOTAL		18	(1)	9517341	9633266	0		
Glenrock, S	CO	Block A	Dakota	7	(2)	1025799			Alluvium	
			Upper Muddy	1	(3)	20273			Alluvium	
		Block B	Dakota	26	(10)	4703171			Madison, Tensleep	
			Lower Muddy	13	(16)	1192694			Madison, Tensleep	
			Upper Muddy	19	(16)	2163067			Madison, Tensleep	
		TOTAL		66	(47)	9105004	8282155	822849		
Grieve	NA	Muddy	Muddy	1	(2)	627064	627285	0	Unknown	May merely be salt water disposal.
Guthery	CR	Minnelusa	Minnelusa	2	(0)	174922	151932	22990	Fox Hills	
Halverson Ranch	CA	Minnelusa	Minnelusa	11	(4)	3055427	1880253	1175174	Fox Hills	
Hamm	CA	Minnelusa	Minnelusa	2?	(0)	992728	628852	363876	Fox Hills	*Temporarily shut-in, June, 1979,* now Tertiary recovery: water/polymer.
Hilight	CA	Grady	Muddy	4	(5)	844761			--	Uses Muddy produced water only.
		Central	Muddy	32	(14)	22340470			Fox Hills	
		Jayson	Muddy	10	(5)	970438			Fox Hills	
		TOTAL		46	(24)	24155669	21880446	2275223		
Hunter Ranch	CA	Hunter Ranch	Muddy	3	(0)	247233	58420	188813	Fox Hills	
Keyhole	CR	16 State	Muddy	1	(1)	1570	404	1166	Lakota	

Table A-4. (continued)

Field	County[b]	Unit	Injected Formation	No. Injectors Active	No. Injectors (Inactive)	Injected Water (1979, bbl)	Produced Water (1979, bbl)	Calculated Makeup[c] Water (bbl)	Makeup Water Source	Remarks
Kuehne Ranch	CA	Kuehne Ranch	Minnelusa	1	(1)	217832	135485	82347	Fox Hills	Water source may be Lakota.
Kummerfeld	CR	Minnelusa	Minnelusa	5	(0)	1000913	1328661	0	Fox Hills	
Lance Creek	NI	Morrison	Morrison	1	(1)	27595 ?	22228869	0	Leo Sand	Uses Leo (Minnelusa) produced water only; may be no injection.
Lazy B	CA	Muddy	Muddy	5	(0)	779716	629747	149969	Fox Hills, Lance	
Lightning Creek	NI	Newcastle	Newcastle	1	(0)	35378	194666	0	White River, Surface	
Little Mitchell Creek	CA	Minnelusa	Minnelusa	1	(0)	363685	101232	262453	Fox Hills	
Meadow Creek	JO	Lakota	Lakota "A"	4	(5)	299435			Madison	
		Shannon A	Shannon	17	(8)	885120			Madison	
		Tensleep A	Tensleep	4	(2)	1784894			Madison	
		A2 Frontier	2nd Frontier	5	(0)	348163			Madison	
		TOTAL		30	(15)	3317612	3822409	0		
Mellott Ranch	CR	Minnelusa	Minnelusa	2	(1)	840679	632102	208577	Fox Hills	
Moorcroft, W	CR	Newcastle	Muddy	7	(4)	969211			Dakota	Uses Dakota produced water from nearby field.
		Waters	Newcastle	6	(3)	79604			Dakota	Tertiary recovery: water/polymer and soda ash.
		TOTAL		13	(7)	1048815	1042969	5846		
Mule Creek	NI	Argo Lease	Lakota	2	(0)	414604	480136	0	--	
Mush Creek	WE	Michael #4	Newcastle	1	(0)	4363			Dakota, Lakota	
		Rogers	Newcastle	1	(2)	30107			Dakota, Lakota	
		State	Newcastle	1	(4)	15172			Dakota, Lakota	
		Thorson	Newcastle	1	(1)	181			Dakota, Lakota	
		Updike	Newcastle	1	(7)	1990			Dakota, Lakota	
		Wade	Newcastle	6	(2)	174870			Dakota	
		TOTAL		11	(16)	222383	14989	207394		
Mush Creek, W	WE	West Mush Creek Extension	Newcastle	3	(2)	6490	4817	1673	Madison?	
OK	CA	OK	Minnelusa	1	(0)	453067	85603	366464	Fox Hills	Tertiary recovery: water polymer
Osage	WE	Juniper Newcastle	Newcastle	42	(0)	875074			Madison	
		Osage Miscellaneous	Newcastle	34	(0)	400290			Madison, Dakota, Lakota	
		Osage Juniper Area	Newcastle	8	(0)	184435			Madison	
		Osage West	Newcastle	14	(4)	765839			Madison	

Table A-4. (continued)

Field	County[b]	Unit	Injected Formation	No. Injectors Active	No. Injectors (Inactive)	Injected Water (1979, bbl)	- Produced Water (1979, bbl)	= Calculated Makeup[c] Water (bbl)	Makeup Water Source	Remarks
Osage (continued)		Buffalo 028328A Lease	Newcastle	10	(3)	152358+			Madison	Only 5 mos. data available.
		Bradley Newcastle	Newcastle	25	(0)	516810			Madison	
		Somers Area	Newcastle	20	(0)	309945			Madison	
		Coronado Shallow Lense	Newcastle	68	(10?)	1135863			Madison	
		Osage	Newcastle	10	(0)	?			Madison	
		State Waterflood	Newcastle	19	(6)	911490			Madison	
		Osage	Newcastle	16	(3)	276173			Madison	
		Murray Lease	Newcastle	2	(0)	16131			Dakota	Injection started 8/79.
		TOTAL		268	(26?)	5544408+	3827556	1716852+		
Pickrell Ranch	CA	Minnelusa	Minnelusa	1	(2)	50830	54715	0	Fox Hills	
Pleasant Valley	CA	Heptner	Minnelusa	2	(0)	156889	33997	122892	Alluvium	
Poison Draw	CO	Poison Draw	Tekla	1	(0)	0	--	0	Lance, Lewis	
Poison Spider	NA	Bessemer Ch 03787	Sundance	1	(0)	145098	382572	0	--	Uses Sundance produced water only.
Raven Creek	CA	Minnelusa	Minnelusa	15	(4)	5322959	4929200	393759	Fox Hills	
Recluse, N	CA	Muddy	Muddy	6	(22)	770979	680193	90786	Fox Hills, Lance	
Reel	CA	Minnelusa	Minnelusa	4	(1)	1590696	755060	835636	Fox Hills	
Reno	JO	Minnelusa	Minnelusa	3	(1)	1267206	191971	1075235	Fox Hills	May also use Minnelusa produced water from Reno East field.
Robinson Ranch	CR	Minnelusa	Minnelusa	6	(1)	1848841	2448863	0	--	Uses Minnelusa produced water only.
Rourke Gap	CA	Minnelusa Rourke Sand	Minnelusa	2	(0)	1051445	187828	863617	Fox Hills	
Rozet	CA	Muddy	Muddy	25	(8)	3060861	2681341	379520	Fox Hills	
Rozet, E	CA	Minnelusa "A"	Minnelusa	1	(0)	228734			Fox Hills	
		East Rozet Muddy Sand	Muddy	2	(0)	111075			Fox Hills	
		TOTAL		3	(0)	339809	83828	255981		
Rozet, S	CA	Minnelusa "A"	Minnelusa	1	(0)	400773			--	Uses Minnelusa produced water only.
		Mitchell State	Minnelusa	1	(0)	428505			Fox Hills	
		TOTAL		2	(0)	829238	789966	39272		
Rozet, W	CA	Minnelusa	Minnelusa	4	(0)	3766292	1846370	1919922	Fox Hills	

Table A-4. (continued)

Field	County[b]	Unit	Injected Formation	No. Injectors Active	No. Injectors (Inactive)	Injected Water (1979, bbl)	- Produced Water (1979, bbl)	= Calculated Makeup[c] Water (bbl)	Makeup Water Source	Remarks
Sage Spring Creek	NA	Sage Spring Creek Unit A	Dakota	5	(0)	1019781	589696	430085	Parkman	
Salt Creek	NA	Staley Gov't	2nd Wall Creek	10	(0)	2994985			Madison	
		Light Oil Unit - Lease #1	1st Wall Creek	171	(86)	37615771			Madison	
			2nd Wall Creek	345	(46)	125943112			Madison	
			3rd Wall Creek	3	(6)	48354			Madison	
		Salt Creek	Wall Creek	4	(0)	?			Unknown	Tertiary recovery: water/ micellar.
		Salt Creek South	2nd Wall Creek	109	(48)	26473746			Madison	
		TOTAL		642	(186)	193075968	250346003	0		
Salt Creek, E	NA	2nd Wall Creek	2nd Wall Creek	3	(2)	989785			Tensleep	
		Tensleep	Tensleep	1	(0)	330317			--	Uses Tensleep produced water only.
		TOTAL		4	(2)	1320102	1218465	101637		
Semlek, W	CR	Minnelusa	Minnelusa	1	(0)	479580	566466	0	--	Uses Minnelusa produced water only.
Sharp	CA	Minnelusa	Minnelusa	(2)	(0)	259405	32258	227147	Fox Hills	
Shostak	WE	Shostak	Muddy	1	(0)	Unknown	Unknown	Unknown	Unknown	
Simpson Ranch	CA	Simpson Ranch	Minnelusa	1	(0)	122871 ?	377	122494 ?	Fox Hills	May be no injection.
Skull Creek	WE	Newcastle	Newcastle	10	(1)	1288035			Lakota	
		Newcastle	Newcastle	10	(2)	722053			Dakota	
		Bock	Newcastle	3	(2)	148613			Lakota, Dakota	
		Donielson	Newcastle	6	(1)	423409			Fox Hills	Purchased water.
		Skull Creek South	Newcastle	3	(2)	491241			Lakota	
		TOTAL		32	(8)	3073351	1740819	1332532		
Skull Creek, N	WE	Skull Creek North	Newcastle	8	(1)	336731	308859	27872	Lakota	
Springen Ranch	CA	Muddy	Muddy	10	(11)	1669290	1475536	193754	Fox Hills, Lance	
Stewart	CA	Minnelusa	Minnelusa	11	(2)	3244230	1314296	1929934	Fox Hills	
Sussex	JO	Lakota "A"	Lakota	1	(1)	38865			Madison	
		Shannon "C"-"E"	Shannon	1	(17)	138179			Madison	
		Sussex "C"	Sussex	7	(7)	464862			Madison	
		Sussex "D"	Sussex	1	(7)	135374			Madison	
		Tensleep "A"	Tensleep	5	(2)	350251			Madison	

Table A-4. (continued)

Field	County[b]	Unit	Injected Formation	No. Injectors Active	No. Injectors (Inactive)	Injected Water (1979, bbl)	- Produced Water (1979, bbl)	= Calculated Makeup[c] Water (bbl)	Makeup Water Source	Remarks
Sussex (continued)		Tensleep "B"	Tensleep	11	(1)	7151688			Madison	
		Shannon "D"	Shannon	1	(6)	140900			Madison	
		TOTAL		27	(41)	8420119	4650459	3769660		Makeup water used may be 213784 bbl less if surplus from Dugout Creek Unit is utilized.
Sussex, W	JO	West Sussex	Shannon	17	(19)	1568505	1923487	0	Madison	
Teapot	NA	Teapot Dome	2nd Wall Creek	10	(0)	739713	2515930	0	Madison	
Tholson	CA	Minnelusa "A"	Minnelusa	2	(0)	485652	162707	322945	Fox Hills	
Tisdale, N	JO	North Tisdale	Curtis Ss.	6	(5)	780497	1475536	0	Unknown	Tertiary recovery: water/thermal
Tomcat Creek	CR	Fall River	Fall River	4	(0)	129882	70303	59579	Lakota	
Ute	CA	Muddy	Muddy	13	(0)	2291718			Fox Hills	
		Olmstead	Muddy	4	(0)	369534			Fox Hills	
		TOTAL		17	(0)	2661252	513104	2148148		
Wagonspoke	CA	Minnelusa	Minnelusa	1	(0)	621024	0	621024	Fox Hills	
Wallace	CA	Minnelusa	Minnelusa	9	(0)	2495907	485091	2013816	Fox Hills	
Whitetail	CA	Whitetail Muddy	Muddy	9	(0)	2933594			Fox Hills	
		South Whitetail	Muddy	3	(0)	0			Fox Hills	Injection not initiated until 5/80.
		TOTAL		12	(0)	2933594	2689313	244281		

[a]Data from files of the Wyoming Oil and Gas Conservation Commission and Wyoming Oil and Gas Conservation Commission (1980b).

[b]County abbreviations:

CA - Campbell County
CO - Converse County
CR - Crook County
JO - Johnson County
NA - Natrona County
NI - Niobrara County
SH - Sheridan County
WE - Weston County

[c]Amount of makeup water calculated by subtracting reported amount of produced water from reported amount of injected water. At several fields, notably Salt Creek, Meadow Creek, and Sussex, the amount injected may be mostly fresh water, with much of the produced water discharged as waste.

Table A-5. Water use by petroleum refineries in the Powder River basin.[a]

Company	Location	Rated Production Capacity (bbls/day)	Water Consumption	Water Source	Discharge
Amoco Oil Co.	Casper	43,000	2,000 gpm	N. Platte River	1,400-1,500 gpm to Soda Lake
Texaco Oil Co.	Casper	21,000	3,082 gpm	N. Platte River	Unknown
Little America Refining Co.	Casper	24,500	347 gpm	N. Platte River	Unknown
C & H Refining	Lusk	250	Unknown	Arikaree aquifer	Unknown
Wyoming Refining Co.	Newcastle	10,500	40 gpm	Madison aquifer	Pit
Sage Creek Refining Co.	Cowley	Unknown	Negligible amounts	Unknown	Discharge to pit is recirculated

[a]Data from authorized personnel at respective refineries.

Table A-6. Water use by active coal mines within the Powder River basin.[a]

Company	Mine	Location	1979 Production (million tons)[b]	Discharge from Pit and Wells	Surface Water Effluent Discharge Point	Overall Water Use[c]
Amax Coal Co.	Belle Ayr	Portions of T. 48 N., R. 71 W. and T. 47 N., R. 71 W.	14.996	Discharge from coal pit is pumped to NPDES settling ponds where portions that are not used for dust suppression are discharged to surface drainage. 3 wells supply water for dust supression in coal prep plant and shop in addition to domestic use - 28.9 x 10^6 gals. in 1979.	Caballo Creek	DS, DOM, Prep plant, & IRR Avg. 420,000 gal/day for dust suppression.
Amax Coal Co.	Eagle Butte	T. 51 N., R. 72 W.	3.732	349 acre-feet pumped from pit and adjacent "clinker" wells as of May 1, 1979.	Little Rawhide Ck.	DS, DOM, Prep plant
Big Horn Coal Co.	Big Horn	T. 57 N., R. 84 W.	3.523	Average discharge from NPDES settling ponds is 696,115 gal/day (11-1-78)-(10-31-79). Maximum groundwater discharge into pit is 14,400 gal/day.	Goose Creek and Tongue River	Dust control and Prep plant
Carter Mining Co.	Caballo	Portions of T. 48 N., R. 70 W., and T. 48 N., R. 71 W.	1.272	Pit inflows estimated at 100,000-500,000 gal/day. Water from "clinker" wells is used for dust control. Caballo #1 well supplies 120 gpm to office and maintenance facilities.	Tisdale Creek	DS, DOM, Maintenance Most of the water pumped from the pit into NPDES settling ponds is used for dust control
Carter Mining Co.	Rawhide Mine	T. 51 N., R. 72 W.	3.593	Pit discharge rates are not available.	Dry Fork Little Powder River, Rawhide Creek & Red Fox Draw.	DS, DOM, Equipment washdown
Cordero Mining Co.	Cordero Mine	Portions of T. 46 N. R. 71 W., and T. 47 N., R. 71 W.	3.832	Pit discharge rates not available Two deep wells supply potable water	Belle Fourche River via unnamed drainages	DS, DOM, Plant wash down Plant washdown is returned to settling ponds Domestic consumption is est. @ 15,000 gal/day for 3 shifts

Table A-6. (continued)

Company	Mine	Location	1979 Production (million tons)[b]	Discharge from Pit and Wells	Wells	Surface Water Effluent Discharge Point	Overall Water Use[c]
Glenrock Coal Co. (NERCO)	Dave Johnston	Portions of T. 35 N., R. 75 W. and T. 36 N., R. 75 W.	3.828	All pit discharge water is used for dust control.		Bishop, Shelly, and Jeni Draws	DS, DOM, Equipment washdown
Kerr-McGee Coal Corp.	Clovis Point	T. 50 N., R. 70 W.	.293	Estimated pit discharge is 600 gpm. 5 wells permitted to withdraw 600 gpm for dust control.		Unnamed closed basins locations - T. 50 N., R. 70 W., Secs. 22 & 28	DS, DOM
Kerr-McGee Coal Corp.	Jacobs Ranch	T. 43 N., R. 70 W.	4.681	No pit discharge estimate available. Barnds reservoir receives waters pumped from pit #2. Wells JRM #6 and enlarged JRM #2 used for dust suppression fire control and Prep plant washdown.		East and west forks Burning Coal Draw	DS, DOM, IRR
Thunder Basin Coal Co., (ARCo)	Thunder Basin	T. 43 N., R. 70 W.	6.244	Discharge from BT Pit #1 is pumped to NPDES settling pond #004. Substantial quantities of NPDES pond water are used for dust control. 50,000 gal/week is discharged from NPDES Reservoir 004 to N. Prong Little Thunder Creek. Wells BTF 17-1, 17-2, and SWP-3 are used for equipment wash, domestic, and maintenance.		North Prong Little Thunder Creek and two unnamed playas	DS, DOM, Equipment washdown and sewage treatment. Water from NPDES Reservoir 007 is used for dust suppression.
Wyodak Resources	Wyodak	T. 50 N., R. 71 W.	2.364	239.6 gpm discharges from pit into South Pit sediment pond. Water used for dust control is taken from pit before entering pond.		Donkey Creek	DS

[a]Water use data from mining permits and annual reports, Department of Environmental Quality, State of Wyoming, Cheyenne, Wyoming.

[b]Glass, 1980.

[c]
DS - Dust Suppression
DOM - Domestic
IRR - Irrigation
NPDES - National Pollutant Discharge Elimination System

Table A-7. Existing and proposed coal-fired steam-generated electric power plants within the Wyoming portion of the Powder River basin.

Plant Name	Operator	Location	Nameplate Generating Capacity (megawatts)	Cooling System	Water Used For Power Generation (AF/YR)	Water Source	Supplemental Source and Domestic Supply	AF Water Needed to produce Megawatt
			EXISTING PLANTS					
Dave Johnston	Pacific Power and Light[a]	5 miles east of Glenrock	750 MW	Wet	9600 AF	N. Platte River	Ground water-Domestic supply from N. Platte River	12.8 AF
Neil Simpson	Black Hills Power and Light[b]	WYODAK-6 miles east of Gillette (adjoins WYODAK #1 plant)	21.8 MW	Dry	16.1 AF	1 well-Ft. Union aquifer, estimated yield-10 gal./min.	Additional well within Ft. Union Fm. capable of producing 95 gal./min. is used as domestic supply for Neil Simpson and WYODAK plants, WYODAK mine, WYODAK Village and other services within the area.	.74 AF
Osage	Black Hills Power and Light[c]	Osage	35.5 MW	Wet	806.5 AF	1 well-Madison aquifer, estimated yield-500 gal./min.	Additional well within the Madison Limestone is used to supply domestic needs within the plant and for the town of Osage. Any surplus from this well is used at the plant. Estimated yield-200 gal./min.	22.7 AF
WYODAK #1	Pacific Power and Light-Black Hills Power and Light[d]	WYODAK-6 miles east of Gillette (adjoins Neil Simpson Plant)	330 MW	Dry	324 AF	Sewage effluent from Gillette sewage treatment facility	Domestic water supplied by Neil Simpson Plant	1.0 AF
TOTAL			1137.3		10,746.6 AF			
			PROPOSED PLANTS					
WYODAK #2	Pacific Power and Light-Black Hills Power and Light[d]	WYODAK-6 miles east of Gillette (will adjoin WYODAK #1)	330 MW	Dry	1300-1450 AF	Negotiations are in progress for additional sewage effluent from Gillette. Water from Gillette Madison Project might also be used.	WYODAK #2 water requirements for electricity production will be the same as for WYODAK #1. Additional water will be used for SO_2 emission control.	3.9-4.4 AF

[a]Personal Communication with Herb Roose, Electrical Engineer, Dave Johnston Plant, Pacific Power and Light Co., Glenrock, Wyoming, April 15, 1980.

[b]Personal Communication with Vern Schild, Plant Superintendent, Neil Simpson Plant, Black Hills Power and Light Co., WYODAK, Wyoming, April 15, 1980.

[c]Personal Communication with David Eatherton, Osage Plant, Black Hills Power and Light Co., Osage, Wyoming, April 15, 1980.

[d]Personal Communication with authorized personnel, Pacific Power and Light Co., WYODAK, Wyoming, April 15, 1980.

Table A-8. Water use by active commercial uranium mines and mills, Powder River basin.[a]

Company	Mine	Location	1979 Production[b]	Water Production	Overall Water Use
Exxon Minerals Co.	Buffalo Shaft Underground Mine	T. 36 N., R. 72 W.	131,000 tons of ore	300-500 gpm from 16 dewatering wells around underground mine.	4 wells supply domestic and utility water to whole Exxon operation Surface water runoff and ground water produced are routed to the mill or used for dust control.
	Highland Operations Surface Mine			400-800 gpm, produced from pit sumps (includes surface water runoff).	
	Mill				Excess water is released into North Fork Box Creek via unnamed drainages according to NPDES standards. 2000 tons/day of solid waste (40% solids by volume) into tailings pond. Solid wastes consist of barren sand grains and spent process solutions (primarily sulfuric acid).
	Solution Mine		1,154,000 tons of ore	80,000 barrels of ground water have been produced from solution mining pilot leach area.	
Kerr McGee Nuclear Corp.	28-33 Pit 3-10 Pit	T. 37 N., R. 73 W.	245,165 tons of ore	Average discharge from two pits is 150 gpm. One domestic well produces 5 gpm.	Most of the water produced is used for dust control.
Rocky Mountain Energy Co.	Bear Creek Open Pit Mine and Mill	T. 38 N., R. 73 W.	420,000 tons of ore	Pit B-3: variable discharge of 400-1200 gpm; Dilts Pit: 450-550 gpm; B-1 Pit: 70-90 gpm.	Shop well produces 18 gpm for domestic and equipment water supplies. Dust control water is taken from pit discharge. 2 wells (300 gpm) supply office domestic and mill process water. Mill process water is used in closed circuit. Excess surface water is discharged via NPDES settling ponds to Dry Fork Cheyenne River and Gene Draw.
Wyoming Minerals Corp.	Irrigary In-situ Mine	T. 45 N., R. 77 W.	None	Net production is 10-12 gpm which is discharged to lined evaporation ponds. 800 gpm is the maximum amount permitted for recovery. Recovery minus net discharge is injected.	Two wells currently supply sanitary, potable, equipment wash, and fire protection water. Application for NPDES surface water discharge permit is pending approval by Wyoming State DEQ.

[a]Data from mining permits and annual reports, Department of Environmental Quality, State of Wyoming, Cheyenne, Wyoming.

[b]1979 production figures from John T. Goodier, Department of Economic Planning and Development, State of Wyoming, 1980, personal communication.

APPENDIX B

STRATIGRAPHIC VARIATIONS OF WATER-BEARING BEDROCK UNITS IN THE POWDER RIVER BASIN

STRATIGRAPHIC VARIATIONS OF WATER-BEARING BEDROCK UNITS IN THE POWDER RIVER BASIN

Madison Aquifer System

Cambrian

Basal Cambrian sandstones are potentially important aquifers (Hodson and others, 1973), but are not extensively utilized currently due to depth of burial.

The Deadwood Formation, of Upper Cambrian and Lower Ordovician age, lies unconformably on Precambrian rocks of the eastern basin study area. It is composed of a basal conglomeratic sandstone, a middle unit of thin interbedded shales and dolomites, and an upper massive sandstone, often dolomitic or ferruginous (McCoy, 1958a). Sandstone porosities of almost 20 percent are present in northern Crook County (Blankennagel and others, 1977).

In the western Powder River basin Cambrian deposition started earlier and three distinct formations are recognized (McCoy, 1958a). The basal Cambrian Flathead Sandstone is similar to the Deadwood. Overlying the Flathead, and isolating it hydrologically where present (Huntoon, 1976), are the Gros Ventre Formation, a grey green shale with interbedded sandstone lenses and flat pebble limestone conglomerates, and the Gallatin Formation, a grey limestone containing limey shales and flat pebble limestone conglomerates (Cygan and Koucky, 1963).

Cambrian strata, over 1,100 feet thick in western Sheridan County, thin to the south and east, and are probably absent in the southeastern Powder River basin (McCoy, 1958a).

Ordovician

Where present, Ordovician carbonates have good water-bearing potential but they have not been extensively developed in the basin because they underlie the Madison aquifer, which produces adequate yields.

Found only in the northern part of the basin (McCoy, 1958b; Huntoon, 1976), Ordovician strata consist of an upper carbonate unit and lower clastic sequence (Jenkins and McCoy, 1958). In the Black Hills the upper unit, the Whitewood Dolomite, is a massively bedded dolomite, equivalent in part to the Red River Formation in Montana (McCoy, 1958b). The lower sequence includes, from top to bottom, the Roughlock Siltstone, Ice Box Shale, and Aladdin Sandstone, and is roughly equivalent to the Winnipeg Formation of Montana (McCoy, 1958b). In the Bighorn Mountains the carbonate unit, the Bighorn Dolomite, is a massive dolomite, more thinly bedded at the top (Lowry and Cummings, 1966). The lower thin clastic unit is either considered as a basal sandstone member of the Bighorn (Lowry and Cummings, 1966) or separately named (Cygan and Koucky, 1963). Aggregate thickness of Ordovician strata ranges from over 400 feet, at the Montana state boundary, to zero, at the Crook-Weston County boundary in the east (Jenkins and McCoy, 1958) and in southern Johnson County in the west (Huntoon, 1976).

Porosities over 20 percent have been recorded for both the Red River and Winnipeg in northern Crook County (Blankennagel and others, 1977). Some secondary fracture porosity due to structural deformation of the more brittle carbonate units may exist but the present data base is inadequate for quantification. An active modern karst is forming in the Bighorn Dolomite but has not yet become extensively developed (Huntoon, 1976), and therefore is not an important source of porosity.

Devonian and Mississippian

The upper part of the Mississippian Madison Limestone is the most productive part of the Madison aquifer system, primarily due to localized zones of secondary porosity and permeability.

The Madison Limestone, a regional term for extensive Mississippian carbonate beds in northeastern Wyoming, is generally used interchangeably with the Pahasapa Limestone of the Black Hills and the Guernsey Formation of the Hartville uplift (Andrichuk, 1955). In the eastern basin the conformably underlying Englewood Formation, equivalent to the Devonian lower Guernsey, has been included in some discussions of the Madison (Andrichuk, 1955). Devonian rocks of the northern Bighorn Mountains include the basal Madison and underlying Jefferson Formation (Sandberg and Klapper, 1967).

The Madison is typically a light colored, massive, medium- to fine-grained limestone or dolomitic limestone (Andrichuk, 1955). In the Black Hills the underlying Englewood Formation is moderately thin-bedded alternating shales and shaley limestones or dolomites. The underlying Jefferson Formation, only present in the northwestern corner of the Powder River basin, is predominantly dolomite, with interbedded argillaceous dolomites and sands (Sandberg, 1963). Also present only in the northwestern basin is a basal dark dolomitic shale member of the Madison (Sandberg and Klapper, 1967). In the southeast part of the basin the basal Madison is an Early Mississippian arkosic sandstone (Maughn, 1963), previously considered the Deadwood Formation (Condra and Reed, 1950).

Almost 1,000 feet thick at the Montana-Wyoming state boundary, the Madison thins southward and is only about 200 feet thick in southern Niobrara County (Swenson and others, 1976), due to nondeposition of younger Madison units (Andrichuk, 1955). Extensive pre-Minnelusa erosion, which may also contribute to the southward thinning, has resulted in an upper Madison surface of considerable local relief (Swenson and others, 1976). Subjacent units become progressively younger to the north, ranging from Precambrian to Ordovician in age, and reflect erosional trunction of pre-Devonian rocks. The isolated Devonian occurrences reflect similar, pre-Madison, erosion.

Porosity in the Madison is intercrystalline, intergranular or interparticulate, and vuggy, modified by secondary fracturing and solution (Andrichuk, 1955). Head and Merkel (1977) calculated Madison porosity from geophysical logs--it averaged 5.5 percent, ranging from 2.3 to 13 percent, and was considered by them to be too low for economic water well development in the absence of secondary porosity. Lithologic variation results in stratigraphic porosity zonation (Woodward-Clyde, 1980).

Geographically localized secondary fracture porosity is derived from both Mississippian and Laramide deformation. Paleostructural maps show a system of extensional and pure-shear fracture zones which resulted from tectonic deformation during Madison deposition (Cushing, 1977). The U.S. Geological Survey test well program found fractures associated with these zones but they were generally healed below 6,000 feet (Brown and others, 1977). Laramide deformation has also resulted in zones of fracturing and secondary porosity in the Madison (Huntoon, 1976).

On the west side of the basin the upper 350 feet of the Madison contains an extensive Mississippian paleokarst characterized by enlarged joints, sinkholes, caves, and solution zones (Sando, 1974). Many of these paleokarst features have been infilled by silty Pennsylvanian sediment (Sando, 1974) and have little modern hydrologic significance according to Huntoon (1976).

Secondary porosity due to solution is also reported on the east side of the basin. Huntoon and Womack (1975) report an active karst is presently developing in and near outcrop areas. Swenson and others (1976) report locally occurring paleokarst collapse breccias, involving overlying strata, east of Newcastle. Some water wells drilled in the Black Hills region have encountered cavernous zones in the Upper Madison (Whitcomb and Gordon, 1964; Whitcomb and others, 1958), which are either unfilled paleokarst or modern solution features and yield most of the well production.

Permo-Pennsylvanian

Permo-Pennsylvanian rocks of the Powder River basin provide adequate yields to wells but may contain water of poor quality. The Permo-Pennsylvanian Minnelusa Formation of the Black Hills and eastern Powder River basin is correlated with the Hartville Formation to the southeast, and the Casper Formation to the south (Foster, 1958). Several units of the formation important to oil production have been informally named, such as the "red shale marker" at the base of the Permian (Foster, 1958). In the western Powder River basin the Tensleep

Sandstone and Amsden Formation are time-stratigraphic equivalents to the middle and lower Minnelusa, respectively (Foster, 1958). Minnelusa Formation nomenclature is often used in the entire basin (Foster, 1958; Tranter and Petter, 1963).

Foster (1958) divided the Minnelusa into three members, separated by regional unconformities. Locally and regionally changing lithologies result in variable aquifer characteristics, and interbedded shales in all three members partially isolate sandstone units. Primary porosity may be over 20 percent in sandstone with little shale content (Head and Merkel, 1977) but is generally less (Table IV-5).

The Permian upper Minnelusa is typically thick red and yellow sandstones, anhydrite, thin limestones and dolomites, and minor red mudstones (Bowles and Braddock, 1963). The sandstones, informally called the "Converse sands," are more prevalent in the west and north parts of the basin (Foster, 1958). Head and Merkel (1977) report calculated primary porosity is lower near the basin axis, due to both lower sand percentages and compaction. Anhydrite and other evaporite deposits are most prevalent in the southeast, but also occur in the subsurface in the northeast. Secondary porosity, well developed in the eastern upper Minnelusa near outcrops, results from brecciation due to collapse after anhydrite dissolution (Bowles and Braddock, 1963).

The middle Minnelusa, Middle and Upper Pennsylvanian in age, is cherty yellow dolomitic limestones and yellow sandstones, the "Leo sands," with thin persistent black shales (Bowles and Braddock, 1963; Foster, 1958). Carbonate percentage increases to the southeast. Sandstone content increases to the southwest and west (Foster, 1958), and the unit is termed the Tensleep Sandstone in the Bighorn Mountains. Although the Tensleep Sandstone is a productive aquifer, the middle Minnelusa is an aquitard in the eastern part of the basin (Eisen and others, 1981).

The Lower Pennsylvanian basal Minnelusa has, in the east, an upper interbedded shale and cherty carbonate unit, a middle cherty limestone unit, and a basal sandstone, the "Bell" (Foster, 1958). The sandstone, water-bearing and hydrologically connected to the Madison, is not always present; its erratic distribution is controlled by the underlying Madison Limestone topography (Foster, 1958). In the western basin the Amsden Formation has an upper massive cherty carbonate, a middle red shale and siltstone, and a similar basal quartz sand, the Darwin (Mallory, 1967). Where it is unfractured the Amsden hydrologically isolates the Tensleep and Madison (Huntoon, 1976).

Thickness of the Minnelusa Formation and its equivalents varies from over 1,400 feet in southeastern Niobrara County (Bates, 1955) to about 200 feet in northern Sheridan County (Lowry and Cummings, 1966), due to both nondeposition and regional erosional truncation (Foster, 1958). Measured surface sections in the Black Hills may be 250 feet thinner than nearby subsurface sections due to anhydrite dissolution in outcrop areas (Bowles and Braddock, 1963).

Permo-Triassic Aquifers

Minnekahta Limestone

The Permian Minnekahta Limestone was deposited over much of the Powder River basin but is considered a potential aquifer only in the northeastern part of the basin. It is underlain by the Opeche Shale and overlain by the Glendo Shale. In the southwestern part of the basin it is often considered a member of the Goose Egg Formation.

The Minnekahata is a thin-bedded limestone in Crook County (Whitcomb and Morris, 1964). In other parts of the basin it may be dolomitic or anhydritic (Privrasky and others, 1958). Thickness varies from 10 feet in the southwestern part of the basin to over 50 feet in the Black Hills. The limestone is absent in Sheridan County (Privrasky and others, 1958).

Chugwater Formation

The water-bearing Triassic Chugwater Formation of the southern and western parts of the basin is in part stratigraphically equivalent to the upper part of the Spearfish Formation in the Black Hills. In most of the basin the formation consists of 600 to 700 feet of "redbeds" which are predominantly siltstone, with claystones and sandstones (Crist and Lowry, 1972; Whitcomb and Morris, 1964). In the Black Hills area the lower part of the formation incorporates massive gypsum beds (Whitcomb and Morris, 1964). In Natrona County the Alcova limestone and Crow Mountain Sandstone members overlie the "redbed" sequence (Crist and Lowry, 1972) but in the Black Hills equivalent units are absent (Privrasky and others, 1958). The Alcova is a 10 to 20 foot thick limestone; the Crow Mountain is a red or orange fine-grained calcerous sandstone, often silty, which is about 100 feet thick (Privrasky and others, 1958). Porosity of the Crow Mountain is 25 percent at the Tisdale anticline (Wyoming Geological Association, 1958).

Sundance Aquifer

Sundance Formation

The Jurassic Sundance Formation is present throughout the Powder River basin and is locally important as a water source in Crook County. It unconformably overlies either the Jurassic Gypsum Springs Formation, where this formation is present in the northern part of the basin, or the Triassic Chugwater (Spearfish) Formation. Contact with the overlying Morrison Formation is generally conformable and often gradational.

Typically, the Sundance is divided into the nonglauconitic, often red and sandy "lower Sundance" and the glauconitic, shaley "upper Sundance" (Love, 1958), which represent different southward marine transgressions (Peterson, 1958). Imlay (1947) recognized five members in the Black Hills; in ascending order they are the Canyon Springs Sandstone, Stockade Beaver Shale, Hulett Sandstone, LAK, and Redwater Shale members. The first four of Imlay's members are equivalent to the "lower Sundance" and the Redwater Shale is the "upper Sundance" (Peterson, 1958). Contacts between members of the "lower Sundance" are gradational (Robinson and others, 1964; Peterson, 1958) while the lower contact of the Redwater ("upper Sundance") is sharp (Love, 1958; Robinson and others, 1964).

The Sundance Formation thickens to the north, ranging from 150 to 400 feet thick in the basin. Thickness of individual members of the formation is variable but in general shales thin where sandstones thicken (Robinson and others, 1964).

The Canyon Springs Sandstone Member ranges up to 40 feet in thickness in Crook County, is discontinuous, and is a very fine-grained calcerous sandstone which can locally be coarse and conglomeratic (Robinson and others, 1964). In the Glendo area Canyon Springs (?) Sandstones range up to about 75 feet thick and are coarse, quartzose, and may be oolitic (Love, 1958).

The Hulett Sandstone Member is the principal water-bearing horizon. It is a fine-grained, calcerous, thin- to thick-bedded, well-cemented sandstone which averages 70 feet thick, ranging from 55 to 90 feet (Robinson and others, 1964). The sandstone is best developed within the basin in Crook County.

Porosity of Sundance Formation sands ranges from 11 to 30 percent at producing oil fields in the southern basin (Table IV-7).

Dakota Aquifer System

Lakota Formation

The Lakota, the lower member of the Inyan Kara Group, underlies most of the Powder River basin and is exposed or near the surface over large areas on the western flanks of the Black Hills, where it is an important aquifer. In the southern and western basin equivalent strata are included in the basal part of the Cloverly Formation (Waage, 1959). Contact with the underlying Morrison Formation is variable, ranging from conformable gradation to local angular unconformity, and is often arbitrarily placed at the base of the first massive sandstone above Morrison claystones (Waage, 1959).

The Lakota is a varied sequence of continental rocks consisting of overlapping lenticular quartzose channel sandstones and conglomerates, interbedded with siltstones, claystones, and minor limestones and coals (Waage, 1959). The composition changes rapidly, both laterally and vertically, but in general the Lakota fines upward into a sequence of variegated blocky claystones and silty claystones sometimes termed the Fuson Shale (Waage, 1958). The upper boundary of the Lakota is a transgressive disconformity (Waage, 1959).

Lakota thickness is extremely variable, ranging from 50 to 300 feet in Crook County (Whitcomb and Gordon, 1964), and up to 370 feet in the southeastern basin (Hodson and others, 1973). The entire Cloverly Formation is about 150 feet thick in the western basin (Hodson and others, 1973), but in places only the basal 30 feet is sandstone (Whitcomb and others, 1966).

Porosity of the Lakota, determined at a few producing oil fields, is between 15 and 20 percent (Table IV-9).

<u>Fall River Formation</u>

The Fall River Formation is an important shallow water source in the northeastern part of the Powder River basin. It is the upper member of the Inyan Kara Group and is principally marine and marginal marine in depositional environment, in contrast to the continental phase represented by the Lakota (Waage, 1959). In the western basin the formation is less distinctive; the "rusty beds" of the upper Cloverly are equivalent. The Fall River is termed the "Dakota" by the petroleum industry (Runge, 1968).

The Fall River is dominantly fine-grained quartzose and locally micaceous sandstones containing significant ferruginous material (Waage, 1959). Thin-bedded shales and siltstones are interbedded with the individual sandstone bodies. Extensive blanket sandstones and more geographically limited channel and bar sandstones are all present (Dondanville, 1963).

Thickness of the Fall River is fairly uniform, ranging from 110 to 160 feet in the eastern basin (Waage, 1958). At its top the formation grades rather abruptly into the conformably overlying Skull Creek (Thermopolis) Shale (Waage, 1959), which is considered a sealing caprock by Harris (1976).

Sandstone porosity in the formation is variable due to the wide range of depositional environments, but in general, average oil field porosities range from 15 to 20 percent (Table IV-9). Secondary fracture porosity is locally encountered (Runge, 1968).

Newcastle/Muddy Sandstone

Muddy Sandstone is a common subsurface term used by the petroleum industry in the Powder River basin. It correlates with the Newcastle and Dynneson formations of the Black Hills (Wulf, 1963, 1968). It is a sequence of at least five lenticular fine-grained slightly clay-filled quartzose sandstones which are interbedded with siltstones and shales, lie unconformably between the Skull Creek and Mowry shales, and laterally grade into these units. The Newcastle/Muddy is a westward extension of time-equivalent strata which comprise the Dakota Formation, an important artesian aquifer east of the Black Hills.

Aggregate thickness of sandstones comprising the Muddy is 0 to 140 feet (Stone, 1972). The lenticular nature of the individual sandstones and the presence of intervening shales imply that the individual sandstones could be hydrologically isolated. Limited oil field data (Stone, 1972) and geochemical data (Wulf, 1963) support this hypothesis.

Average sandstone porosities are 18 and 20 percent for the lower and upper Muddy sandstones, respectively (Wulf, 1963). Porosities range from 5 to 27 percent (Table IV-9), reflecting the lithologic variability of the formation.

Isolated Upper Cretaceous Sandstone Aquifers

Frontier Formation

The Frontier Formation is a marine and deltaic clastic unit present in the southwest part of the Powder River basin. It is up to 1,000 feet thick in Natrona County and contains several locally water-bearing sand horizons, known as the Wall Creek Sands, which grade laterally to shales (Haun, 1958). Formations of approximately equivalent age include in the west the lower Cody Shale and in the east the Belle Fourche Shale, Greenhorn Limestone, and Carlile Shale. The Turner Sandy Member of the Carlile Shale is equated with the Wall Creek Sandstone Member at the top of the Frontier (Haun, 1958). The Frontier is overlain by the Cody Shale and underlain by the Mowry Shale.

The Frontier (Wall Creek) sandstones are more prominent near the top of the formation and are usually interbedded with and hydrologically isolated by siltstones and shales. The sandstones are typically thinly bedded and very fine to fine-grained but coarsen upward (Merewether and others, 1976). They are quartzose but also contain feldspars, chert, and rock fragments (Goodell, 1962) and are often calcerous and glauconitic (Merewether and others, 1976). Aggregate sand thickness up to 300 feet is present in Natrona County but decreases to the north and east (Goodell, 1962).

Reported porosities of Frontier Formation oil-producing horizons range from 12 to 26 percent (Table IV-10).

Cody Shale

The Cody Shale is a thick marine shale which is equivalent to the lower part of the Pierre Shale and also the Niobrara and Carlile shales of the eastern part of the basin. In the western part of the basin it lies conformably between and interfingers with the Frontier Formation, below it, and the Mesaverde Formation, above it. In the western and central part of the basin it includes several shale-isolated potentially water-bearing marine sandstone bodies, among which are, in descending order, the Sussex, Shannon, and Gammon Sands (Crews and others, 1976). The Shannon Sands are contemporaneous with the Groat sandstone bed of the Gammon Ferruginous Member of the Pierre Shale in Crook County (Robinson and others, 1964) which may possibly have local water-bearing potential (Whitcomb and Morris, 1964).

Individual sand bodies are discontinuous, range up to 60 feet thick, and number up to a dozen (Crews and others, 1976). They typically occur within limited stratigraphic intervals, are up to a few miles wide, 30 miles long, and trend approximately N. 30° W., although the Gammon Sands are interpreted as more sheet-like (Crews and others, 1976). The sandstones are thin-bedded and vary from tabular to crossbedded. Usually they are fine-grained, glauconitic quartzose sand, which may contain clay clasts (Spearing, 1976).

Shannon porosity ranges from 12 to 25 percent at producing oil fields (Table IV-10).

Mesaverde Formation

Within the Powder River basin in Wyoming the Mesaverde Formation is a relatively untapped potentially important aquifer (Hodson and others, 1973). It consists of two principal sandstone tongues, the Teapot and Parkman sands, along with intervening shales. The formation lies between the Cody and Lewis shales in the western part of the basin and grades into the Pierre Shale to the east. Within the basin it is thickest in Natrona County, reaching up to 1,000 feet thick (Purcell, 1961). The sandstones represent deltaic deposition during regressions of the sea depositing the Pierre Shale (Purcell, 1961).

The Parkman Sandstone Member represents the base of the formation and is very fine to fine-grained, micaceous, glauconitic, and calcerous sandstones (Purcell, 1961). Grains are fairly well sorted and angular. Coals and carbonaceous shales are often present (Headley, 1958). Bedding ranges from thin to massive but continuity of individual beds is limited (Purcell, 1961). Net thickness of porous sands ranges up to 250 feet in Natrona County (Headley, 1958) although total thickness of the Parkman is up to 500 feet (Crist and Lowry, 1972).

The upper member of the Mesaverde Formation is the Teapot Sandstone Member, which is lithologically similar to the Parkman sand but has shale partings. Net Teapot porosity within the basin ranges up to 100 feet (Headley, 1958).

At the Dead Horse Field west of Gillette porosity of the oil-producing zone is 15 to 21 percent.

Fox Hills/Lance Aquifer System

Fox Hills Sandstone

The Fox Hills is a distinctive water-bearing sandstone deposited as nearshore sand bodies in the retreating Late Cretaceous sea. It conformably overlies marine shales, variously called the Lewis, Pierre, or Bearpaw, and conformably underlies the nonmarine Lance Formation.

The sandstone is generally fine- to medium-grained, thin to massive bedded, weakly cemented, friable, lenticular, and interbedded with carbonaceous shale and siltstones. In the southwestern basin the basal part of the Fox Hills is a massive, cliff-forming sandstone (Kohout, 1957), while the upper part has increased shale interbeds (Crist and Lowry, 1972). In the southeastern basin limonitic concretions are common (Whitcomb, 1965).

In the southern basin thickness of the Fox Hills ranges from 400 to 500 feet in Niobrara County (Whitcomb, 1965) to 700 feet in Natrona County (Crist and Lowry, 1972). The sandstone thins to the north and also contains more shale. In Crook County it is 150 to 200 feet thick (Whitcomb and Morris, 1964). In the northwestern basin the Fox Hills is not mapped as a separate unit but equivalent strata are included in the basal Lance Formation (Whitcomb and others, 1966).

Lance Formation

The continental deposits of the Upper Cretaceous Lance Formation are closely associated with the retreating sea which deposited the Fox Hills. At any single point the nonmarine Lance generally overlies the marine Fox Hills but they may locally interfinger (Lowry, 1972). The upper contact of the Lance is arbitrarily defined on the basis of a paleontological change rather than lithology; the conformably overlying Tullock Member of the Fort Union Formation contains a Tertiary flora and no dinosaur bones (Brown, 1958).

The Lance is typically interbedded, light yellow grey, fine- to medium-grained, crossbedded, lenticular water-bearing sandstones, grey carbonaceous shales, and siltstones. It also contains thin coals and bentonitic beds (Dunlap, 1958). Individual sandstone beds are a few inches to a few feet thick. In Montana the upper part of the Lance Formation is more fine-grained.

Thickness of the formation varies from 3,000 feet in Natrona County (Crist and Lowry, 1972) to 1,600 to 2,500 in Niobrara County (Whitcomb, 1965) to less than 1,000 feet in Crook County (Whitcomb and Morris, 1964). In Johnson County the reported thickness is 1,950 to 2,200 feet (Whitcomb and others, 1966), but this includes strata equivalent to the Fox Hills and Tullock.

Tullock Member of the Fort Union Formation

The Tullock Member of the Fort Union has been separately mapped only in the northeast part of the Powder River basin. Both its upper and lower boundaries are conformable, transitional zones. Lowry (1972) informally redefined the Tullock as a time transgressive rock stratigraphic unit and recognized equivalent strata in the Upper Lance in the western basin.

Overall lithology of the Tullock is similar to the Lance but several differentiating criteria have been suggested. Robinson and others (1964) considered the Tullock lighter in color, more evenly bedded, and richer in coal. Dunlap (1958) considered Tullock sands dirty, conglomeratic, and coal-rich in comparison to the Lance. Lowry (1972) found that geophysical logs show the Tullock has higher electrical resistivity and is thinner-bedded than the Lance.

Mapped thickness of the Tullock in the eastern basin is generally about 1,000 feet but it thins to 500 feet at the Montana-Wyoming boundary (Robinson and others, 1964). Lowry (1972) found Tullock lithology, previously mapped as the Lance Formation, varied from 1,400 feet thick in the southwestern basin to about 700 feet near Sheridan.

Wasatch/Fort Union Aquifer System

Fort Union Formation

The Fort Union Formation consists of as much as 4,000 feet of Paleocene continental deposits, thickest in the southwest, derived from the surrounding low positive topographic features of Paleocene time. It is conformably underlain by the Cretaceous Lance Formation and the gradational contact is arbitrarily defined (see above). The Eocene Wasatch Formation unconformably overlies the Fort Union.

In the north part of the basin the formation has been divided into three members: the Tullock (see above), Lebo Shale, and Tongue River, in ascending order (Robinson and others, 1964). The Lebo Shale is about 250 feet of dark grey claystone and shale with beds of brown carbonaceous shale, thin discontinuous lenses of fine-grained sandstone, and an absence of coal. Increased shale in the Lebo in comparison to the underlying Tullock is distinctive on geophysical logs (Lowry, 1972), and makes the member a partial hydrologic barrier. The Tongue River is about 800 feet thick in the northeast but thickens westward. It is light-colored interbedded fine-grained sandstone, siltstone, sandy shale, and coal. The Tongue River and Lebo are not differentiated in eastern basin outcrops south of T. 47 N.

In the southern part of the basin, Sharp and Gibbons (1964) have described a two-fold division of the Fort Union. The lower member is principally flat-bedded clayey fine-grained sandstone with minor amounts of siltstone and coal while the upper member is clayey siltstone containing ironstone lenses and coals.

In the western basin there are localized lenticular conglomeratic beds and coarse-grained sandstones near the middle of the formation (Whitcomb and others, 1966).

Wasatch Formation

The Eocene Wasatch Formation reaches a thickness of as much as 1,600 feet in southwestern Campbell County although in much of the basin erosion has removed about half the originally deposited material. The Wasatch/Fort Union contact is a pronounced angular unconformity in the western basin but becomes paraconformable to the east. The exact stratigraphic location of the contact in the eastern basin has been disputed (Brown, 1958; Sharp and Gibbons, 1964), but it appears to coincide with subtle mineralogical and geochemical changes in the sandstones (Connor and others, 1976). The contact with the overlying local remnants of the Oligocene White River Formation is an erosional unconformity.

Typically the Wasatch is variegated claystones, lenticular and continuous thin-bedded fine-grained water-bearing sandstones, and thin coal and carbonaceous shale beds (Love, 1952). The sandstones are generally more arkosic and variable than those of the Fort Union. Near the Bighorn Mountains the Wasatch is divisible into the Kingsbury Conglomerate, containing well-rounded cobbles of sedimentary rocks, and the overlying Montcrief boulder beds, which include Precambrian rock fragments (Hose, 1955). Both members grade laterally into typical Wasatch beds.

Porosity of Wasatch Formation sands measured at the Highland Mine in central Converse County averaged 29 percent (Wyoming Department of Environmental Quality mine permit files).

Coal and "Clinker"

Coals in the Tertiary rock sequence are specifically mentioned because they are the only water-bearing strata within the aquifer system with areal extent. Individual coals are up to 80 feet thick, occur most abundantly in the upper part of the Fort Union, and underlie most of the central basin.

Associated with Powder River basin coal beds are "clinker" areas. These are regions of fractured, baked, and fused bedrock, which result from near-surface burning of coal beds. Clinker bodies which are both saturated and regionally extensive can produce large quantities of good quality water.

Middle Tertiary Aquifers

Within the study area Middle Tertiary rocks are extensively present only in the southern parts of Converse and Niobrara counties, where they unconformably overlie older rocks.

White River Formation

The Oligocene White River Formation is predominantly siltstone and claystone but may also contain numerous channel deposits of sandstone and conglomerate. Thickness ranges from about 550 feet in Niobrara County to a reported maximum of 1,500 in Converse County (Rapp, 1953).

In Niobrara County the lower 200 feet is a color banded silty claystone equated with the Chadron Formation in Nebraska, while the upper 350 feet is a massive pinkish-grey siltstone equated with the Brule Formation (Whitcomb, 1965).

West of Douglas the formation is a massive buff siltstone but south of Douglas it is more clay rich and contains increased numbers of channel sandstones (Rapp, 1953).

Rapp (1953) reports that numerous small fractures within the formation enhance its water-bearing characteristics.

Arikaree Formation

The Miocene Arikaree Formation is a massive sandstone, containing lesser amounts of siltstone, volcanic ash, and lenticular well-cemented concretionary sandstone, and is underlain by a persistent coarse basal conglomerate. Although about 500 feet thick near Lusk, east of the study area boundary, it thins to less than 100 feet in Converse County.

It unconformably overlies the White River Formation and, because it is more resistant to erosion, caps numerous ridges within the area. Locally, where the basal conglomerate is absent, the two formations appear to be in gradational contact.

APPENDIX C

CHEMICAL ANALYSES OF POWDER RIVER BASIN GROUND WATERS SAMPLED BY WRRI

Table C-1. Chemical analyses of Powder River basin ground waters sampled by WRRI, June, 1980. (Values reported as mg/l unless specified otherwise).

Location:	33/75-8 db	40/79-26 ca	48/64-18 bd	48/65-21 bb	55/61-26 da	55/66-1 bb	57/61-27 bd	36/77 5 bbb	37/63-13 cb	40/78-26 cba	42/62-30 aa	45/71-36 bb	50/68 1
Aquifer:	Madison[b]	Madison	Fall River	Lakota	Fall River	Lakota	Fall River	Lance[c]	Fox Hills	Fox Hills	Fox Hills	Lance[c]	Lance
Field Temperature (°C)	43	74	15	15	15	13	16	18	18	17	15	27	
Field pH (units)	7.5	7.0	8.4	9.0	8.2	7.3	7.5	8.2	8.5	7.2	7.3	7.8	
Conductivity (micromhos @ 68°F)	3450	3450	1000	885	3050	2380	435	2000	2225	3775	1400	400	1335
Total Suspended Solids	1.6	10.0	8.8	0.4	59.6	4.8	3.6	2.8	2.0	3.2	2.8	32.2	0.4
Total Dissolved Solids	2954	2886	800	690	2552	2136	316	1524	1728	3074	1070	288	1004
Calcium	317	327	3	3	68	168	34	9	5	56	42	15	21
Magnesium	60	60	1	1	27	46	16	3	1	15	25	2	11
Sodium	492	496	250	232	750	436	44	580	625	950	308	96	334
Potassium	50	46	3	2	16	35	7	6	5	10	6	8	6
Bicarbonate	93	122	122	207	305	342	195	669	493	420	634	264	634
Carbonate	0	0	60	48	0	0	0	0	43	0	0	0	0
Sulfate	1200	1075	350	240	1290	1060	85	599	733	1700	330	18	268
Chloride	568	648	10	12	128	12	6	10	20	36	12	24	8
Arsenic (0.01)[a]	N.D.[a]	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D
Barium (0.05)	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D
Cadmium (0.01)	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D
Chromium (0.05)	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D
Flouride	3.5	3.6	0.42	0.80	2.50	0.11	0.40	0.19	0.71	0.33	0.39	1.17	0.8
Lead (0.05)	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D
Mercury (0.001)	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D
Nitrate (N)(0.01)	0.02	0.33	0.02	0.01	0.04	0.02	N.D.	0.04	N.D.	N.D.	N.D.	0.01	0.
Selenium (0.01)	N.D.	N.D.	N.D.	N.D.	0.02	N.D.	N.D.	N.D.	N.D.	0.02	N.D.	N.D.	N.D
Silver (0.01)	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.
Uranium (U_3O_8)(0.001)	0.012	0.008	0.019	0.015	0.023	0.010	0.006	0.001	0.020	0.021	N.D.	0.011	0.

N.D. indicates not detected; number in parentheses is detection limit (mg/l).

Owner claims well is completed in Tensleep and Madison aquifers.

Owner claims well is completed in Fox Hills aquifer.

APPENDIX D

LOCATION-NUMBERING SYSTEM

Well locations are designated by a numbering system based on the federal system of land subdivision.

The first number denotes the township, the second number denotes the range, and the third number denotes the section. One or more letters following the section number denote the location within the section. The section is divided into four quarters (160 acres) and lettered a, b, c, and d in a counterclockwise direction, beginning in the northeast quarter. Similarly, each quarter may be further divided into quarters (40 acres) and again into 10-acre tracts and lettered as before. The first letter following the section number denotes the quarter section; the second letter denotes the quarter-quarter section; and the third letter, if shown, denotes the quarter-quarter-quarter section, or 10-acre tract (Figure D-1).

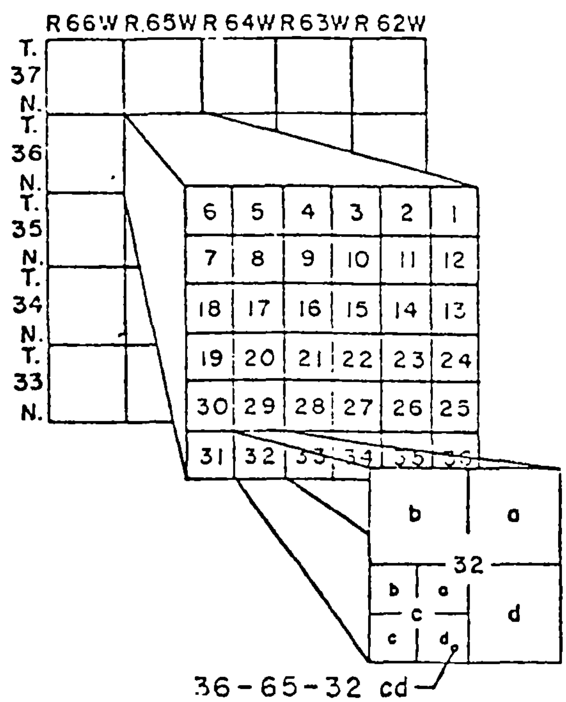

Figure D-1. Well identification system based on township-range subdivisions.