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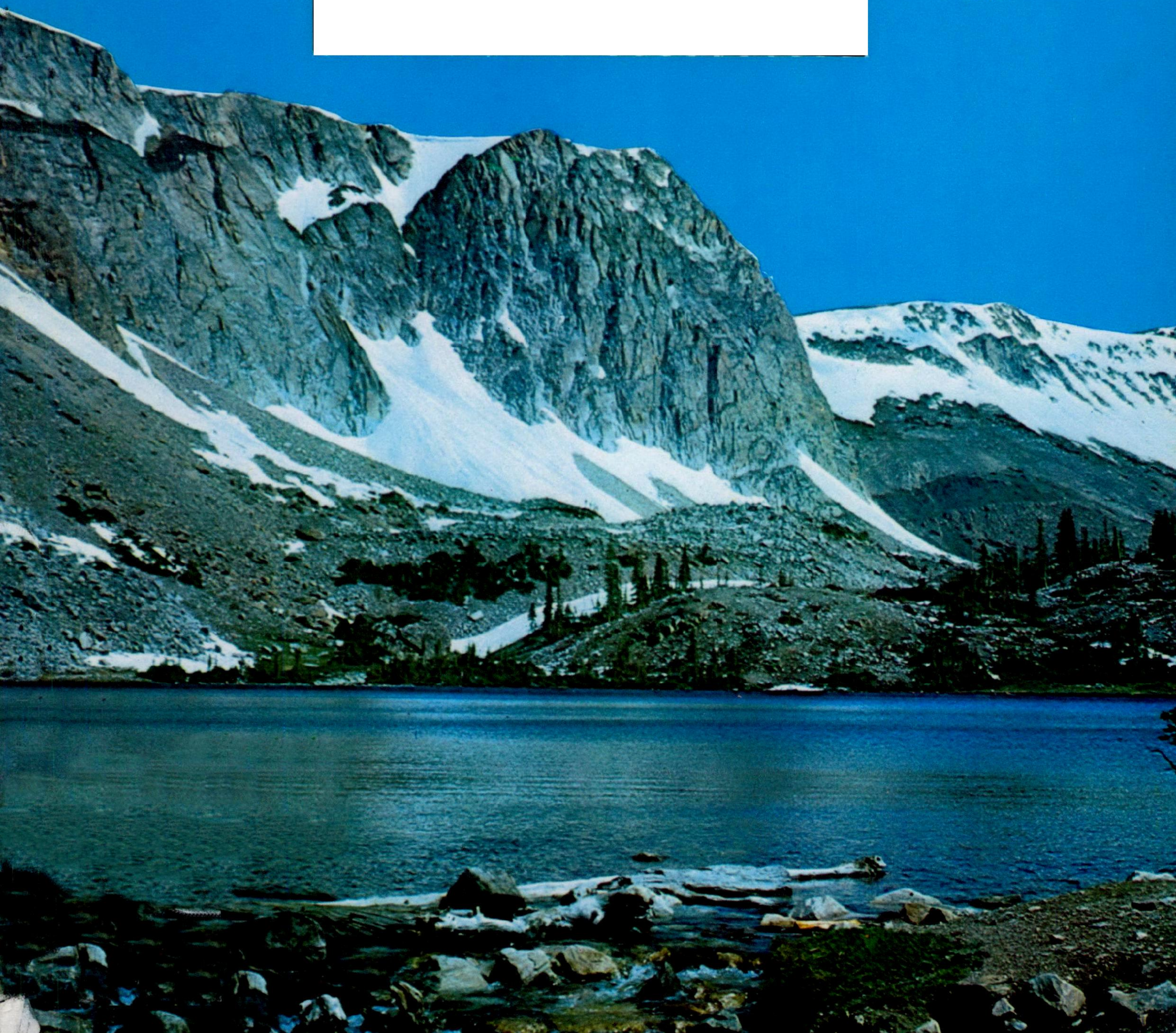
OCCURRENCE AND CHARACTERISTICS OF GROUND WATER IN THE DENVER-JULESBURG BASIN, WYOMING



Volume VII-A

OCCURRENCE AND CHARACTERISTICS OF

GROUND WATER IN THE DENVER-JULESBURG BASIN,

WYOMING

by

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Introduction

This report presents the findings of a ground-water study of the Denver-Julesburg basin in southeastern Wyoming. The study was funded by the U.S. Environmental Protection Agency (EPA) for the Underground Injection Control (UIC) program. The UIC is designed to protect sources of usable ground water from possible contamination caused by underground injection of liquid wastes and other fluids. This ground-water report is one of seven prepared by the Wyoming Water Resources Research Institute for the EPA. These reports cover all of the state of Wyoming with the exception of the Yellowstone National Park area in the northwestern part of the state. The results of the study are primarily intended for use by the EPA and Wyoming state agencies concerned with development and preservation of the ground-water resources of the area.

The purpose of this report is to delineate, characterize, and document ground-water occurrence, flow, quality, and use in the Denver-Julesburg basin. The findings are based on available information; no site-specific ground-water investigations were conducted during the course of this study by the Wyoming Water Resources Research Institute (WRRI). Specific work activities conducted by WRRI included (1) field geologic reconnaissance of some parts of the study area and adjacent areas; (2) collection, screening, and analyses of existing spring, water well, and oil test well data; and (3) review of previous reports.

Water well, spring, and oil test well data were obtained from records at the Wyoming State Engineer's Office, Wyoming Geological

Survey, Wyoming Oil and Gas Conservation Commission, and from tabulated data in previous reports.

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I. SUMMARY OF FINDINGS

I. SUMMARY OF FINDINGS

1. Identified as water-bearing zones within the Denver-Julesburg basin are, in ascending stratigraphic order: (1) weathered surficial zones in Precambrian rocks; (2) the Paleozoic aquifer system; (3) several dispersed, permeable sandstone horizons within the predominantly shale and siltstone Mesozoic sequence; (4) the Lance/Fox Hills aquifer; (5) the Tertiary aquifer system; and (6) Quaternary alluvial aquifers. The most productive units are members of the Paleozoic and Tertiary aquifer systems, and Quaternary alluvial aquifers. These aquifers are dependable sources for stock and domestic needs throughout the basin and commonly yield sufficient quantities of water for irrigation, municipal, and industrial use.

2. Ground-water movement within the Paleozoic aquifer system is away from outcrop recharge areas located along uplifted basin margins. Ground-water circulation within other pre-Tertiary aquifers is unknown, but is considered similar to flow within the Paleozoic aquifer system due to similarities in geographic extent and structural setting. Ground-water movement within the Tertiary aquifer system is topographically controlled, from elevated areas along the western and northern basin margins towards lowlands to the east.

3. Available data indicate that the Tertiary aquifer system, consisting of the White River Group, Arikaree, and Ogallala formations, regionally produces the largest quantities of good quality water within the basin. This system is extensively developed for irrigation use,

with lesser withdrawals for municipal, industrial, domestic, and stock water supplies.

Coarse-grained lenses and channel deposits within the Ogallala Formation and zones of secondary permeability within the White River Group have the greatest water-producing capabilities within the Tertiary aquifer system. Yields over 1,000 gpm are common and transmissivities in excess of 500,000 gpd/ft are reported. The Arikaree Formation is the thickest unit within this system, has generally low permeabilities but large saturated thicknesses. Commonly, yields and transmissivities from this areally extensive unit are several hundred gpm and 10,000-30,000 gpd/ft, respectively.

Water from the Tertiary aquifer system generally contains less than 500 mg/l TDS. Calcium and bicarbonate are the dominant ions in solution. Some White River aquifer waters contain over 500 mg/l TDS, and are sodium enriched. High nitrate and uranium concentrations exist locally.

4. Where present, Quaternary flood plain and terrace aquifers, composed primarily of coarse sand and gravel deposits, are dependable large-scale ground-water sources within the basin. These aquifers supply large amounts of generally good quality water for irrigation, with lesser withdrawals for municipal, domestic, and stock water supplies. Well yields are commonly 500 to 1,000 gpm, and transmissivity estimates often exceed 100,000 gpd/ft. Where thick saturated deposits of coarse materials are present, yields and transmissivities in excess of 3,000 gpm and 1,500,000 gpd/ft, respectively, are reported.

Quaternary aquifer waters generally contain less than 500 mg/l TDS. Calcium and bicarbonate are the primary constituents of waters containing less than 500 mg/l TDS, with higher TDS concentrations related to sodium and sulfate enrichment. Objectionable levels of nitrate are present locally.

5. The Paleozoic aquifer system, consisting of the Flathead Sandstone, Guernsey, Casper, and Hartville formations, represents a potentially important, though largely undeveloped, source of good quality ground water. Current withdrawals are mainly for stock and domestic supplies from relatively few wells.

Permeable sandstones and fractured carbonate rocks within the Casper and equivalent Hartville formations represent the major water-producing zones of the Paleozoic aquifer system. Undeformed sandstones have yields and transmissivities to 80 gpm and 10,000 gpd/ft, respectively. Sparse data from fractured carbonates indicate yields in excess of 750 gpm.

Near outcrop, Paleozoic waters contain TDS concentrations of less than 500 mg/l, with calcium and bicarbonate the dominant ions in solution. Deep basin chemical data are lacking. High fluoride concentrations are present in the far northeastern part of the basin.

6. Sandstones within the Upper Cretaceous Lance/Fox Hills aquifer are mainly developed for domestic and stock water supplies where they crop out in the east-central part of the basin. Sandstones within this unit are fine-grained, and generally of low permeability. Most reported yields are less than 25 gpm, but locally reach 100 gpm. Transmissivity estimates vary from 400 to 5,000 gpd/ft. Higher yields may be possible from wells penetrating large thicknesses of the aquifer.

TDS concentrations in Lance/Fox Hills aquifer waters vary from less than 250 to over 4,000 mg/l, with TDS levels greater than 1,000 mg/l limited to outcrop areas. Sodium and bicarbonate are the dominant ions in solution. High fluoride concentrations are present locally.

Where exposed or near the surface, dispersed Mesozoic sandstones provide adequate yields for stock and domestic use. Yields rarely exceed 25 gpm. Sparse hydrologic data indicate generally low transmissivities.

Sparse chemical data indicate generally poor water quality for these units. Total dissolved solids levels below 1,000 mg/l are limited to near-outcrop waters, with deep basin waters containing over 15,000 mg/l TDS. Major ion composition varies from sodium-bicarbonate sulfate to sodium-chloride with increasing salinity.

Weathered zones in Precambrian granites are developed for domestic and stock use along the western basin boundary. Yields are generally less than 25 gpm. Dissolved solids concentrations are less than 500 mg/l. Major ion compositions are not reported.

7. Species which exceed U.S. Environmental Protection Agency primary drinking water standards include fluoride in Lance/Fox Hills aquifer waters and nitrite in waters from Quaternary aquifers and the Tertiary aquifer system. High nitrates are related to areas of human habitation and agricultural activities.

In general, secondary drinking water standards are not exceeded in waters from the Tertiary aquifer system or Quaternary aquifers. Existing data indicate sulfate and chloride standards are exceeded locally in deeper aquifers.

8. Water use within the basin is estimated to be about 411,000 acre-feet/year. Water for irrigation and other agricultural needs constitute about 85 percent of this total, with public and domestic

water supplies and industrial water needs comprising roughly equal parts of the remainder. Ground-water sources, mainly the Tertiary aquifer system and Quaternary aquifers, supply about 192,000 acre-feet of water per year, 47 percent of the basin's total water demand.

9. Agricultural ground-water use for irrigation is estimated at 164,500 acre-feet/year. Major sources of irrigation ground water are the Tertiary aquifer system and Quaternary aquifers. Stock water use is about 3,760 acre-feet/year. Virtually all water-bearing units within the basin provide stock water.

10. Ground-water withdrawals for public and domestic drinking water supplies total about 18,000 acre-feet/year. The Tertiary aquifer system and Quaternary aquifers supply most of this water. The Lance/Fox Hills aquifer, the Precambrian aquifer, and to a lesser extent Mesozoic sandstone aquifers supply water to domestic wells locally.

11. Industrial water use within the basin is roughly 5,000 acre-feet/year. Major industrial uses of ground water are for power generation, chemical processing, and oil production and refining. The Tertiary aquifer system supplies virtually all industrial ground water used within the basin.

II. GEOGRAPHIC AND GEOLOGIC SETTING

II. GEOGRAPHIC AND GEOLOGIC SETTING

PHYSIOGRAPHY

The Wyoming part of the Denver-Julesburg basin covers an area of about 8,000 square miles in the southeast corner of the state (Figure II-1). The basin is bounded on the west by the Laramie Mountains, on the north and northwest by the Hartville Hills and associated uplifts, and on the south and east by the Wyoming-Colorado and Wyoming-Nebraska state lines, respectively. As defined, the basin includes all of Laramie and Goshen, the majority of Platte, and parts of Niobrara and Albany counties.

Topography

Much of the Denver-Julesburg basin is occupied by the High Plains surface (Figure II-1), a gently rolling tableland sloping eastward at 20 to 100 feet per mile. Elevation of the surface varies from over 7,000 feet in the west to about 5,000 feet at the Wyoming-Nebraska state line. In the east-central part of the basin this surface has been breached by the North Platte River and its tributaries, forming the Goshen Hole Lowland, a gently rolling plain (Figure II-1). The lowland is comprised of two subareas, Goshen Hole proper to the south, and the North Platte River Valley to the north. The area is surrounded by discontinuous escarpments rising several hundred feet that mark the edge of the High Plains surface. Elevations within the lowland vary between 4,000 and 5,000 feet.

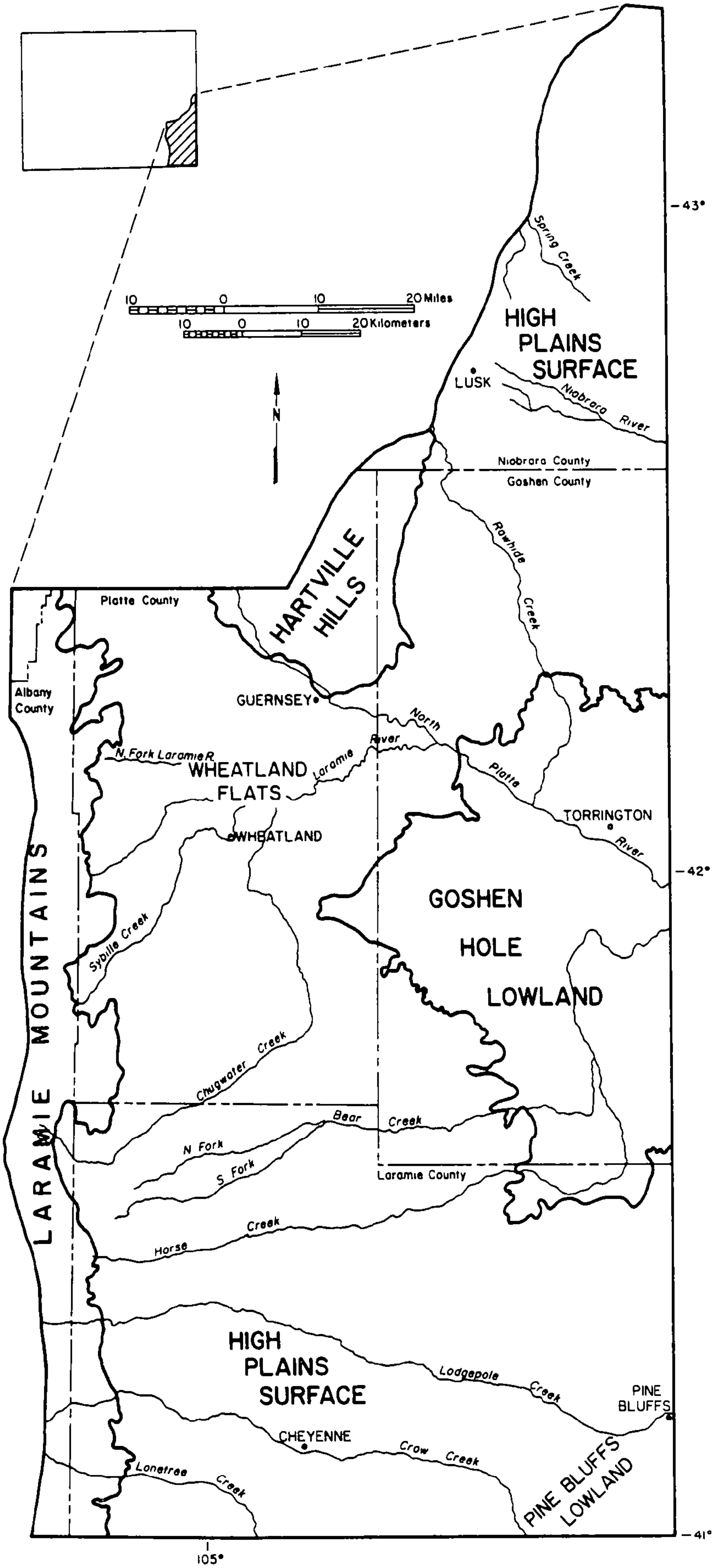

Figure II-1. Location map of the Denver-Julesburg basin.

Two terraced, alluviated lowland areas, Wheatland Flats and the Pine Bluffs Lowland, identify depressions in the High Plains surface in central Platte and southeast Laramie counties, respectively (Figure II-1).

The Laramie Mountains, a high eastward-sloping plateau broken locally by steep-sided valleys and rugged peaks, form the west border of the basin (Figure II-1). The mountains rise moderately above the High Plains surface along most of the western basin, reaching elevations of 8,000 to 8,500 feet.

Near the north-central basin boundary the High Plains surface is disrupted by the Hartville Hills (Figure II-1), a broad uplifted area which rises to elevations over 6,000 feet. The North Platte River dissects the southern end of the hills, resulting in rugged topography and relief in excess of 1,500 feet locally.

The highest elevation in the basin, about 8,500 feet, is along the west basin boundary in the Laramie Mountains. The lowest elevation, about 4,000 feet, occurs where the North Platte River crosses the Wyoming-Nebraska state line. Total basin relief, therefore, is about 4,500 feet.

Surface Drainage

The Denver-Julesburg basin lies within the Missouri River drainage (Table II-1). Most of the basin is drained by the North Platte River and its tributaries (Figure II-1). The majority of these tributaries head in the Laramie Mountains west of the basin, with the exceptions of Rawhide Creek, which originates within the basin, and the Laramie River, which heads in Colorado and crosses the Laramie Mountains. Several streams originating along the southern end of the Laramie Mountains (Figure II-1)

Table II-1. Surface drainage systems in the Denver-Julesburg basin, Wyoming.

- Missouri River[a]
  - Platte River[a]
    - North Platte River
      - Laramie River
        - North Fork Laramie River
        - Chugwater Creek
        - Sybille Creek
      - Horse Creek
        - Bear Creek
    - South Platte River[a]
      - Lodgepole Creek
      - Crow Creek
      - Lone Tree Creek
    - Niobrara River
    - Cheyenne River[a]
      - Lance Creek[a]
        - Old Woman Creek[a]
          - Spring Creek

[a]Stream lies outside of Denver-Julesburg basin.

flow into the South Platte River, with the divide between the North Platte and South Platte drainages in northern Laramie County. The far northeastern part of the basin is drained by the Niobrara River, a tributary of the Missouri River, or by Spring Creek, part of the Cheyenne River system.

Climate

The climate of the Denver-Julesburg basin is typified by low precipitation, a high rate of evaporation, and widely variable temperatures. Precipitation over most of the basin varies between 12 and 16 inches per year, with the higher elevations in the Laramie Mountains receiving over 20 inches annually. About half of the annual precipitation falls during April, May, and June, mainly through sporadic and unevenly distributed thunderstorms. Average maximum and minimum temperatures in the warmest month of the year, July, are about 88°F and 55°F, respectively, for most of the area. Average maximum and minimum temperatures for January, the coldest month, are about 40°F and 10°F, respectively. The growing season averages 140 to 150 days for most parts of the basin.

HUMAN GEOGRAPHY

Population Distribution

Preliminary 1980 Census figures (Table II-2) indicate that about 95,000 persons reside in the Denver-Julesburg basin. Almost one-half of the total basin population lives in the City of Cheyenne (Figure II-1) and more than two-thirds reside in Laramie County, mainly in the Cheyenne vicinity. No municipality in the basin, with the exception of

Table II-2. Population figures for counties and incorporated areas, Denver-Julesburg basin, Wyoming.

County/Incorporated Place	1980[a]	1970[b]
Laramie	68,022	56,360
Platte[c]	12,022	5,989
Goshen	11,199	10,885
Niobrara[c]	1,995	2,154
Total	94,979	75,229
Albin	128	118
Burns	267	185
Cheyenne	47,207	41,254
Chugwater	285	187
Ft. Laramie	356	197
Guernsey	1,503	793
Hartville	148	246
LaGrange	232	189
Lingle	474	446
Lusk	1,654	1,495
Pine Bluffs	1,082	937
Torrington	5,431	4,237
Van Tassel	10	21
Wheatland	5,655	2,498
Yoder	110	101
Total	64,542	52,904

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

[b]U.S. Department of the Interior, 1974.

[c]Estimated population of county area within the basin.

Cheyenne, has a population in excess of 10,000; only six incorporated towns have more than 1,000 residents (Table II-2).

A comparison of 1970 and preliminary 1980 Census figures (Table II-2) indicates a 26 percent population increase over the past decade. This increase is lower than the 41 percent increase for all of Wyoming for the same period. The Denver-Julesburg basin does not contain the wealth of mineral resources found in many parts of the state, and therefore has not experienced the population growth associated with resource development. The areas within the basin which had the greatest population increases over the last decade are within or adjacent to Cheyenne and Wheatland (Figure II-1). Population increases in the Wheatland area are due mainly to construction of a large power generating plant. Growth around Cheyenne, the state capital, is a reflection of rapid population growth in the state as a whole.

Land Use and Ownership

Approximately 95 percent of the land within the basin is utilized for agricultural purposes, mainly for stock grazing with lesser acreages used to raise crops. The small amount of non-agricultural land in the basin is used for human habitation and recreation. About 88 percent of the basin lands are privately owned, with most of the remainder owned by the state.

GEOLOGY

Stratigraphy

The Denver-Julesburg basin is underlain by up to 12,000 feet of sedimentary rocks which range in age from Cambrian to Recent and include both marine and non-marine deposits. The sedimentary deposits unconformably overlie Precambrian basement rocks which are exposed in the Laramie Mountains and Richeau dome on the west side of the basin, and in the Hartville Hills (Figure II-3).

A generalized stratigraphic column for the Denver-Julesburg basin indicating lithologies and stratigraphic sequence is given in Figure II-2. Detailed descriptions of individual geologic units may be found in Darton and others (1910), Denson and Botinelly (1949), Condra and Reed (1950), McGrew (1953), Rapp and others (1953, 1957), Morris and Babcock (1960), Denson and Bergendahl (1961), and Maughan (1963, 1964). Summary descriptions of the units are included in Table IV-1.

Rocks of Paleozoic age generally consist of sandstones, shales, and carbonates and are over 1,000 feet thick in the eastern part of the basin. Outcrops of Paleozoic rocks are limited to the east edge of the Laramie Mountains, Richeau dome, and the Hartville uplift.

Mesozoic rocks are divisible into three general lithologic assemblages. The lowest unit consists of shales, siltstones, and sandstones which range in age from Triassic to Lower Cretaceous and may exceed 3,000 feet thick near the Denver-Julesburg basin trough. The middle assemblage is a sequence of marine shales of Lower to Upper Cretaceous age. This unit is up to 7,000 feet thick in some areas of the basin. The two lower units of the Mesozoic rocks crop out over small areas immediately east of the Laramie Mountains and along the crest of Old Woman anticline (Figure II-3). The upper assemblage is composed of up to 2,000 feet of sandstones and shales and crops out in southern Goshen County.

Tertiary age sediments consist of fine- to coarse-grained sandstones, siltstones, and claystones with a maximum thickness of more

Era	System	Lithology	Geol. Symbol	Geologic Unit		Thickness, (ft)
CENOZOIC	Quat.		Qal	Alluvium, terrace, dune deps.		0-200
	Tertiary		To	Ogallala Formation		0-330
			Ta	Arikaree Formation		0-1200
			Twr Tb	White River Group	Brule Formation	0-420
			Twr Tc		Chadron Formation	0-700
MESOZOIC	Upper Cretaceous		Kl	Lance Formation		0-1500
			Kfh	Fox Hills Sandstone		0-550
			Kp	Pierre Shale		0-5700±
			Kn	Niobrara Formation		0-500±
			Kf	Frontier Formation and equivalents		0-1400±
	Lower Cretaceous		Kmr	Mowry Shale		80-220±
			Knc	Newcastle Sandstone		0-1100±
			Ksc	Skull Creek Shale		70-200+
			Kcv	Cloverly Formation		0-300
	Jurassic		Jm	Morrison Formation		0-250
			Js	Sundance Formation		0-550
	Triassic		₮c	Chugwater Formation		0-675
			₮Pg	Goose Egg Formation		0-450
PALEOZOIC	Perm.					
	Penn.		PℙPh	Hartville Formation		0-1050±
			PℙPc	Casper Formation		0-1225
	Miss. Dev.		Mdg	Guernsey Formation		0-200±
	Cambrian		€f	Flathead Formation		0-60±
PRE€			p€r	Precambrian rocks		?

Figure II-2. General geologic column, Denver-Julesburg basin, Wyoming.

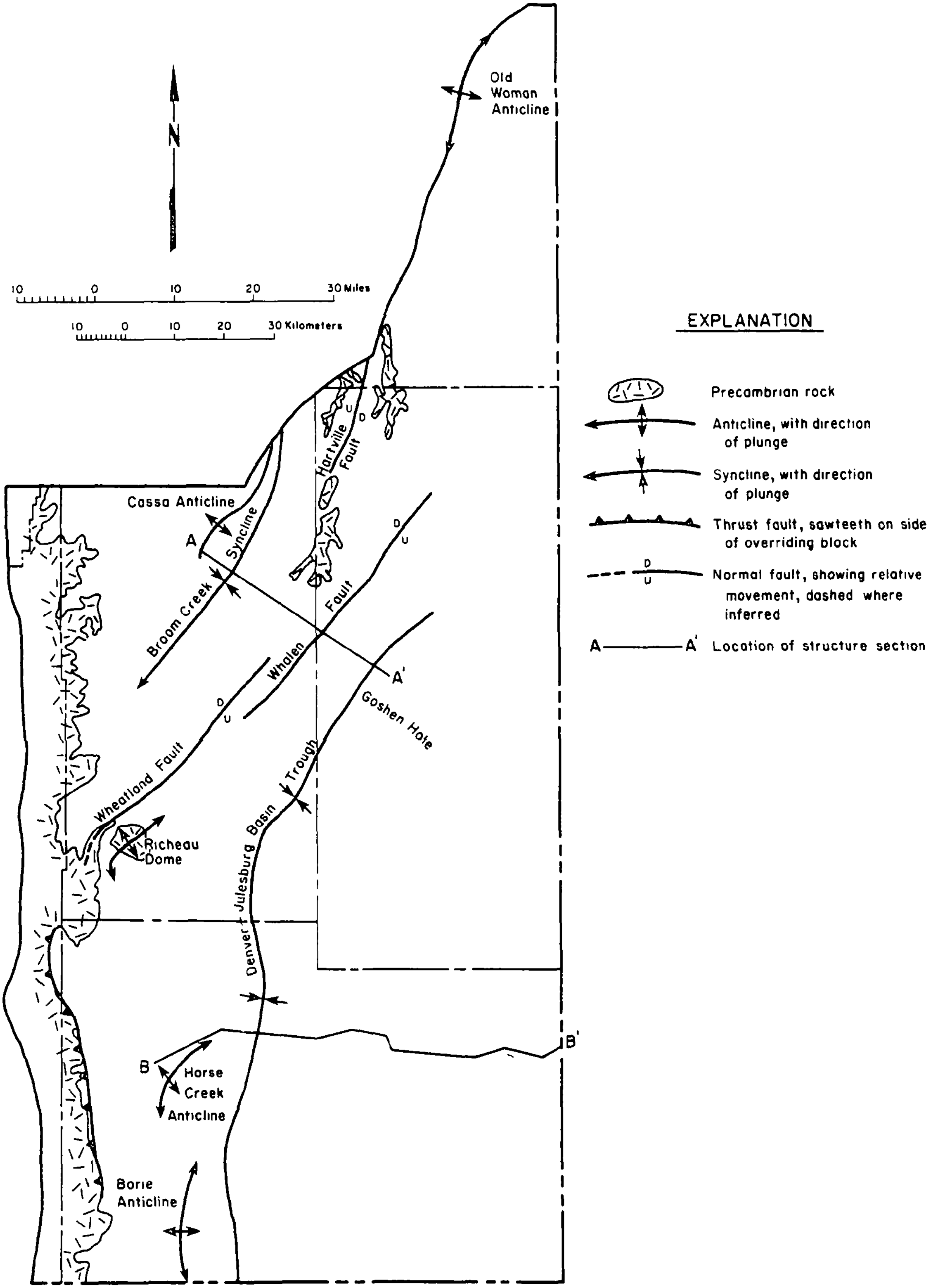

Figure II-3. Major structural features of the Denver-Julesburg basin, Wyoming.

than 2,000 feet. Tertiary rocks are at the surface or covered by Quaternary deposits throughout over 90 percent of the Denver-Julesburg basin.

Quaternary age alluvial, terrace, flood plain, and dune deposits range from 0 to 200 feet thick. Alluvial deposits occur in all of the major stream valleys of the basin and cover large lowland areas in western Platte County and southeastern Laramie County.

Structural Geology

The general structural setting of the Denver-Julesburg basin is depicted in Figures II-3 and II-4 and Plate 1.

The Denver-Julesburg basin is a broad synclinal trough located immediately east of the Laramie Mountains, a northern extension of the Rocky Mountain Front Range. The axis of the syncline trends north to south in the southern part of the basin and northeast to southwest in the northern part (Figure II-3 and Figure II-4). Pre-Tertiary rocks adjacent to the Laramie Mountains are steeply dipping (Dockery, 1939). East of the synclinal axis, sediments are nearly horizontal.

The basin is bounded on the west by the Laramie Mountains, and on the north by the Hartville uplift and Old Woman anticline. The structural basin extends eastward to the Chadron-Cambridge arch, 70 to 180 miles east of the Wyoming-Nebraska boundary, and southward to the Las Animas arch, more than 160 miles south of the Wyoming-Colorado boundary. For a descriptive summary of the structural features in the Denver-Julesburg basin outside of Wyoming, refer to Anderman and Ackman (1963).

The east flank of the Laramie Mountains is bounded by a series of high angle thrust faults and tightly flexed folds from the

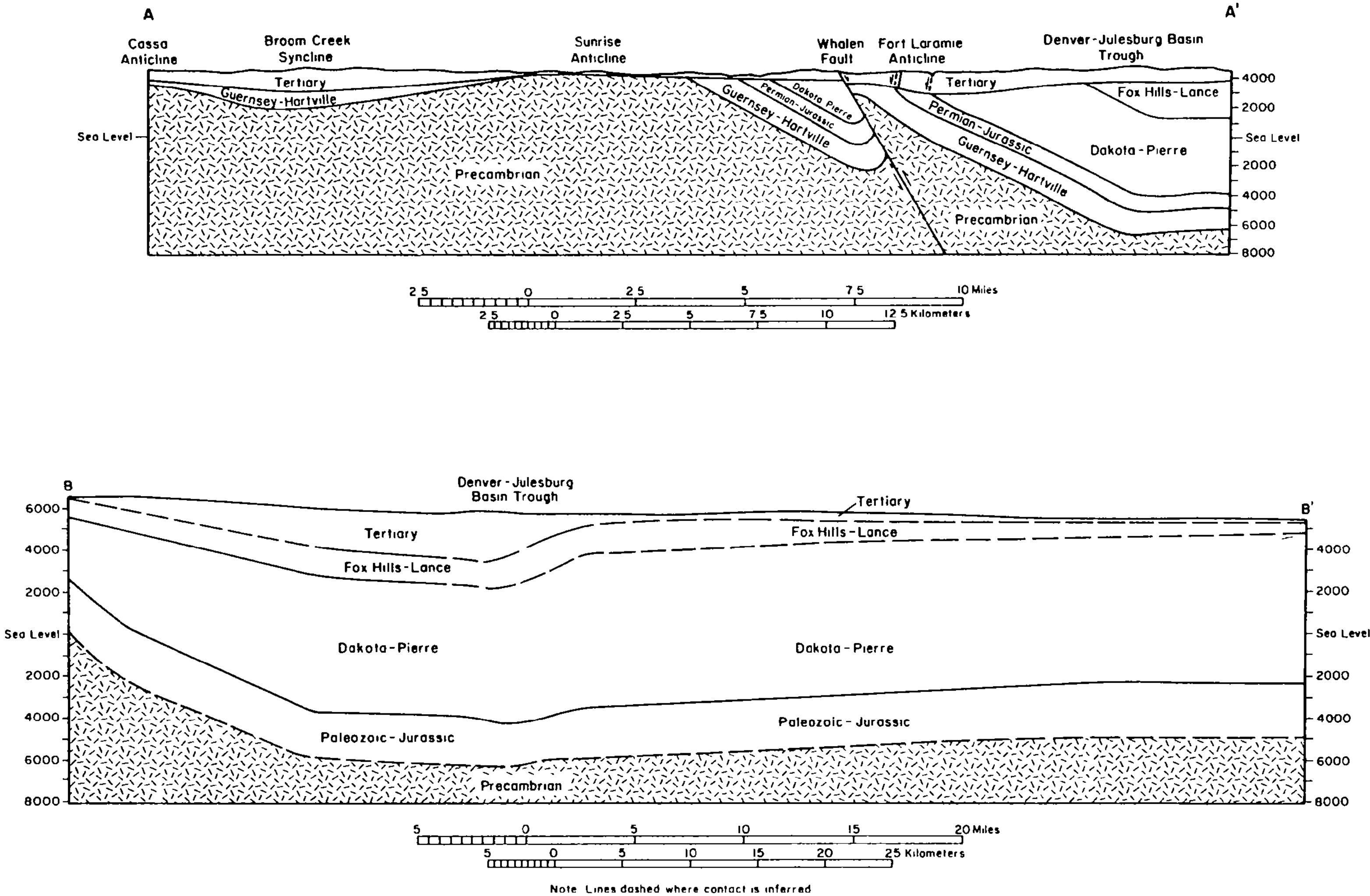

Figure II-4. Structural cross-sections, Denver-Julesburg basin, Wyoming. Lines of sections are shown on Figure II-3. (A-A' after Droullard, 1963; B-B' based on data from Petroleum Information files of the Wyoming Geological Survey.)

Wyoming-Colorado state line north to the Hartville uplift (Figure II-3). Maximum structural relief is approximately 17,000 feet between the exposed Precambrian rocks of the Laramie Mountains and the Denver-Julesburg basin trough near Cheyenne (Anderman and Ackman, 1963).

Separating the Denver-Julesburg basin from the Powder River basin to the north is the Hartville uplift (Figure II-3 and Figure II-4, cross-section A-A'). The uplift includes a broad southwest plunging syncline (Broom Creek syncline), with the asymmetric Cassa anticline and Hartville fault forming the western and eastern boundaries of the topographically elevated Hartville Hills, respectively. Up to 12,000 feet of structural relief occurs between the Hartville uplift and the trough of the Denver-Julesburg basin (Droullard, 1963). The southeast flank of the uplift has a complex series of normal faults with associated overturned beds. These include the Wheatland, Whalen, and Hartville faults (Figure II-3).

To the west of the Cassa anticline the Hartville uplift is deformed by the Elkhorn anticline and several small attendant faults. This uplift extends west to the Laramie Mountains.

The Wheatland-Whalen fault system (Figure II-3 and Figure II-4, cross-section A-A') produces major stratigraphic discontinuities between the Hartville Uplift and the Denver-Julesburg basin proper. Along the Whalen fault, evidence exists for two separate episodes of movement--northwestward thrusting during the Laramide Orogeny and normal faulting, with downdropping of the southeast block, during post-Miocene time (Denson and Botinelly, 1949; Anderman and Ackman, 1963). Vertical displacement in Paleozoic strata is 4,800 feet along the Whalen fault, whereas displacement in Tertiary beds is only 300 to 700 feet (Droullard, 1963).

Hydrostratigraphy

All stratigraphic units within the Denver-Julesburg basin can locally produce adequate amounts of water for stock or domestic use. However, few of these units can regionally produce sufficient quantities to be characterized as dependable water-bearing units. The hydrostratigraphy for the Denver-Julesburg basin has been identified through analysis of water yield reports in Wyoming State Engineer permit records, oil and gas well test results, and previously published ground-water studies.

Aquifers are defined herein as parts or all of geologic formations that regionally produce adequate amounts of water for exploitation. Aquifer stratigraphic boundaries are not necessarily limited by formational boundaries; they are, however, limited by the relative permeabilities of the rock units. Aquifers are classified as minor or major, with minor aquifers characteristically producing sufficient water only for stock or domestic purposes. Low permeability zones, composed of siltstone, claystone, and shale, will generally yield little water to wells, act to restrict ground-water flow between aquifers, and are termed confining beds, or aquitards.

Where aquifers are not separated regionally by an aquitard, and have similar recharge/discharge mechanisms and therefore similar ground-water flow paths, they are considered to be in hydraulic connection and are grouped as an integrated aquifer system. Individual member aquifers within an aquifer system may be hydraulically isolated to varying degrees locally by intervening low permeability horizons.

Figure II-5 delineates the hydrostratigraphy of the Denver-Julesburg basin. Several distinct water-bearing horizons are identified. Where exposed, surficial weathered zones of Precambrian granites and metasediments constitute a minor aquifer. The oldest sedimentary rocks found within the basin--the Cambrian Flathead Sandstone, limestones of the Mississippian-Devonian Guernsey Formation, and sandstones and carbonates of the Pennsylvanian-Permian Casper and equivalent Hartville formations--comprise the Paleozoic aquifer system. The Hartville (Casper) aquifer has the greatest water producing capability. This system is isolated from younger aquifers by shales of the overlying Permian-Triassic Goose Egg Formation (Figure II-5).

The sequence of rocks from the Triassic Chugwater Formation through the Upper Cretaceous Pierre Shale consists primarily of low permeability shales and siltstones, but contains several dispersed permeable sandstone horizons which are minor aquifers (Figure II-5). These sandstones, with the exception of the lower Cretaceous Cloverly Formation, are generally lenticular, discontinuous units which grade laterally and vertically into relatively impermeable shales and siltstones.

The Upper Cretaceous Fox Hills Sandstone and Lance Formation (Figure II-5) consist of permeable sandstone beds and thin shale layers. Collectively, the permeable sandstones constitute a minor aquifer. The Lance/Fox Hills aquifer overlies the Pierre Shale, a thick (+5,000 feet) regional aquitard, and is isolated from younger aquifers by the relatively impermeable claystones and siltstones of the Oligocene White River Group.

Geologic Age	Lithology	Geologic Unit	Hydrologic Role	Hydrologic Unit
Quaternary		Alluvial, flood plain and terrace deposits	Major Aquifer	Quaternary Aquifers
Tertiary		Ogallala Formation	Major Aquifer	Tertiary Aquifer System
		Arikaree Formation		
		White River Group — Brule Fm.	Aquitard w/Discontinuous Major Aquifers	
		White River Group — Chadron Fm.	Aquitard w/Discontinuous Minor Aquifers	
Upper Cretaceous		Lance Formation	Minor Aquifer	Lance-Fox Hills Aquifer
		Fox Hills Sandstone		
		Pierre Shale	Major Aquitard with Discontinuous Minor Aquifers	
		Niobrara Formation		
		Frontier Formation		
Lower Cretaceous		Mowry Shale		
		Newcastle Sandstone	Minor Aquifer	Newcastle Aquifer
		Skull Creek Shale	Aquitard	
		Cloverly Formation	Minor Aquifer	Cloverly Aquifer
Jurassic		Morrison Formation	Aquitard w/Discontinuous Minor Aquifers	
		Sundance Formation	?	?
Triassic		Chugwater Formation	Aquitard w/Discontinuous Minor Aquifers	Chugwater Aquifer
		Goose Egg Formation	Aquitard	
Permian		Hartville Formation	Major Aquifer	Paleozoic Aquifer System
Pennsylvanian		Casper Formation		
Mississippian / Devonian		Guernsey Formation	Minor Aquifer	
Cambrian		Flathead Formation		
Precambrian		Precambrian Rocks	Minor Aquifer	Precambrian Aquifer

Figure II-5. Hydrostratigraphy of the Denver-Julesburg basin, Wyoming.

The youngest water-bearing bedrock unit within the basin is the Tertiary aquifer system. This system is comprised of sandstones and conglomeratic lenses and channel deposits of the Miocene Arikaree and the Miocene-Pliocene Ogallala formations (Figure II-5). Locally, where the underlying White River Group contains coarse-grained channel deposits or zones of secondary permeability, it is considered part of the system. Elsewhere, the siltstones and claystones of the White River Group hydraulically isolate the Tertiary aquifer system from underlying water-bearing zones.

Where present, Quaternary age flood plain and terrace deposits of sand and gravel represent a major aquifer.

Available data on the hydrologic properties of and circulation of ground water within the above aquifers is presented in Chapter IV. Ground-water quality is discussed in Chapter V.

III. WATER USE

III. WATER USE

Water use within the Denver-Julesberg basin is estimated at approximately 410,000 acre-feet/year; of this total about 53 percent (218,000 acre-feet/year) is surface water and 47 percent (192,000 acre-feet/year) is ground water.

Agricultural water use accounts for about 87 percent (355,260 acre-feet/year) of the total basin water use, almost solely for irrigation. Slightly more than half of the irrigation water is supplied by the North Platte River; the Tertiary aquifer system and Quaternary aquifers supply most of the ground water.

Public and domestic water use is estimated at 7 percent (29,000 acre-feet) of the basin's annual water demand. About two-thirds of the public and domestic water demand is met by ground water, derived mainly from the Tertiary aquifer system. Interbasin transfer of surface water supplies the remaining public water needs.

Industrial use is about 6 percent (26,000 acre-feet/year) of the basin's total water needs, with surface water supplying about 80 percent of these demands. Ground water for industrial use is supplied by the Tertiary aquifer system.

Water use by economic sector is discussed below, and summarized in Table III-1 and Figure III-1. Additional data on water use are contained in Appendix A.

Table III-1. Water use in the Denver-Julesburg basin, Wyoming.

Economic Sector	Estimated Total Water Use (ac-ft/yr)	Estimated Ground-Water Use (ac-ft/yr)			Percent of Total Ground-Water Use	Estimated Surface Water Use (ac-ft/yr)			Percent of Total Surface Water Use	Percent of Total Water Use
		Total	Percent[a]	Source		Total	Percent[a]	Source		
Agriculture										
Irrigation	331,500	165,200	47	Tertiary aquifer system, Quaternary aquifers	86	186,300	53	North Platte system	85	86
Stock	3,760	3,760[b]	100	Tertiary aquifer system	2	-	-	-	-	1
Industrial Water Supply	26,000	5,000	19	Table A-1	3	21,000	81	Table A-1	10	1
Domestic Water Supply	5,505	5,505	100	Tertiary aquifer system, Quaternary aquifers	3	-	-	-	-	6
Public Water Supply										
Municipal	22,050	12,050	52	Table A-2	6	11,000	48	Douglas Creek	5	5
Non-Municipal	180	180	100	Table A-3	<0.01	0	-	-	-	<1
Non-Community	233	233	100	Table A-4	<0.01	0	-	-	-	<1
	410,228	191,928	47			218,300	53			

[a]Percent of total use for the economic sector.

[b]For calculations assuming all stock use is supplied by ground water.

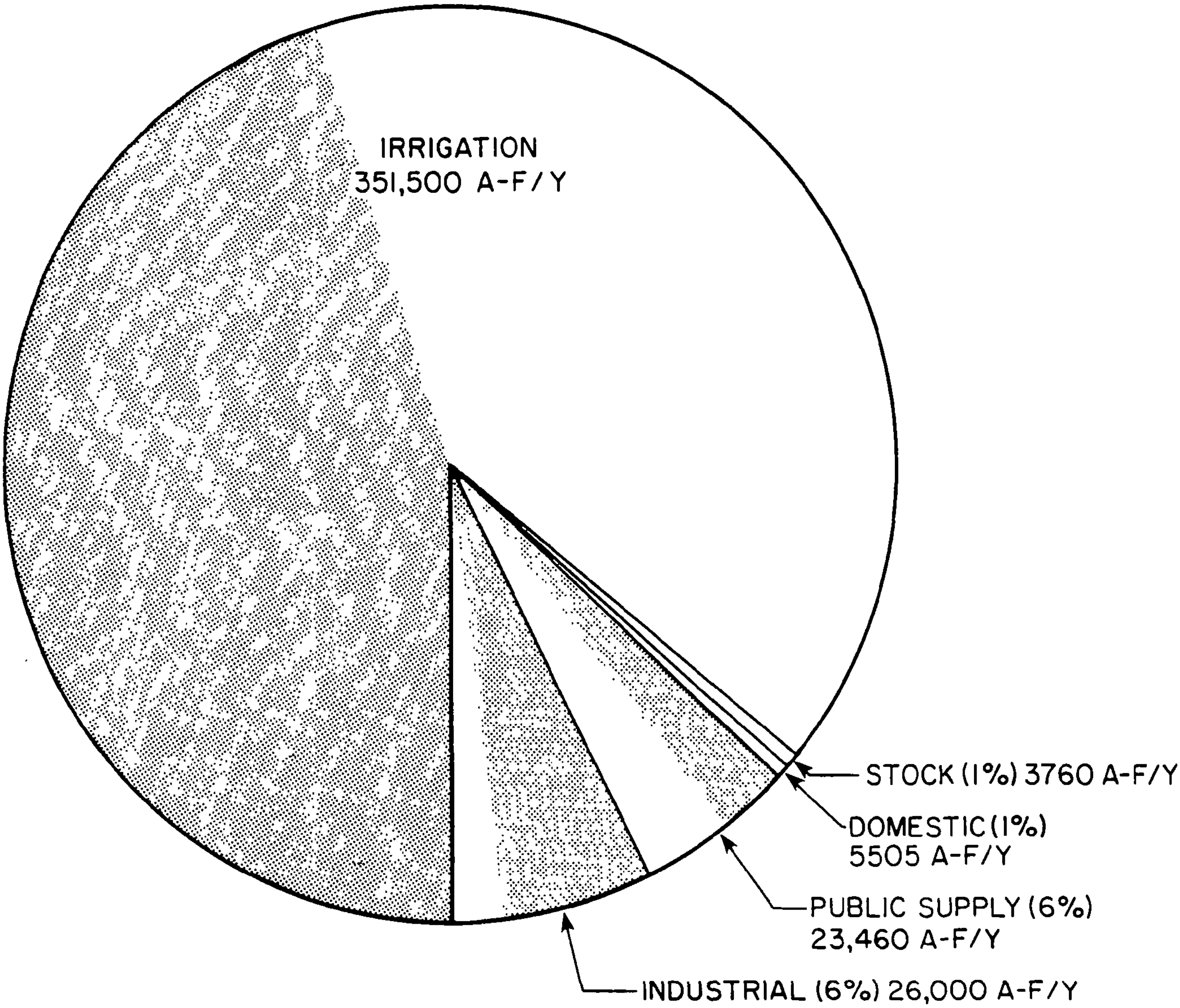

Figure III-1. Estimated water use in the Denver-Julesburg basin, Wyoming. Shaded area represents surface-water use; unshaded area represents ground-water use.

AGRICULTURAL WATER USE

Irrigation

An estimated 296,000 acres of land are permitted for irrigation within the basin. About 138,000 acres are irrigated with ground water (Wyoming State Engineer, 1981). The Wyoming Water Planning Program (1971) indicates that as of 1969, roughly 158,000 acres were permitted for surface water irrigation within the basin boundaries. More recent figures on lands irrigated with surface water are not available. However, the 1969 estimate is considered accurate, as dependable surface water supplies within the basin were largely appropriated by 1930 (Wyoming Water Planning Program, 1973).

During 1978, about 212,500 acres of irrigated land were cultivated within the basin (Wyoming Crop and Livestock Reporting Service, 1979), 72 percent of the total permitted acreage. Acreages of the various crops harvested and the average annual consumptive water requirements for the respective crop types were used to estimate a basinwide irrigation water use of about 351,500 acre-feet/year (Table III-2). Assuming a constant irrigated acreage, and similar crop type distribution on lands irrigated by surface water and by ground water, roughly 186,500 acre-feet/year of surface water and about 164,500 acre-feet/year of ground water are used for irrigation.

Use of ground water for irrigation is largely limited to specific areas within the basin. Aquifers developed for irrigation within these areas include: (1) the Arikaree aquifer (Tertiary aquifer system) in parts of northern Goshen and southern Niobrara counties; (2) the Arikaree aquifer and Quaternary aquifers in Wheatland Flats and adjacent areas; (3) Quaternary terrace aquifers and the White River aquifer

Table III-2. Irrigation water use, Denver-Julesburg basin, Wyoming.

County	Crop	Acreage[a]	Annual Consumptive[b] Irrigation Requirement (inches)	Annual Water Use (acre-feet)
Goshen	wheat-barley-oats	5,900	23.06	11,338
	beans	11,800	11.65	11,455
	beets	14,200	16.66	19,714
	corn	33,300	17.82	49,450
	hay	40,600	21.12	71,456
	county total	105,800	-	163,413
Laramie	wheat-barley-oats	9,300	21.86	16,941
	beans	700	10.98	7,686
	beets	300	15.39	1,026
	corn	2,600	16.45	3,564
	hay	25,000	19.94	41,542
	county total	37,900	-	70,759
Niobrara	wheat-barley-oats	5,200[c]	20.13	8,723
	corn	1,700[c]	16.13	2,285
	hay	10,500[c]	18.46	16,152
	county total	17,400[c]	-	27,160
Platte	wheat-barley-oats	4,700	24.14	9,474
	beans	2,100	12.97	2,270
	beets	2,600	17.66	3,826
	corn	13,000	19.23	20,833

Table III-2. (continued)

County	Crop	Acreage[a]	Annual Consumptive[b] Irrigation Requirement (inches)	Annual Water Use (acre-feet)
Platte (contd.)	hay	29,000	22.23	53,722
	county total	51,400	-	90,126
Basin Total		212,500	-	351,458

[a]Wyoming Crop and Livestock Report, 1979.

[b]From Trelease and others, 1972. Stations used to calculate county irrigation requirements are Torrington (Goshen Co.), Pine Bluffs (Laramie Co.), Lusk (Niobrara Co.), and Wheatland (Platte Co.).

[c]Includes all of Niobrara County.

(Tertiary aquifer system) in the area around Pine Bluffs and the southeast part of Goshen Hole; and (4) the Ogallala aquifer (Tertiary aquifer system) in northeast Laramie County.

The North Platte River system supplies virtually all surface water used for irrigation.

Livestock

Livestock water use within the basin is estimated at 3,760 acre-feet/year, based on cattle and sheep populations of about 239,000 and 52,000, respectively (Wyoming Crop and Livestock Reporting Service, 1979), and daily water consumption of about 15 and 3 gallons per day (gpd), respectively. Ground water is assumed to supply all stock-water use. The Tertiary aquifer system and Quaternary aquifers are the major sources of stock water, although older aquifers are used where they are not deeply buried along the basin periphery.

PUBLIC AND DOMESTIC WATER USE

Public and domestic drinking water use is estimated at 29,000 acre-feet/year (U.S. Environmental Protection Agency, 1978, and preliminary 1980 Census figures). About 18,000 acre-feet/year is derived from ground-water sources, with the remainder being surface water transferred into the basin. Public and domestic water uses are discussed separately below.

Public Water Use

Public water systems are subdivided into municipal, non-municipal community, and non-community supplies. Municipal systems are publicly owned and operated, and within the basin serve incorporated places or water-user districts. Non-municipal community systems are privately owned, and serve a permanent population of 25 or more. These systems are associated with trailer courts and one company town in the basin. Non-community systems are privately owned, serve a transient population of over 25, and are mainly restaurants, inns, schools, and recreation areas.

Municipal Water Use

Municipal water use is about 23,050 acre-feet/year. Slightly over one-half (12,050 acre-feet/year) is derived from ground-water sources, mainly the Tertiary aquifer system with lesser amounts withdrawn from the Quaternary and Lance aquifers (Appendix A, Table A-1). The remainder of municipal water demands, 11,000 acre-feet/year, is supplied by water transferred from the Little Snake River system of south-central Wyoming for the City of Cheyenne. This surface water transfer is about 75 percent of the city's water supply.

Non-Municipal Community and Non-Community Water Use

Non-municipal community and non-community water systems use about 180 and 233 acre-feet/year, respectively. The Tertiary aquifer system supplies most of this water. Tables A-2 and A-3 (Appendix A) summarize water use for these systems.

Domestic Water Use

No records of domestic water use exist for the basin. According to 1980 preliminary census figures and data from the U.S. Environmental Protection Agency (1978), roughly 28,600 persons are not served by a community water system. Based on an average use of 180 gallons/capita/day (Wyoming Water Planning Program, 1973), domestic use is estimated at 5,175 acre-feet/year. Ground water from several aquifers is used for domestic supplies (Plate 2), although the vast majority of permitted domestic wells are completed in the Tertiary aquifer system or Quaternary aquifers. Within Goshen Hole (Figure II-1) where the Lance aquifer crops out, this unit is developed for domestic needs. Older units, especially weathered surficial zones of the Precambrian, are used where they crop out along basin margin uplifts.

INDUSTRIAL WATER USE

Industrial water use within the basin is estimated at 26,000 acre-feet/year, and is supplied by about 21,000 acre-feet/year of surface water and 5,000 acre-feet/year of ground water. This estimate includes a 23,250 acre-feet/year projected water use for the Missouri Basin Power Project, currently under construction near Wheatland (Figure II-1) and scheduled for completion in the early 1980s. Ground-water withdrawals of 2,750 acre-feet/year from the White River aquifer (Tertiary aquifer system) are permitted for the project (Wyoming State Engineer, 1981), with surface water from the Greyrocks Reservoir (Laramie River) (Figure II-1) furnishing the remainder of the project's needs.

Petroleum industry water use is about 1,900 acre-feet/year. The majority of this water, about 1,680 acre-feet/year, is used by the Husky Oil Company Refinery near Cheyenne, and is purchased from the City of Cheyenne. Additional petroleum industry water use includes about 145 acre-feet/year withdrawn as a by-product of petroleum production, mainly from the Newcastle aquifer at Horse Creek oil field (T. 16-17 N., R. 68 W.); about 88 acre-feet/year is withdrawn from the White River aquifer (Tertiary aquifer system) at Horse Creek, and is used for secondary oil recovery.

Other industrial water users in the basin are Wycon Chemical Company, which withdraws about 870 acre-feet/year from the Ogallala aquifer (Tertiary aquifer system) in T. 13 N., R. 67-68 W., and Holly Sugar Company, which uses about 40 acre-feet/year, mainly from the North Platte River. Industrial water use is summarized in Table A-4 (Appendix A).

IV. AQUIFER PROPERTIES AND GROUND-WATER CIRCULATION

IV. AQUIFER PROPERTIES AND GROUND-WATER CIRCULATION

Existing data from water wells and oil well tests indicate that virtually all strata within the Denver-Julesburg basin yield water to wells. Even thick shale sequences, generally considered aquitards, will yield water from fractured zones and sandy intervals. However, only a few units are considered aquifers on a regional basis. The following sections discuss the hydrologic properties of and ground-water circulation within the important aquifers and aquifer systems identified in the basin. Hydrologic and lithologic characteristics for all stratigraphic units within the basin are summarized in Table IV-1. The well numbering system used in this report is explained in Appendix B.

PALEOZOIC AQUIFER SYSTEM

The Paleozoic aquifer system consists of up to 1,300 feet of Cambrian through Permian age sandstones and carbonates. Formational members of this system include the Cambrian Flathead Sandstone, the Mississippian-Devonian Guernsey Formation, and the Pennsylvanian-Permian Casper and equivalent Hartville formations.

The Flathead Sandstone, present in parts of the northern basin, consists of up to 60 feet of quartzitic sandstone and conglomerate (Morris and Babcock, 1960). The Guernsey Formation contains mainly limestones and dolomites with minor interbedded shales and siltstones. Maximum thickness is about two hundred feet. In the far northern part of the basin the equivalent Madison Limestone is present and varies from 100 to 300 feet in thickness (Eisen and others, 1980).

Table IV-1. Lithologic and hydrologic characteristics of rock units in the Denver-Julesburg basin, Wyoming.

ERA	System	Series	Geologic Unit	Thickness (ft)	Lithologic Characteristics[a]	Hydrologic Characteristics
CENOZOIC	Quaternary	Recent and	Alluvial flood plain and terrace deposits	0-200	Fine sands, silts, and clays, to poorly sorted coarse sands and gravels, cobbles and boulders locally.	Major aquifer. Main deposits located along N. Platte River, Wheatland Flats Pine Bluffs Lowland. Developed heavily for irrigation in these areas. Yields are generally 500-1,000 gpm but exceed 3,000 gpm locally. Permeability: 700-9,600 gpd/ft^2 Transmissivity: 6,500-1,650,000 gpd/ft Specific Capacity: 2.5-250 gpm/ft
		Pleistocene			Sand, gravel, cobbles, and boulders, contain some lenses of clay, silt, and fine sands.	
	Tertiary	Pliocene	Ogallala Formation	0-330	Heterogeneous deposits of gravel, sand, and silt containing some cobbles and boulders. May be either unconsolidated or well cemented. Increases in thickness in southern portion of study area. Present mainly as channel deposits in Platte and Goshen counties.	Major aquifer. Member of Tertiary aquifer system. Present mainly in Laramie County and is utilized for irrigation, municipal and industrial supplies. Yields of several hundred gpm common, and coarse channel deposits yielding over 1,000 gpm. Permeability: 160-4,000 gpd/ft^2 (?) Transmissivity: 1,610-700,000 gpd/ft Specific Capacity: 0.26-229 gpm/ft
		Miocene	Arikaree Formation	0-1200	Loose to moderately cemented very fine to fine grained sand and silt. The basal unit consists of coarse channel conglomerate.	Major aquifer. Member of Tertiary aquifer system. Present over much of the basin. Developed for irrigation, municipal, and industrial supplies. Yields are commonly several hundred gpm to over 1,000 gpm locally. Permeability: 1.3-375 gpd/ft^2 Transmissivity: 110-77,000 gpd/ft Specific Capacity: 0.2-230 gpm/ft
		Oligocene	White River Group	0-1120	Argillaceous siltstone with channel deposits of sand and sandstone, localized beds of limestone, moderately thick beds of clay and a few beds of volcanic ash.	Aquitard with discontinuous major aquifers. Member of Tertiary aquifer system where coarse channel deposits or zones of secondary permeability are present. Yields over 1,000 gpm possible often in these areas. Elsewhere yields are low, although adequate for stock or domestic use. High yields available in southeast and east-central basin. Permeability: <0.02-36 gpd/ft^2 Transmissivity: 480-780,000 gpd/ft Specific Capacity: 0.4-257 gpm/ft
			Brule Formation	0-420		

Table IV-1. (continued)

ERA	System	Series	Geologic Unit	Thickness (ft)	Lithologic Characteristics[a]	Hydrologic Characteristics
CENOZOIC (cont.)	Tertiary (cont.)	Oligocene	Chadron Formation	0-700	Consists mainly of bentonitic, loosely to modererately cemented clay and silt. Contains channel deposits of sandstone and conglomerate. Lower unit consists of variegated fluviatile deposits.	Aquitard with discontinuous minor aquifers. Developed for stock and domestic use in Goshen Hole area. Dispersed, coarse-grained channel deposits are major water-bearing zones. Yields are commonly less than 15 gpm.
MESOZOIC	Cretaceous	Upper Cretaceous	Lance Formation	0-1500	Sandstone with beds of soft shale and coal. Absent in northern portion of study area.	Minor aquifer. Developed mainly where exposed in Goshen Hole for stock or domestic supplies; also supplies town of Yoder. Yields generally <25 gpm to 100 gpm locally. Permeability: 7.5-125 gpd/ft^2 Transmissivity: 450-5,000 gpd/ft Specific Capacity: 0.4-257 gpm/ft
			Fox Hills Sandstone	0-550	Medium-grained silty sandstone interbedded with shale.	Minor aquifer (?). Not developed as a water source within basin; hydrologic properties unknown.
			Pierre Shale	0-5700	Predominantly shale containing thin to moderately thick beds of sandstone.	Major aquitard with discontinuous minor aquifers. Dispersed sandstone beds yield 10-25 gpm to stock/domestic wells in outcrop areas.
			Niobrara Formation	0-500	Calcareous shale with a 20-foot bed of nearly pure chalk near the middle. Contains thin bentonite beds in some areas. Base is a 25-foot bed of dense sandstone.	Aquitard with discontinuous minor aquifers. Not developed as a water source within basin. Basal sandstone will likely yield water to wells.
			Frontier Formation	0-1400±	Mainly shales with beds of limestone and sandstone. Includes formations from top of Lower Cretaceous to base of Niobrara Formation.	Aquitard with discontinuous minor aquifers. Not developed as a water source within basin. Dispersed sandstones might yield water. Porosity: 4-17% Permeability: <0.05 gpd/ft^2

Table IV-1. (continued)

ERA	System	Series	Geologic Unit	Thickness (ft)	Lithologic Characteristics[a]	Hydrologic Characteristics
MESOZOIC (cont.)	Cretaceous (cont.)	Lower Cretaceous	Mowry Shale	80-220±	Siliceous shale containing numerous beds of bentonite. Formation thins out to the southeast.	Aquitard. Not developed as a water source within basin; hydrologic properties unknown.
			Newcastle Sandstone	0-1100±	Coarse-grained massive sandstone interbedded with siltstone and claystone. Equivalent to the Muddy Sandstone.	Minor aquifer. Yields of 10-20 gpm likely, sufficient for stock or domestic use. Porosity: 2-25% Permeability: 0-4.7 gpd/ft^2 Transmissivity: 0-41 gpd/ft
			Skull Creek Shale	70-200+	Fissile shale interbedded with limestone.	Aquitard. Not developed as a water source within basin. Hydrologic properties unknown.
			Cloverly Formation	0-300	Sandstone, conglomerate, quartzite, siltstone and shale. In outcrop upper and lower sandstone units are separated by shale. Equivalent to Inyan Kara Group to the north of study area.	Minor aquifer. Yields 10-20 gpm in far northeast part of basin, 33 gpm to spring in north-central basin. Porosity: 7.3-12.2% Permeability: 0-0.3 gpd/ft^2
	Jurassic		Morrison Formation	0-250	Variegated shale, thin sandstone, and limestone beds.	Aquitard with discontinuous minor aquifers. Yields 5 gpm to one well along western basin flank. Sandstone units are local aquifers.
			Sundance Formation	0-550	Predominantly sandstone and sandy shale.	Minor aquifer (?). Not developed as a water source within basin. Sandstones would likely yield adequate stock and domestic water supplies.
	Triassic		Chugwater Formation	0-675	Siltstone and very fine-grained sandstone.	Aquitard with discontinuous minor aquifers. Yields 5-15 gpm to stock/domestic wells along west basin margin.

Table IV-1. (continued)

ERA	System	Series	Geologic Unit	Thickness (ft)	Lithologic Characteristics[a]	Hydrologic Characteristics
MESOZOIC (cont.)	Triassic (cont.)		Goose Egg Formation	0-450	Siltstone and sandstone interstratified with limestone, dolomite, and gypsum.	Aquitard. Not developed as a water source within basin. Sandstones may produce small yields.
PALEOZOIC	Permian Pennsylvanian		Hartville Formation (Casper Fm. equivalent)	0-1225	Primarily carbonate sequence with interbedded silts and shales and distinct upper and lower sandstone members ("Converse sands" and Fairbank Member, respectively). To the southwest, near the Laramie Mountains, sandstone percentage increases and shale and limestone percentages decrease (Casper Formation). Sandstones are arkosic, quartzitic and cross-bedded.	Major aquifer. Member of Paleozoic aquifer system. Sandstones and fractured carbonates represent major water-bearing zones. Yields generally less than 100 gpm, but locally up to 800 gpm. Where fractured, high yields are likely. Permeability: 0.7-86 gpd/ft^2 Transmissivity: 340-10,300 gpd/ft Specific Capacity: 0.06-4.8, possibly 400(?) gpm/ft
	Mississippian Devonian		Guernsey Formation	0-200	Cherty, massive to thin-bedded carbonates with minor dolomitic shale and siltsonte.	Minor aquifer. Member of Paleozoic aquifer system. Not generally developed as a water source within basin. One well in north-central basin reportedly yields 750 gpm.
	Cambrian		Flathead Sandstone	0-60±	Coarse-grained conglomeratic quartzitic sandstone.	Minor aquifer (?). Member of Paleozoic aquifer system. Not developed as a water source within basin. Will likely yield small quantities of water.
	Precambrian		Igneous and Metamorphic Rocks	?	Complex sequence of gneiss, schist, granite, phyllite, quartzite, and limestone; intruded by ultrabasic rocks and permatite dikes.	Minor aquifer. Weathered surficial zones will yield adequate water for stock and domestic use.

[a]Data sources: Darton and others (1910), Maughan (1963), Maughan (1964), Denson and Botinelly (1949), Denson and Bergendahl (1961), Rapp and others (1953), Rapp and others (1957), Condra and Reed (1950), Morris and Babcock (1960), and McGrew (1953).

The Pennsylvanian-Permian Casper Formation, present along the southern part of the Laramie Mountains, consists of 1,100 to 1,200 feet of interbedded limestones and sandstones. Limestone units reach thicknesses of over 150 feet, with the sandstone interbeds rarely exceeding 80 feet in thickness. Total sandstone content of the Casper is 30 to 40 percent in this area (Eisen and others, 1980). The Hartville Formation is present in the Hartville Hills area, and consists primarily of carbonates and fine-grained clastic rocks, with lesser amounts of sandstone. Three sandstone horizons, commonly termed the "Converse" and "Leo" sands and the Fairbank Member, exist within the upper, middle, and lower parts of the Hartville, respectively. The "Converse" sands and Fairbank Member reach 100 feet in thickness locally, while the "Leo" sands are considerably thinner and locally absent. Where the Hartville Formation crops out in the Hartville Hills, the "Converse" sands have been largely eroded away. Total sandstone percentage of the Hartville Formation is generally less than 20 percent and decreases to the east (Eisen and others, 1980).

The Paleozoic aquifer system crops out along the southern part of the Laramie Mountains, in the Richeau dome, and in the Hartville Hills (Figure II-3 and Plate 3). Between the Richeau dome and Hartville Hills, and westward to the Laramie Mountains, the system is absent (Figure IV-1). Throughout much of the basin, the system lies at great depths, exceeding 10,000 feet along the basin axis.

The low permeability shales of the overlying Permian-Triassic Goose Egg Formation isolate the Paleozoic aquifer system from younger aquifers. Precambrian granites and metasediments underlie the system.

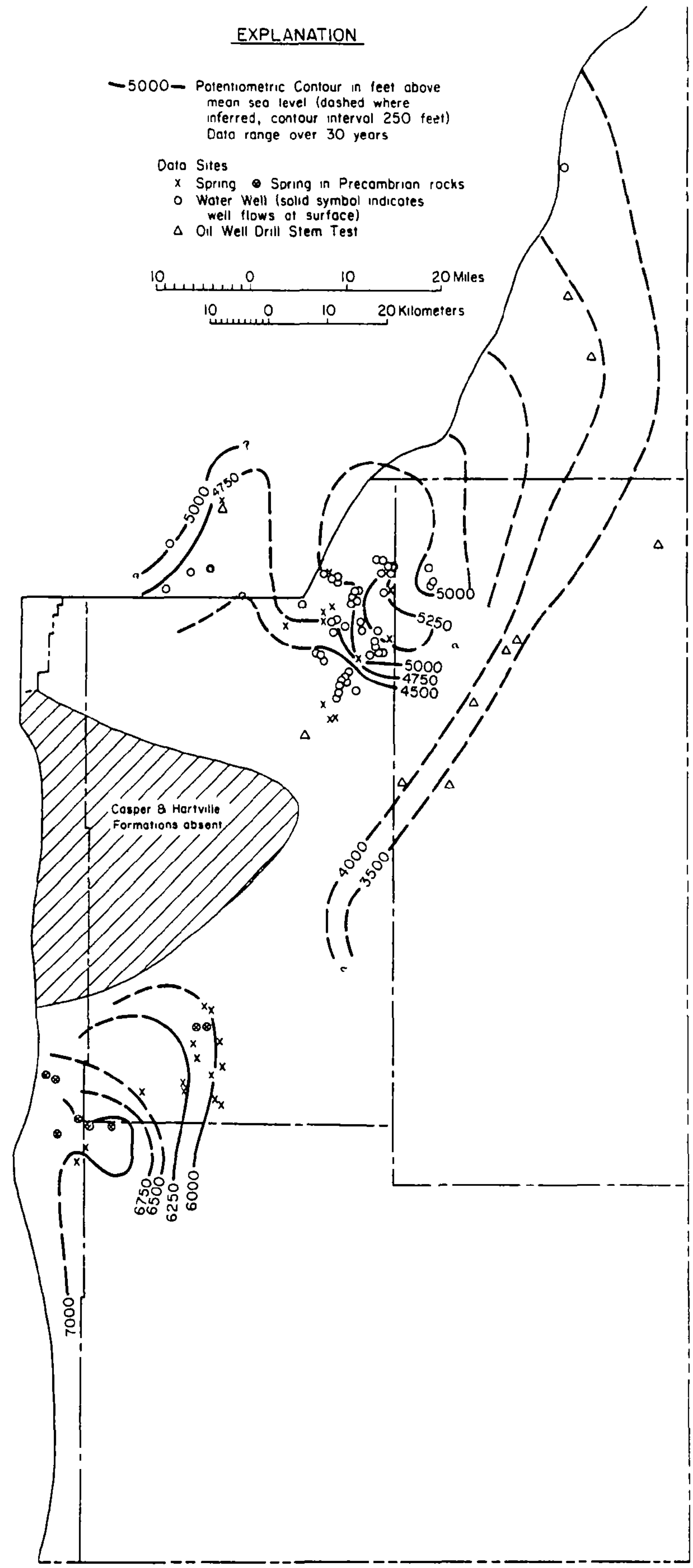

Figure IV-1. Potentiometric map of the Paleozoic aquifer system, Denver-Julesburg basin, Wyoming (modified from Eisen and others, 1980).

Identified as major water-producing zones within the Paleozoic aquifer system are the permeable sandstones of the Casper and Hartville formations, and, where structural deformation has produced significant fracturing, carbonate rocks of the Casper, Hartville, and Guernsey formations. Eisen and others (1980) identify areas along the Laramie Mountains and within the Richeau dome and Hartville Hills areas where significant fracturing of the Paleozoic strata has occurred. Unfractured carbonate rocks within the system have generally low permeabilities and are considered minor aquifers. Water production potential of the Flathead Sandstone is largely unknown.

Hydrologic Properties

Available data on the hydrologic properties of the Paleozoic aquifer system within the Denver-Julesburg basin are sparse. No reported permeability or transmissivity values exist. Data from pump tests of three wells located one to three miles north of the basin boundary (T. 29 N., R. 68-69 W.) indicate that, where undeformed, the "Converse" sands have permeabilities between 22 and 86 gallons per day per square foot (gpd/ft^2) and transmissivities between 2,000 and 10,300 gallons per day per foot (gpd/ft). One test in unfractured Hartville carbonates in the same area indicates permeability and transmissivity of 0.7 gpd/ft^2 and 340 gpd/ft, respectively (Welder and Weeks, 1965).

Data from the Laramie basin indicate that, where fractured, permeabilities of the Casper aquifer are 125 to 300 gpd/ft^2 and locally 10,000 gpd/ft^2. Associated transmissivities vary from 8,000 to 195,000 gpd/ft, and may exceed 1,000,000 gpd/ft (Lundy, 1978; Richter, 1980). Fractured Paleozoic zones within the Denver-Julesburg basin may have permeabilities and transmissivities of similar magnitude to those of the Casper aquifer in the Laramie basin (Eisen and others, 1980).

Available specific capacity data for the Paleozoic aquifer system within the basin are for Hartville carbonates in the Hartville Hills area (Table IV-2), and vary from less than 0.1 to 5.0 gallons per minute per foot of drawdown (gpm/ft). Well yields are generally 10 gpm or less from Hartville carbonates, and up to 80 gpm from the "Converse" sands. Two anomolously high yields, 750 and 800 gpm, are reported for the Guernsey and Hartville carbonates, respectively. These high yields suggest the presence of secondary permeability.

Ground-Water Circulation

A potentiometric map for the Paleozoic system is shown in Figure IV-1. Outcrop areas in the Laramie Mountains, Richeau dome, and Hartville Hills act as recharge zones. Flow from the Laramie Mountains/ Richeau dome outcrops is to the east and northeast, into the basin. Available data indicate flow from the Hartville Hills outcrops is to the southwest, converging along the Broom Creek syncline. Additional flow is to the northeast, roughly paralleling basin-bounding structures. Flow to the southeast is disrupted by the Whalen fault. The nature of this disruption is not currently known.

Recharge to the system is through direct outcrop infiltration of precipitation and leakage from streams and reservoirs. Estimates by Eisen and others (1980) indicate outcrop areas on the east flank of the Laramie Mountains and within the Hartville Hills receive 5,200 and 8,400 acre-feet/year of recharge, respectively, from precipitation. An unknown quantity is discharged by springs, and therefore limits intrabasin recharge. Additionally, about 6,600 acre-feet/year enters

Table IV-2. Hydrologic properties of the Paleozoic aquifer system, Denver-Julesburg basin, Wyoming.

Well Location	Test Duration (hours)	Drawdown (ft)	Discharge (gpm)	Specific Capacity (gpm/ft)	Transmissivity (gpd/ft)	Storage Coefficient	Permeability (gpd/ft^2)	Remarks[a]	Source[b]
27/65-7 ac			750					Well completed in Guernsey(?) aquifer	10
27/66-15 aaa			15(?)					Well completed in Hartville and Guernsey aquifers	9
27/66-22 cb	4	14	32	2.3					9
27/66-27 cb	4		7						9
27/70-24 ad	4	2(?)	800	400(?)					9
28/65-14 dba		50	3	0.06					9
28/65-20 ccc			3						9
28/65-30 ddd	1	70	3	0.04					9
26/66-1 bcd	2	5	20	4.0					9
26/66-2 bac	2	0	20						9
26/66-13 cdd	1	0	10						9
26/66-24 cad	1	1	5	50					9
26/66-28 abc			5						9
29/64-19 bad	1	0	10						9
29/64-30 dcb			3						9
29/65-21 cdb	1	30	10	0.33					9
29/66-14 ca			20						9
29/66-15 bb			2						9
29/66-20 cab			5						9
29/66-26 bd			3						9
29/66-35 dac	2		40						9
29/66-35 dad	2	0	40						9
29/68-20 abb	0.5	126	33	0.3					3
29/68-20 abd	24	30	78	2.6	10,300	2×10^{-4}	86	Well in "Converse Sand" of Hartville aquifer; well completed several miles north of basin boundary.	4
29/69-24 dbc	12	67	38	0.6	340		0.7	Well in "Converse Sand" of Hartville aquifer; well completed several miles north of basin boundary.	4
29/69-24 dbc	24	27	60	2.2	2,100		25	Well in "Converse Sand" of Hartville aquifer; well completed several miles north of basin boundary.	4
29/69-33 bac	12	5.8	14.6	2.5	2,000		22	Well in "Converse Sand" of Hartville aquifer; well completed several miles north of basin boundary.	4

[a]Data are for the Hartville aquifer unless otherwise noted.

[b]Data sources for hydrologic properties are listed in Table IV-10, unless given.

the system as leakage from the Guernsey Reservoir-North Platte River system (Eisen and others, 1980), just north of the basin boundary. Total recharge to the system, therefore, is about 20,000 acre-feet/year, less spring discharge.

MESOZOIC AQUIFERS

The sequence of rocks from the Triassic Chugwater Formation through the Upper Cretaceous Pierre Shale is composed of primarily low permeability shales and siltstones. Several permeable sandstone horizons within this sequence are identified as minor aquifers. These include: (1) discontinuous sandstones within the Triassic Chugwater and Jurassic Morrison formations; (2) two sandstone units within the Lower Cretaceous Cloverly Formation; (3) the Lower Cretaceous Newcastle Sandstone; (4) discontinuous sandstones within the Upper Cretaceous Frontier Formation; and (5) discontinuous sandstones within the Upper Cretaceous Pierre Shale (Table IV-1). Development of these aquifers, for stock and domestic purposes, is limited to outcrop and near-outcrop areas adjacent to the Laramie Mountains and along the flanks of Old Woman anticline in the far northeast part of the basin.

Hydrologic Properties

Hydrologic properties of Mesozoic aquifers are poorly known, and limited to data from the petroleum industry (Table IV-3). The majority of the data are for the Newcastle aquifer, historically a major zone for oil exploration in the area. Newcastle porosities are generally about 15 percent, and locally exceed 20 percent. Reported permeabilities vary from essentially 0 to about 5.0 gpd/ft^2, and tested interval transmissivities range up to about 40 gpd/ft. Sparse data from other Mesozoic

Table IV-3. Hydrologic properties of Mesozoic aquifers, Denver-Julesburg basin, Wyoming.[a]

Location	Aquifer	Porosity (%)	Permeability (millidarcies)	Permeability (gpd/ft^2)	Tested Interval Thickness (ft)	Tested Interval Transmissivity (gpd/ft)	Depth to Tested Interval (ft)
13/61-8 db	Newcastle	8-19	<1-1	<0.02			7,820
13/63-4 aa	Newcastle	7-12	-	-			8,350
14/60-5 bc	Newcastle	17.7-20	130-249	2.4-4.5			7,362
14/60-22 ac	Newcastle	13.7	13-55	0.2-1			7,549
14/60-27 cb	Newcastle	23.3	43-63	0.8-1.1			7,346
14/60-27 dc	Newcastle	22	64	1.1	7	8	7,484
14/60-27 cc	Newcastle	18.6	24	0.4			7,365
14/60-29 bc	Newcastle	6.2-17.5	<3	<0.05			7,406
14/60-30 da	Newcastle	9-17	<14	<0.25			7,419
14/60-33 ca	Newcastle	18	5	0.09	5	<1	7,521
15/60-15 db	Newcastle	8.6-13	2-121	0.04-2.2			7,513
15/61-28 bd	Newcastle	17.2	71	1.3	14	18	7,653
15/61-29 da	Newcastle	13.8	39	0.8	6	5	7,700
15/67-19 bb	Newcastle	2.9-12	<1	<0.02			10,442
16/61-19 db	Newcastle	17.3	99	1.8	23	41	7,673
16/62-19 db	Newcastle	17.7	76	1.4	10	14	8,036
16/62-19 bd	Newcastle	11.9	21	0.4	9	4	8,082
16/62-20 bd	Newcastle	15.7	51	0.9	14	12.6	7,969
16/64-5 da	Newcastle	12.6	3	0.05	11	<1	8,729
16/64-23 bb	Newcastle	13.7	<3.2	<0.06			8,591
17/62-14 bb	Newcastle	14.7-19	2-256	0.04-4.7			7,889
17/62-19 da	Newcastle	10.9-22.2	2-138	0.04-2.5			8,107
17/63-13 bb	Newcastle	6.8-23.7	1-45	<0.02-0.8			7,990
17/64-5 dd	Newcastle	4.5-23.3	0-61	0-1.1			8,723
18/64-35 cc	Newcastle	3.4-13.4	<1	<0.02			8,400
19/60-15 aa	Newcastle	21	160	2.9	2	6	6,670
19/60-15 da	Newcastle	25	172	3.1			6,762
20/67-26 cc	Newcastle	3.7-11.8	<0.6	<0.05			9,204
21/63-10 aa	Newcastle	4.6-7.3	<0.1	<0.02			8,004
21/64-15	Newcastle	12.7	0.2	<0.02			8,812
22/62-7	Frontier	4.4-16	0-1.3	<0.02	24	<1	6,953
22/62-7	Newcastle	7.8-16.1	0.1-1.4	<0.02			7,724
22/63-27	Cloverly	7.3-12.2	0.1-18	0-0.3			8,131
23/61-4	Newcastle	13-20	0-63	0-1.1			6,984
23/62-27	Frontier	7.4-17.8	<3	<0.05			6,491
23/66-5	Frontier	4.4-15.9	0.2-1.4	<0.02			3,538
23/67-1	Newcastle	1.2-15.6	0-2.4	<0.04			3,003
24/61-20	Newcastle	5.2-19.5	0-128	0-2.3			6,578
25/60-31	Mowry	2.4-8.4	0-0.1	<0.02			6,265
25/62-25	Newcastle	2-18	0-137	0-2.5			6,265
26/60-31	Newcastle	19.2-22.1	1.2-2.2	<0.04			6,646
28/60-22	Newcastle	4.1-21.5	0-69	0-1.2			5,341
28/60-35	Newcastle	16-25.8	1.1-18	0.02-0.3			5,575
30/62-1	Newcastle	13.8-23.4	6.7-168	0.12-3.1			2,566

[a]Data source: 11 (see Table IV-10).

aquifers indicate generally lower porosities and permeabilities, relative to the Newcastle aquifer (Table IV-3).

Well and spring yields from Mesozoic aquifers are given in Table IV-4. Yields are generally about 10 gpm. The highest reported yield is 33 gpm from a group of Cloverly aquifer springs (29/68-35 cb). In areas immediately north of the Denver-Julesburg basin, the Cloverly is an important aquifer capable of yields up to 250 gpm (Crist and Lowry, 1972) and may represent an important, though currently undeveloped, water source in parts of the basin.

Ground-Water Circulation

Ground-water movement within Mesozoic aquifers is generally unknown. The dispersed, discontinuous nature of sandstone aquifers within all units except the Cloverly make interpretation of potentiometric data difficult.

Stock (1981) has developed potentiometric data for the Cloverly aquifer in the far northern end of the basin. In this area, the Cloverly crops out along the east flank of the Old Woman anticline (Figure II-3). Outcrop recharge waters move downdip, to the east, into South Dakota. Artesian conditions exist east of outcrop, with several flowing wells reported.

LANCE/FOX HILLS AQUIFER

The Lance/Fox Hills aquifer consists of the Upper Cretaceous Lance Formation and Fox Hills Sandstone, and is comprised of about 1,500 feet of fine-grained sandstones with occasional interbedded shales and thin coal layers (Table IV-1). The main exposure of this aquifer is within the Goshen Hole area, with small outcrop areas present locally along the

Table IV-4. Yields of Mesozoic aquifers, Denver-Julesburg basin, Wyoming.

Location	Aquifer	Yield[a] (gpm)
14/69-5 aa	Pierre	10
14/69-5 da	Pierre	6
14/69-5 bb	Pierre	12
14/69-5 cb	Pierre	8
14/69-31 ab	Pierre	10
16/70-4 dd	Pierre	25
17/69-29 cb	Pierre	4
17/70-24 dd	Pierre	25
17/70-35 db1	Pierre	10
17/70-35 db2	Pierre	17.5
17/70-35 db3	Pierre	17.5
19/70-3 db	Pierre	5
19/70-31 ca	Chugwater	10
19/70-31 db1	Chugwater	10
19/70-31 db2	Chugwater	7.5
19/70-31 db3	Chugwater	10
19/70-32 ca	Chugwater	7.5
20/69-23 ad	Chugwater	15
20/69-23 cd	Chugwater	15
20/69-25 bc	Chugwater	3
20/69-25 dd	Chugwater	5
20/69-26 cd	Morrison	5
29/68-35 cb	Cloverly	33
35/60-27 ab	Pierre	10
36/61-5 bb	Newcastle	15
36/61-24 bc	Cloverly	10
36/62-3 bd	Cloverly	0.2
37/62-1 ab	Cloverly	7
38/61-15 ca	Cloverly	18

[a]Data source: 9 (see Table IV-10).

east flank of the Laramie Mountains. Throughout most of the basin the aquifer lies at depths of 1,000 feet or more. The Lance/Fox Hills aquifer is isolated from older water-bearing zones by the underlying Pierre Shale, a thick (±5,000 feet) regional aquitard. Low permeability claystones and siltstones of the Oligocene White River Group act as the overlying confining unit (Table IV-1).

The fine-grained sandstones comprising most of the Lance/Fox Hills are the major water-producing zones within this aquifer. Locally, interbedded low-permeability shales cause hydrologic isolation of discrete sandstone beds, forming subaquifers. However, these shales are generally discontinuous, and the Lance/Fox Hills is regionally considered as one aquifer.

Hydrologic Properties

Hydrologic data for the Lance/Fox Hills aquifer are available from wells completed in the Lance Formation in the Goshen Hole Lowland (Figure II-1) where the formation crops out. No data are available for the Fox Hills Sandstone within the basin.

No reported permeability or transmissivity data exist for the Lance/Fox Hills aquifer within the basin. Order of magnitude estimates of these parameters using specific capacities (Theis and others, 1963) and thickness of producing zones are given in Table IV-5. Permeabilities vary from 7.5 to 125 gpd/ft^2, with transmissivities of 400 to 5,000 gpd/ft. These data are derived from fairly shallow (<300 feet) stock and domestic wells. Wells penetrating a complete section of the aquifer would likely have higher transmissivities.

Reported specific capacities for the Lance aquifer vary from less than 0.1 to 3.0 gpm/ft drawdown. Well yields are generally 25 gpm or

Table IV-5. Hydrologic properties of the Lance aquifer, Denver-Julesburg basin, Wyoming.

Well Location	Test Duration (hours)	Drawdown (ft)	Discharge (gpm)	Specific Capacity (gpm/ft)	Transmissivity (gpd/ft)	Storage Coefficient	Permeability[a] (gpd/ft^2)	Remarks	Source[b]
21/62-13 cc1	4	20	3.5	0.17					10
21/62-13 cc2	24	57	15	0.20	450		7.5	Transmissivity estimated from specific capacity.	10
22/60-6 ba	48	6	16.7	2.80	5,000		125	Transmissivity estimated from specific capacity.	
22/62-11 da	2	100	7	0.07					10
22/62-15 ba	8	218	10	0.05	775		19	Transmissivity estimated from specific capacity.	10
22/62-17 aa	0.5	2	4	2.0					10
22/64-34 ca	4	29	12	0.41					10
23/60-20 cd	24	35	10	0.29	400		11.4	Transmissivity estimated from specific capacity.	10
23/60-21 da	24	15	18	1.20	3,500		16	Transmissivity estimated from specific capacity.	10
23/60-31 bb	18	35	25	0.70	1,300		30	Transmissivity estimated from specific capacity.	10
23/60-32 ab	1	15	15	1.0					10
23/61-2 ab	48	10	16	1.6	3,200		25	Transmissivity estimated from specific capacity.	10
23/61-14 cb	8	12	9	0.75	1,500			Transmissivity estimated from specific capacity.	10
23/62-34 cd	?	67	100	1.5				Discharge estimated.	10
25/63-25 bd	?	6.6	31	4.7					10

[a]Permeability from transmissivity estimate ÷ reported thickness of producing zone(s).

[b]Data sources for hydrologic properties are listed in Table IV-10.

less, but reach 100 gpm locally (Table IV-5). Larger yields are possible from wells penetrating a greater thickness of the aquifer, although Rapp and others (1957) state it is doubtful that supplies adequate for irrigation or large industrial applications could be obtained from this aquifer.

Ground-Water Circulation

Regional ground-water movement within the Lance/Fox Hills aquifer is unknown. Downdip flow to the east from near-vertical outcrops along the Laramie Mountains is likely. Rapp and others (1957) compiled water data for wells completed in the unconfined Lance sands within a portion of Goshen Hole. These data indicate ground-water flow toward the North Platte River. Deeper Lance wells within Goshen Hole produce water under artesian pressure, indicating that interbedded shales act as confining zones.

TERTIARY AQUIFER SYSTEM

The Tertiary aquifer system consists primarily of up to 1,500 feet of permeable sandstones, conglomeratic lenses, and channel deposits. Included within the system are the Miocene Arikaree and Miocene-Pliocene Ogallala formations.

The Arikaree Formation consists of up to 1,200 feet of very fine to fine-grained sandstones with scattered coarse-grained channel deposits, beds of siltstone, volcanic ash, and, commonly a basal conglomerate (Morris and Babcock, 1960; Lowry and Crist, 1967). The Arikaree is present over most of the basin, except uplifted areas along the west and north margins and within the Goshen Hole Lowland (Figure II-1 and Plate 7).

The Ogallala Formation is highly heterogeneous and consists of lenticular beds and channel fills of semiconsolidated to unconsolidated sand and gravel with occasional beds of siltstone, clay, and limestone. The Ogallala Formation is present in Laramie County, with equivalent rocks found in parts of Platte County. The maximum thickness of the formation is 330 feet (Lowry and Crist, 1967).

Regionally, the Tertiary aquifer system is isolated from deeper aquifers by the underlying White River Group, which consists of an upper and lower member, the Brule and Chadron formations, respectively. The Brule Formation consists primarily of massive siltstone, and reaches thicknesses of over 400 feet (Morris and Babcock, 1960). The Chadron Formation consists of up to 700 feet of claystone, siltstone, and dispersed sandstone. Low permeability within this sequence is indicated by: (1) Brule Formation primary permeability less than 0.2 gpd/ft^2 (Rapp and others, 1957), and (2) spring discharge at the contact between the Brule and Arikaree formations (Rapp and others, 1953; 1957).

Locally, permeable zones exist within the White River Group due to the presence of coarse-grained channel deposits or, within the Brule Formation, through secondary permeability development. The origin of secondary permeability within the Brule Formation has been ascribed to fractures and fissures, which are prominent features of many Brule outcrops and penetrate the unit to unknown depths (Rapp and others, 1957; Morris and Babcock, 1960). Lowry (1966) reported that pipes, tubular openings in semiconsolidated rock, contribute to Brule permeability locally. Crist and Borchert (1972) indicate that where the Brule is a calcareous siltstone, solution of soluble minerals also enhances Brule permeability. Where coarse-grained deposits or zones of secondary permeability exist within the White River Group, the unit is not an effective barrier to ground-water flow, and is considered part of the Tertiary aquifer system.

Identified as major water-producing zones within this system are lenses, beds, and channel deposits of coarse-grained sandstones and conglomerates found within all formational members of the system, and zones of secondary permeability found primarily in the Brule Formation. Yields from these zones are adequate for irrigation, municipal, and industrial water supplies. The massive, fine-grained sandstones of the Arikaree Formation have generally lower permeabilities but are sufficiently thick (300-1,000 feet) to yield more than adequate supplies for stock and domestic use, and locally for municipal and irrigation demands (Morris and Babcock, 1960; Whitcomb, 1965).

Hydrologic Properties

Hydrologic properties of the Tertiary aquifer system are highly variable, due to differing lithologies and thicknesses of water producing zones. Numerous data are available due to the widespread development of the system as a water source.

Permeability

Permeability data are available for all formational members of the Tertiary aquifer system. The highest permeability estimates (5,000 to 6,000 gpd/ft^2) are from zones of secondary permeability within the White River aquifer (Brule Formation) (Table IV-6) in southwestern Goshen County (Figure II-1). Crist and Borchert (1972) and Borchert (1976) investigated Brule secondary permeability in Goshen County and in southeast Laramie County with a down-hole camera. They described many

Table IV-5. Hydrologic properties of the White River aquifer, Tertiary aquifer system, Denver-Julesburg basin, Wyoming.

Well Location	Test Duration (hours)	Drawdown (ft)	Discharge (gpm)	Specific Capacity (gpm/ft)	Transmissivity (gpd/ft)	Storage Coefficient	Permeability (gpd/ft^2)	Remarks	Source[a]
12/60-5 baa	?	26.8	685	25.6					7
12/60-6 ccd	?	54.3	780	14.4					8
13/60-5 acb	?	4.3	1,105	257					8
13/60-8 bbb	?	15.1	600	39.7					8
13/60-18 dda	?	20	750	37.5					2
13/60-31 aba	?	31.8	476	15.0					8
13/62-26 caa	?	11	400	36.6					2
13/69-16 cbb	?	39	130	3.3					2
14/60-6 dbb	?	36	732	20.3					8
14/60-15 dbb	?	6	500	83.3					8
14/60-16 dcc	?	14.8	1,400	94.7					8
14/60-17 dcb	?	42.2	422	10					8
14/60-28 bbb	?	11.8	1,465	124.2					8
14/60-29 bbc	?	9.8	1,355	138.3					8
14/60-29 cbd	?	13	1,200	92.3					8
14/60-30 bcb	?	8.9	507	57					8
14/60-32 aba	?	6	1,000	166.7					8
14/60-32 dbb	?	7.5	1,105	147.3					8
14/61-21 bbb	?	12	490	40.8					8
14/61-21 caa	?	35	600	17.1					8
14/61-35 abc	?	15	360	24.0					8
14/62-11 dbb	?	20	1,600	80.0					8
14/62-24 bbb	?	11.9	805	67.6					8
15/60-34 bbb	?	13	585	45.0					8
15/69-27 ccd	?	123	450	3.7					2
19/60-8 abb3	?	31.2	375	12				Discharge estimated.	5
19/60-20 dca	?	117	1,050	9					5
19/61-9 cad	?	11	220	20					5
19/61-9 dbb1	24	8.5	580	68	577,000			Pumped well.	5
					504,000	1×10^{-4}	5,240	Observation well 50 ft northwest of pumped well.	5
					627,000	1×10^{-4}	6,000	Observation well 800 feet west of pumped well.	5
19/61-11 abc	?	23.5	800	34	780,000				5
20/60-30 dbb	?	7	920	131					5
20/61-25 acb	?	15.3	980	64					5
20/61-26 aaa	?	22	980	45					5
20/61-30 dba1	?	21	250	12					5
20/61-30 dba2	?	19.5	175	9					5
20/61-30 dbd1	?	23	275	12					5
20/61-30 dbd2	?	18.7	225	12					5
20/61-36 adb	?	12	940	78					5

Table IV-6. (continued)

Well Location	Test Duration (hours)	Drawdown (ft)	Discharge (gpm)	Specific Capacity (gpm/ft)	Transmissivity (gpd/ft)	Storage Coefficient	Permeability (gpd/ft^2)	Remarks	Source[a]
20/65-8 abb	3	3.6	2.5	0.7	480		16		3
22/67-21 aaa	3	5	3.9	0.8	900		36		3
29/68-9 bcd	?	55	10.0	0.2					3
29/69-33 bac	12	7.7	78	10.1					4
34/61-6 ab	?	70	4	0.06					7
34/62-1 ad	?	9.9	4	0.4					7
34/64-9 ac	?	4	6	1.5					7

[a]Data sources for hydrologic properties are listed in Table IV-10.

tubular or cavernous openings with few fractures. Intergranular permeabilities from this area are several orders of magnitude lower (Rapp and others, 1957).

Permeabilities of coarse sand and gravel deposits within the Ogallala aquifer vary from 165 to 4,000 gpd/ft^2, with the higher values from very coarse-grained channel fill in northeast Laramie County (Table IV-7).

Arikaree aquifer permeabilities vary from 1 to 375 gpd/ft^2 (Table IV-8) with higher values from coarse-grained deposits or fractured zones. Whitcomb (1965) considers 65 gpd/ft^2, obtained from a well (32/62-17 cb) completed in unfractured, fine-grained Arikaree sandstone, as a characteristic permeability for the formation. Lines (1976) used permeability estimates of 5 to 50 gpd/ft^2 in construction of a digital model of the Arikaree in central Platte County.

Transmissivity

Transmissivities from zones of secondary permeability within the White River aquifer (Brule Formation) in southeast Goshen County vary from 500,000 to over 780,000 gpd/ft (Table IV-6). Two other available Brule transmissivities are less than 1,000 gpd/ft. These values, although several orders of magnitude lower than transmissivities reported from Goshen County, are enhanced by fractures within the Brule (Morris and Babcock, 1960).

The highest reported Ogallala transmissivity (700,000 gpd/ft) is from a very thick coarse-grained channel deposit in northeast Laramie County (Table IV-7). Borchert (1976) considers this value anomolously high, but reports that transmissivities of over 100,000 gpd/ft are likely in most channel fills thicker than 100 feet. Ogallala

Table IV-7. Hydrologic properties of the Ogallala aquifer, Tertiary aquifer system, Denver-Julesburg basin, Wyoming.

Well Location	Test Duration (hours)	Drawdown (ft)	Discharge (gpm)	Specific Capacity (gpm/ft)	Transmissivity (gpd/ft)	Storage Coefficient	Permeability (gpd/ft^2)	Remarks	Source[a]
13/64-23 aaa	?	7	350	50				Discharge reported.	2
13/64-23 daa	?	7	220	31				Discharge reported.	2
13/66-18 aca	?	308	80	0.26					2
13/67-15 cdd	?	140	42	0.3				Discharge reported.	2
13/67-16 bca	?	32	110	3.4					2
13/67-16 bcc	?	50	130	2.6					2
13/67-16 cbb	?	50	74	1.5					2
13/67-17 add	?	49	108	2.2					2
13/67-17 daa	?	28	84	3					2
13/67-17 dab	?	20	52	2.6					2
13/67-17 dba	?	45	128	2.8					2
13/68-14 bbb					31,700				2
13/68-14 cba					23,392				2
14/67-7 ccb	7				5,580				2
14/67-18 cbd	46	6		4.7	6,900		575		2
	46				13,600	5.6×10^{-4}		Observation well 1,700 ft west of pumped well.	2
14/67-18 ddc	12			1.5	4,300				2
	12				16,400	1.8×10^{-4}		Observation well 1,320 ft west of pumped well.	2
14/67-19 bbd	27			1.5	3,000				2
14/67-24 acb	7				1,670				2
14/68-13 acb	73			15.3	23,000				2
14/68-13 ccd	25			13.5	27,000		358		2
14/68-13 dad	45			2.9	10,800				2
14/68-14 dcd	24				19,200		581		2
	24				31,000	5.9×10^{-5}		Observation well 2,140 ft north of pumped well.	2
14/68-23 ddc	?				4,750				2
14/68-24 bdd	46			5.5	6,200				2
14/68-25 bcd	?				16,750		476		2
14/68-26 bdd	?				1,065				2
14/68-26 cbc	168			5.2	26,400				2
	168				28,200	3.11×10^{-4}		Observation well 1,320 ft west of pumped well.	2
14/68-27 dcc	?				17,000		762		2
14/68-33 bcc	?				34,300		390		2
14/68-34 aab	?				16,400				2
14/68-35 cac	?				12,300		164		2
14/68-36 aac	4				15,000	1.4×10^{-4}		Observation well 2,000 ft west of pumped well.	2
15/67-2 dba	232				39,200				2
15/67-16 bca	56			0.3	1,835	6.7×10^{-5}		Observation well 835 ft west of pumped well.	2

Table IV-7. (continued)

Well Location	Test Duration (hours)	Drawdown (ft)	Discharge (gpm)	Specific Capacity (gpm/ft)	Transmissivity (gpd/ft)	Storage Coefficient	Permeability (gpd/ft^2)	Remarks	Source[a]
15/67-16 bca	56				1,730	4.9×10^{-5}		Observation well 1,981 ft southeast of pumped well.	2
	56				1,870	3.2×10^{-5}		Observation well 1,200 ft southwest of pumped well.	2
15/67-34 ccc	?	15	15	1.0				Discharge reported.	2
16/60-3 bad	?	34	1,835	54					5
16/60-9 abd	?	7	675	96					5
16/60-10 bcc	?	11.8	600	51				Discharge estimated.	5
16/60-10 dda	?	11.8	900	76					5
16/60-27 abc	?	77.8	700	9					5
16/61-2 dcc	?	7.2	730	101					5
16/61-3 bdd	?	7	1,100	157					5
16/61-7 cdd	?	56	1,180	21					5
16/61-9 abd	?	27.9	920	33					5
16/61-10 dbd	?	118.9	830	7					5
16/61-17 cba	?	11	1,600	145					5
17/60-28 ccc	?	9.4	1,150	122					5
17/60-29 cbd	?	14	700	50				Discharge estimated.	5
17/60-29 dca	?	11.5	750	65				Discharge estimated.	5
17/60-33 bcc	?	4.8	1,100	229				Discharge estimated	5
17/60-33 dbb	24	6	850	142	708,000		4,000		5
17/60-34 cac	?	8	1,100	138					5

[a]Data sources for hydrologic properties are listed in Table IV-10.

transmissivities within the Cheyenne municipal well field vary from 1,650 to 39,200 gpd/ft. The heterogeneous nature of the Ogallala results in the wide range of reported values, with higher transmissivities related to wells penetrating thick lenses of gravel and coarse sand. Lowry and Crist (1967) calculated an average transmissivity of 3,800 gpd/ft for the Ogallala in the Cheyenne vicinity, and considered this value representative for the aquifer.

Arikaree aquifer transmissivities vary from 61 to 77,000 gpd/ft (Table IV-8). Wells penetrating fractured zones, coarse sandstone beds, or large aquifer thicknesses yield the highest transmissivities. Results of regional transmissivity analyses (Weeks, 1964), calibrated estimates used in digital models (Lines, 1976), and data from wells completed outside of coarse deposits or fracture zones (Weeks, 1964; Whitcomb, 1965) indicate characteristics Arikaree transmissivities of 10,000 to 30,000 gpd/ft.

Specific Capacity and Well Yields

Specific capacities show a wide range of values, from 0.06 to 275 gpm/ft (Tables IV-6, 7, and 8). Most available specific capacity data have no test duration reported, making comparison of individual values difficult.

Specific capacities from wells completed in the White River aquifer range from 0.06 to 257 gpm/ft and are generally greater than 20 gpm/ft (Table IV-6). Most reported values are from high yield (>300 gpm) Brule aquifer wells located in eastern Laramie and southeastern Goshen counties. Many of the wells withdrawing water from the Brule in this area, particularly in the Pine Bluffs Lowland (Figure II-1), may actually be completed in alluvium derived from the Brule (Lowry and

Table IV-8. Hydrologic properties of the Arikaree aquifer, Tertiary aquifer system, Denver-Julesburg basin, Wyoming.

Well Location	Test Duration (hours)	Drawdown (ft)	Discharge (gpm)	Specific Capacity (gpm/ft)	Transmissivity (gpd/ft)	Storage Coefficient	Permeability (gpd/ft^2)	Remarks	Source[a]
15/61-4 dcb		27	900	33.3					2
15/61-9 bbb		50	200	4.0					2
16/61-4 cca		114	800	7					5
16/61-15 dda		28.9	1,100	38				Discharge estimated.	5
16/63-26 ddd		35	840	24				Discharge estimated.	5
17/60-19 caa		171	685	4					5
17/62-25 cbd		208	830	4					5
17/62-31 acc	48	88	530	6	9,300			Pumped well.	5
	48	NR	--	--	9,225			Observation well 41 ft south of pumped well.	5
	48	NR	--	--	21,725			Observation well 156 ft east of pumped well.	5
17/63-26 dba		43.5	1,000	23					5
18/60-34 dbd		96.7	580	6					5
22/66-12 ddd	5	4.6	1.4	0.3					3
23/68-4 abc	1,000	178	480	2.7				Pumped well.	3
	1,000	--	--	--	9,800	3×10^{-3}		Observation well 100 ft east of pumped well.	6
	1,000	--	--	--	6,200	6×10^{-4}		Observation well 200 ft east of pumped well.	6
	1,000	--	--	--	4,000	5×10^{-5}		Observation well 300 ft east of pumped well.	6
	1,000	--	--	--	9,800	5×10^{-5}		Observation well 1,600 ft east of pumped well.	6
23/68-4 acc	130	128	575	4.5					6
23/68-10 cdc	1	56	250	4.5					6
23/68-27 baa	0.5	35	60	1.7					6
24/66-20 cbc	1	0.33	2.0	6	15,000		375		3
24/66-22 ddd	5	4.6	1.4	0.3	110		1.3		3
24/67-4 acc	NR	21.7	90	4.1					3
24/67-5 acc	140	130	475	3.6	3,200			Pumped well.	6
	140	NR	--	--	3,200	5×10^{-4}		Observation well 400 ft east of pumped well.	6
	140	NR	--	--	2,600	5×10^{-4}		Observation well 800 ft east of pumped well.	6
24/67-6 bcd	120	98	350	3.6	4,000			Pumped well.	6
	120				3,700	3×10^{-4}		Observation well 597 ft east of pumped well.	6
24/67-7 add	1		650		10,000	1.6×10^{-3}		Observation well 660 ft west of pumped well.	6
24/68-12 dbb1		100	220	2.2					6
24/68-12 dbb2		100	560	5.6					6
24/68-12 dbc	46	81.7	600	7.3	9,400	7.5×10^{4}	19		6
24/68-12 dcb		180	1,030	5.7					6
24/68-17 abc	700	120	460	3.8					6
24/68-22 acc	30	80	550	6.9					6
24/68-27 acc	73	44	900	20.5					6

Table IV-8. (continued)

Well Location	Test Duration (hours)	Drawdown (ft)	Discharge (gpm)	Specific Capacity (gpm/ft)	Transmissivity (gpd/ft)	Storage Coefficient	Permeability (gpd/ft^2)	Remarks	Source[a]
24/68-34 bcc					43,000	2.5×10^{3}		Observation well 800 ft north of pumped well.	6
25/67-31 dcc	210	98	415	4.2					6
25/68-31 cdd	144	105	505	4.8	8,000				6
25/68-35 dbc	5	101	600	5.9					6
25/68-36 bcb	8	106	670	6.3					6
25/68-36 ccc	5	124	550	4.4					6
26/65-17 bdd	15	38	6.2	0.2	140		3.1		3
30/66-24 baa	5	10.8	2.2	0.2	61		1.6		3
32/62-17 cd	96	47.4	730	15	32,000	1.5×10^{-3}	64		7
32/63-2 cc	115	10.4	370	36	77,000	2×10^{-3}	310		7
32/63-33 bb	16	20.2	160	8	8,000		30		7
32/64-24 da	72	2.8	650	230					7
34/62-29 cd	17	30	195	6	10,000		100		7

[a]Data source for hydrologic properties are listed in Table IV-10.

Crist, 1967). Well yields of several hundred to over 1,000 gpm are common for the Brule where secondary permeability is developed. Reported specific capacities of less than 2.0 gpm/ft and yields of under 25 gpm are characteristic of the unit where secondary permeability is poorly developed.

Specific capacities for wells completed in the Ogallala aquifer vary from less than 1 to 229 gpm/ft (Table IV-7). Very high specific capacities are limited to wells completed in coarse, relatively thick channel deposits (Borchert, 1976). Away from these channel fills, specific capacities range from less than 1 to 50 gpm/ft. The large range in Ogallala specific capacities reflects the extreme heterogeneity of the aquifer.

Specific capacities for wells completed in the Arikaree aquifer are generally less than 40 gpm/ft (Table IV-8). One anomalously high value, 230 gpm/ft, is reported for a well (32/64-24 da) completed in a fracture zone. Weeks (1964) and Whitcomb (1965) suggest values of at least 5 gpm/ft are typical for the Arikaree, with wells penetrating a large thickness of the aquifer likely to yield values up to 30 gpm/ft.

Ground-Water Circulation

A water table map within the Tertiary aquifer system is given in Figure IV-2. Regionally, ground-water movement is away from uplifts along the west and north edges of the basin. In the northern two-thirds of the area, a significant component of flow is directed toward Goshen Hole and the North Platte River Valley. Locally, smaller drainages have similar effects and flow is from topographic highs toward gaining reaches of streams (Welder and Weeks, 1965). Depth to water

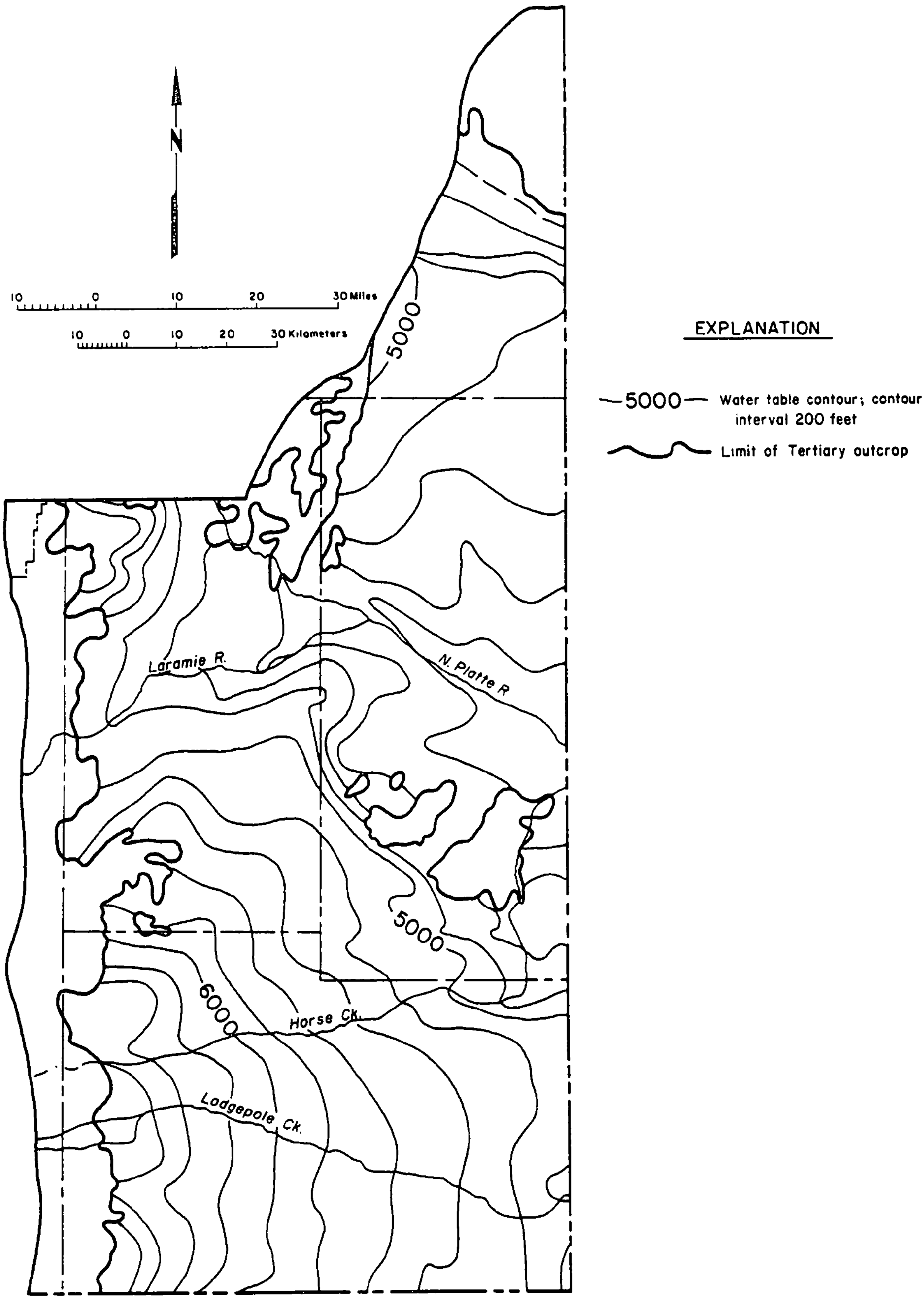

Figure IV-2. Water table map of the Tertiary aquifer system, Denver-Julesburg basin, Wyoming (from Gutentag and Weeks, 1980).

varies from several hundred feet along major interstream divides to near zero along major stream valleys.

Through much of the basin the water table slopes at 40 feet/mile to 140 feet/mile (Lowry and Crist, 1967; Rapp and others, 1957). Where the water table is within low-permeability zones of the White River Group, gradients may reach 400 feet/mile. The Tertiary aquifer system is generally unconfined throughout most of the basin, but confined or semiconfined conditions exist locally in all member aquifers (Weeks, 1964; Lowry and Crist, 1967; Lines, 1976).

Recharge

No regional estimate of recharge to the Tertiary aquifer system has been published for the entire basin. Within the basin, this system is exposed over 8,190 square miles (Gutentag and Weeks, 1980). Assuming an average precipitation of 15 inches/year with 5 percent of the precipitation available as recharge (Rapp and others, 1953; Morris and Babcock, 1960), direct infiltration of precipitation supplies roughly 325,000 acre-feet/year to the Tertiary aquifer system. Recharge from applied irrigation water and seepage from irrigation canals is very important locally, but has not been quantified (Rapp and others, 1957). Leakage from streams, especially near the Laramie Mountains, also recharges the system (Lowry and Crist, 1967). Bjorklund (1959) suggests local upwelling from pre-Tertiary strata occurs where the White River Group has well-developed secondary permeability.

Discharge

Discharge from the Tertiary aquifer system occurs by several processes, including well pumpage, leakage to gaining streams and

Quaternary aquifers, underflow into adjacent states, and through numerous springs and seeps. The regional magnitude of differing discharge mechanisms is unknown, though local estimates have been made.

Morris and Babcock (1960) estimated Tertiary discharge of roughly 28,000 acre-feet/year to the 40-mile reach of the North Platte River in the northwest part of the basin. Tertiary discharge into Quaternary aquifers is unknown. Underflow to adjacent states likely accounts for large discharges of Arikaree waters. Underflow across the Niobrara County-Nebraska boundary was estimated at 5,600 to 8,960 acre-feet/year by Babcock and Keech (1957). Discharge by contact springs occurs along the escarpments bounding the Goshen Hole and Pine Bluffs lowlands, where the White River is overlain by the generally more permeable Ogallala and/or Arikaree aquifers (Rapp and others, 1953, 1957). A line of springs discharging from the Ogallala lies in western Laramie County, and was considered by Morgan (1946) to mark the eastern edge of a thick, highly permeable zone. This spring line has migrated east over the past several decades, in apparent response to pumping at the Cheyenne municipal well field (Lowry and Crist, 1967).

QUATERNARY AQUIFERS

Quaternary age flood plain and terrace deposits are found in numerous parts of the basin. Thick, extensive deposits are generally limited to several distinct areas: (1) adjacent to the North Platte River and its major tributaries, (2) the Wheatland Flats, and (3) the Pine Bluffs Lowland and adjacent areas (Figure II-1). Quaternary deposits consist of lenticular beds of fine to very coarse sand, gravel, silts, and clay with occasional cobbles and boulders (Lowry and Crist, 1967). Thickness of Quaternary deposits is variable, reaching maxima of

200 feet in the North Platte River Valley (Rapp and others, 1957), 85 feet in Wheatland Flats (Morris and Babcock, 1960), and 120 feet in the Pine Bluffs area (Rapp and others, 1953). Alluvium underlying the valleys of smaller drainages, except along their extreme lower reaches, is generally less than 50 feet thick.

Hydrologic Properties

Extensive data are available on the hydrologic properties of Quaternary aquifers, due to the generally excellent water-producing capabilities of terrace and flood plain aquifers.

Permeability

Reported permeabilities for Quaternary aquifers vary from 700 to 9,600 gpd/ft^2 (Table IV-9). This range in permeability is due to differing grain sizes and degrees of sorting in Quaternary deposits. Quaternary aquifers adjacent to the North Platte River have the highest permeabilities, generally exceeding 4,000 gpd/ft^2. Within Wheatland Flats, permeabilities vary from 500 to 5,600 gpd/ft^2, usually exceeding 2,500 gpd/ft^2. Two reported permeabilities from the Pine Bluffs Lowland (Figure II-1) indicate a range of about 700 to 3,000 gpd/ft^2.

Transmissivity

Reported Quaternary aquifer transmissivities range from 6,500 to 1,650,000 gpd/ft (Table IV-9). Transmissivities greater than 150,000 gpd/ft are limited to areas adjacent to the North Platte River and its major tributaries, particularly the reaches of these drainages that lie within the Goshen Hole Lowland. Extensive areas within the Lowland are underlain by greater than 100 feet of coarse-grained, saturated Quaternary gravels (Crist, 1975). Reported transmissivities are

Table IV-9. Hydrologic properties of Quaternary aquifers, Denver-Julesburg basin, Wyoming.

Well Location	Test Duration (hours)	Drawdown (ft)	Discharge (gpm)	Specific Capacity (gpm/ft)	Transmissivity (gpd/ft)	Storage Coefficient	Permeability (gpd/ft²)	Remarks	Source[a]
12/62-2 bcb	97.25			58.0	105,000		3,180	Pumped well.	2
	97.25				146,000	5.43×10^{-2}		Observation well 745 ft west of pumped well.	2
12/62-3 bcc	7.5			37.4	53,300				2
12/62- 22 abb	84.25			13.9	59,000		694	Pumped well.	2
	84.25				44,800	4.65×10^{-3}		Observation well 305 ft east of pumping well.	2
13/61-11 aca	?	21	700	33.3				Discharge reported.	2
14/69-3 cbb	?	5	40	8				Discharge reported.	2
19/61-4 bca	?	15	120	8					5
19/61-4 cbal	?	25	430	17					5
19/61-4 cdd1	?	16.7	600	36					5
19/61-4 cdd3	?	15	380	25					5
19/61-4 cdd4	30				231,000			Pumped well.	5
	30				258,000	4.7×10^{-3}		Observation well 158 ft west of pumped well.	5
	30				370,000	1.9×10^{-2}		Observation well 288 ft west of pumped well.	5
20/61-32 cac	?	11	650	59					5
20/61-32 cad1	?	10	460	46					5
20/61-32 cad3	?	14.6	410	28					5
20/61-32 cad4	?	10	250	25					5
20/61-33 cba	?	22	840	38					5
20/61-33 cbd	?	19.5	800	41					5
20/61-33 cdd1	?	27	780	29					5
20/61-33 cdd2	1.5				129,000				5
20/61-33 dcc	?	24	28	0.9					5
20/67-3 cbb	?	17	100	5.9				Discharge reported.	3
20/67-9 cc	?	7.5	90	12				Discharge reported.	3
20/67-19 bbb	?	15	50	3.3				Discharge reported.	3
20/68-25 bbb	?	16	40	2.5				Discharge reported.	3
20/68-34 baa	?	10	50	5				Discharge reported.	3
22/64-21 aa	?	29	275	9.5					1
23/60-10 aa	?	24	370	15.4					1
23/60-10 bb	?	10	180	18					1
23/60-15 ba	?	11.8	910	79.7					1
23/68-1 ccd	3			44	80,000		4,000		6
24/61-2 cb	12	9.1	1,040	114	335,000		5,900		1
24/61-5 cb1	25	6.1	1,060	174	614,000	0.235	3,800		1
24/61-10 bd	?	11	1,000	91					1
24/61-10 cd1	9	7.6	900	119	250,000		1,500		1
24/61-10 cb1	?	9	650	72					1
24/61-15 cc1	37	18.3	3,400	186	1,650,000	0.235	8,700		1
24/61-23 ac	?	7.2	580	80.1					1
24/61-23 ad	?	8.2	740	90					1
24/63-3 bcb	?	18.1	130	7.2					1

Table IV-9. (continued)

Well Location	Test Duration (hours)	Drawdown (ft)	Discharge (gpm)	Specific Capacity (gpm/ft)	Transmissivity (gpd/ft)	Storage Coefficient	Permeability (gpd/ft^2)	Remarks	Source[a]
24/63-3 bcc	?	10.7	200	19					1
24/63-4 cbc	?	18	230	13					1
24/63-5 acb	?	11.3	320	28					1
24/63-16 ccd	?	14.5	460	32					1
24/63-18 acc	?	9.1	270	30					1
24/63-18 acd	?	2.5	380	150					1
24/67-6 bcd1	170			17	22,000		1,000		6
24/68-2 dcc	354			34	45,000		2,400		6
24/68-3 bcb	10			7	9,000		500		6
24/68-4 cbc	50			13	20,000		1,400		6
24/68-7 dcc	5			8	13,000		1,200		6
24/68-9 ccc2	24			15	22,000		2,500		6
24/68-11cbc	8			10	17,000		700		6
24/68-11 ccc	7			39	70,000		2,600		6
24/68-15 acb	?			28	45,000		4,000		6
24/68-16 cdd	24	14.5	460	32	67,000		2,700		3
24/68-18 acc	6	9.1	270	30	8,700		2,600		3
24/68-20 ccd1	40			40	72,000		5,600		6
24/68-33 cdd2	22			22	36,000		3,600		6
25/61-12 bd	3	9.8	1,590	162	27,000		4,200		1
25/61-27 cb	?	28	800	29					1
25/61-28 bc	?	5.2	560	96					1
25/61-28 cc	?	8	920	115					1
25/61-28 db	?	15	290	19					1
25/61-29 da	?	6.1	860	111.5					1
25/61-31 db	?	8.8	40	4.6					1
25/61-33 ab	24	9.3	1,210	130	310,000	0.216	2,300		1
25/61-33 bb	?	8	1,000	125					1
25/61-33 db	?	47	1,000	21.2					1
25/61-34 bb	?	14	1,160	83					1
25/61-35 bb	?	11	1,200	109					1
25/62-18 ca	?	7	1,040	149					1
25/63-12 bd	3	9.8	1,590	160	270,000				1
25/67-31 ccc2	3	5.2	250	48	120,000				3
25/67-18 db2		4	1,000	250					1
25/67-18 db3		4	1,000	250					1
25/68-36 ccc	1	14.7	160	11					3
26/65-9 cc	0.6	6.3	1,050	170					3
27/66-35 dba		6	330	55					3
28/68-27 abc	1	5.3	66	12	6,500		1,000		3
29/68-21 bcc	3	5.3	770	145	240,000		9,600		3
30/68-17 cbb	0.5	12.2	940	77					3
30/68-18 aac	240	17.5	430	25	90,000		3,000		3

[a]Data sources for hydrologic properties are listed in Table IV-10.

Table IV-10. Data sources for hydrologic properties.

1	Rapp and others, 1957
2	Crist and Lowry, 1967
3	Morris and Babcock, 1960
4	Welder and Weeks, 1965
5	Borchert, 1976
6	Weeks, 1964
7	Whitcomb, 1965
8	Rapp and others, 1953
9	Wyoming State Engineer's Office, Information Files, 1981
10	Dana, 1962
11	Wyoming Geological Survey, Information Files, 1981

generally 10,000 to 70,000 gpd/ft in Wheatland Flats and 50,000 to 150,000 gpd/ft in the Pine Bluffs area.

Specific Capacities and Well Yields

Specific capacities of wells completed in Quaternary aquifers vary from 3.3 to 250 gpm/ft (Table IV-9), and commonly exceed 50 gpm/ft.

Wells developed in Quaternary aquifers commonly yield 500 gpm, often to large diameter (>10-inch) irrigation wells. Locally, yields of over 3,000 gpm are reported.

Ground-Water Circulation

Ground-water movement within Quaternary aquifers generally follows the downstream flow of adjacent drainages in flood plain aquifers, and is toward drainages in terrace aquifers (Crist, 1975). Recharge to the Quaternary aquifers takes place through direct infiltration of precipitation and excess irrigation water, and from influent stream and canal seepage. Locally, water from the underlying bedrock units recharges Quaternary deposits (Welder and Weeks, 1965), though Crist (1975) considers this mechanism insignificant in the thick deposits adjacent to the North Platte River. Ground water discharges from Quaternary deposits into streams at low flow, and to contact springs where terrace deposits overlie less permeable bedrock. Underflow across the Wyoming-Nebraska state line also is significant, especially adjacent to the North Platte Valley. Crist (1975) estimates underflow at about 17,000 acre-feet/year in this area.

Water table conditions exist throughout the Quaternary aquifers. Depth to water varies from a few feet to generally less than 50 feet in flood plain deposits. The water table is usually deeper in terrace deposits, but is rarely over 100 feet below the surface (Rapp and others, 1953, 1957). Near streams, where the water table lies close to the surface, evapotranspiration is a significant discharge mechanism (Morris and Babcock, 1960).

V. WATER QUALITY

V. WATER QUALITY

Approximately 800 water quality analyses were reviewed for this report. Data sources include: the Wyoming Water Resources Research Institute (WRRI) data system (WRDS), the U.S. Geological Survey WATSTORE data system, a compilation of water quality analyses by the U.S. Geological Survey (1971), analyses by Stock (1981), and a compilation of oil field water analyses by Crawford and Davis (1962). All analyses used are published or available elsewhere and therefore are not tabulated in this report.

In general, data availablility and spatial distribution for deeper aquifers (below the Pierre Shale) are poor. While numerous analyses are reported for aquifers above the Pierre Shale, most are for relatively shallow wells.

The first part of this chapter discusses the general water quality (dissolved solids content and major ion composition) of principal aquifers within the basin. Total dissolved solids concentrations for these aquifers are shown on Plates 3 through 8. The second part of the chapter addresses water quality related to U.S. Environmental Protection Agency drinking water standards.

GENERAL WATER QUALITY

Paleozoic Aquifer System

Most water quality data for the Paleozoic aquifer system are analyses of water from shallow wells completed in the Hartville aquifer. Few wells have been drilled into other aquifers of the system, or into the Hartville in the central basin. Therefore, basinwide trends of water quality cannot be identified.

Wells in and near outcrops of the Hartville aquifer produce water with less than 500 mg/l total dissolved solids (Plate 3). These waters predominantly contain dissolved calcium-magnesium-bicarbonate (Figure V-1). A sample of Hartville water away from outcrop, taken from a depth of about 2,300 feet in central Goshen County (28/63-32), contained sodium sulfate rich water, with 2,897 mg/l TDS.

Samples from the Madison Limestone (Guernsey Limestone equivalent) at Old Woman anticline (36/62-28) are mixed-anion waters with TDS concentrations between 500 and 600 mg/l.

Precambrian rocks underlying the aquifer system yield water with less than 500 mg/l TDS to shallow wells in outcrop areas near the western basin boundary (Plate 3). Chemical constituents cannot be characterized because only partial analyses are available.

Mesozoic Aquifers

In the Glendo area, a Goose Egg Formation test well (29/69-24; Welder and Weeks, 1965) produced calcium or sodium sulfate rich waters with 615 to 2,550 mg/l TDS. TDS and calcium concentrations decreased as tested well depth increased, reflecting dilution of calcium-sulfate rich water produced in the shallow-most, gypsiferous strata.

Water from the Cloverly aquifer generally contains under 3,000 mg/l TDS based on available analyses (Plate 4). However, data from the central basin are not available. Wells near outcrops tend to have less than 1,000 mg/l TDS, while wells away from outcrop recharge areas produce more saline water. Dilute (<500 mg/l TDS) waters from the aquifer typically are sodium bicarbonate rich, whereas more saline

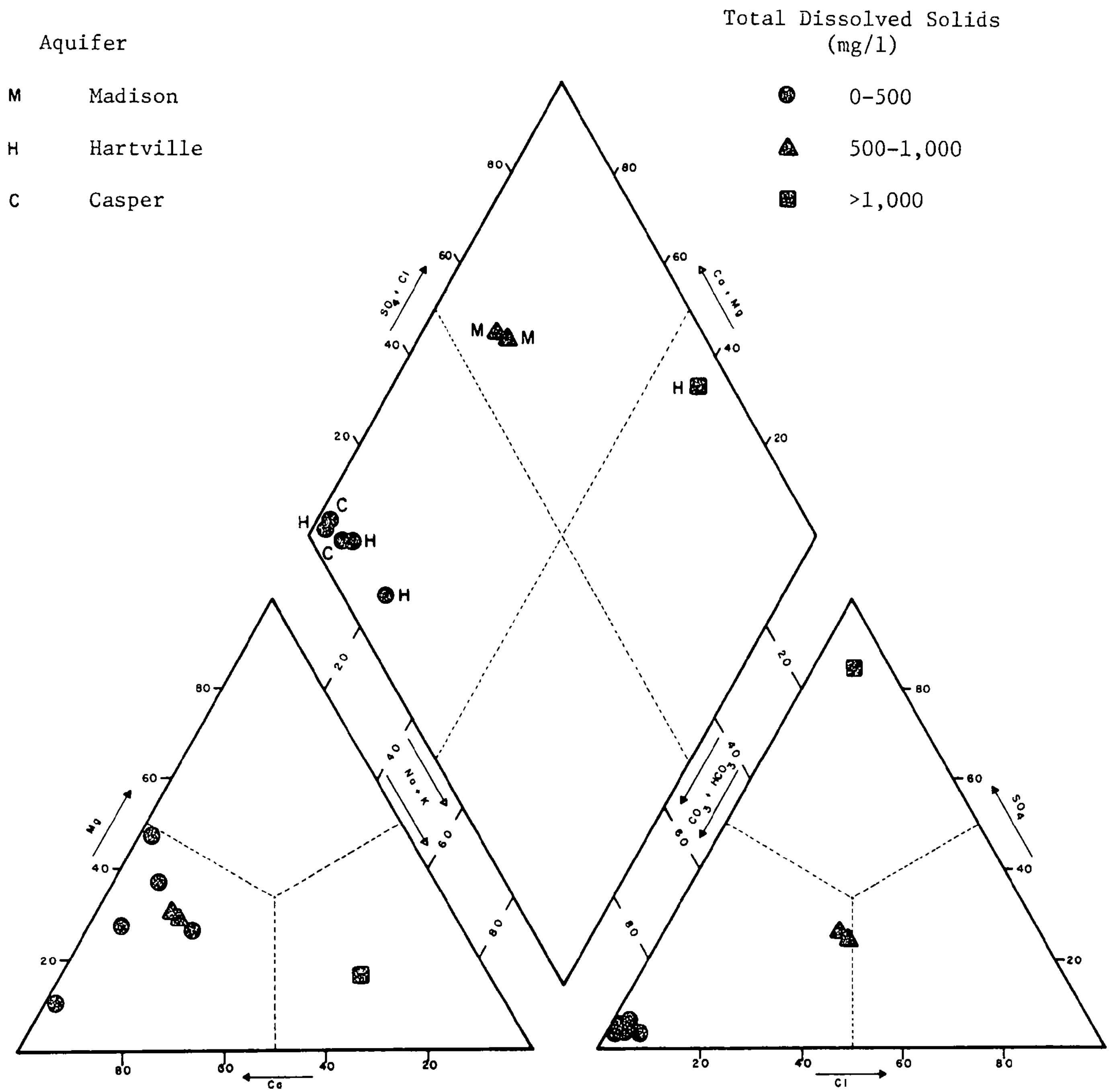

Figure V-1. Major ion compositions of representative waters of the Paleozoic aquifer system, Denver-Julesburg basin, Wyoming.

waters are sodium sulfate enriched (Figure V-2). The dominance of sodium is due to cation exchange reactions. Northeast of the Old Woman anticline and immediately outside the basin boundary, sodium bicarbonate waters with over 1,000 mg/l TDS are typical, with the dominance of bicarbonate caused by reduction of sulfate (Stock, 1981).

Total dissolved solids concentrations of Newcastle aquifer waters range from 860 to 22,918 mg/l, but geographic distribution of reported analyses is poor (Plate 4). Two wells near Newcastle outcrops on the Old Woman anticline have water with 890 and 2,900 mg/l TDS. The remainder of the analyses are from the vicinity of the Borie and Horse Creek oil fields (Plate 1) and range from 15,113 to 22,918 mg/l in TDS. Shallow, relatively dilute (<3,000 mg/l TDS) waters have mixed ion composition, whereas sodium chloride is dominant in water from deeper oil field wells.

Poor water quality within the Newcastle and Cloverly aquifers is caused by leakage from surrounding confining beds and dissolution of soluble salts from the aquifer matrix. Sandstone units within the Newcastle and upper Cloverly are lenticular and often contain siltstone or shale, restricting ground-water circulation and producing high TDS water. Oil field waters are examples for this restricted circulation.

Lance/Fox Hills Aquifer

There are few recorded analyses of Lance/Fox Hills aquifer water, and most are for Lance waters from outcrop areas in Goshen Hole.

Reported total dissolved solids concentrations range from 231 to 4,076 mg/l (Plate 5). TDS concentrations less than 500 mg/l are present in Laramie County, while within Goshen Hole the outcrop area west of

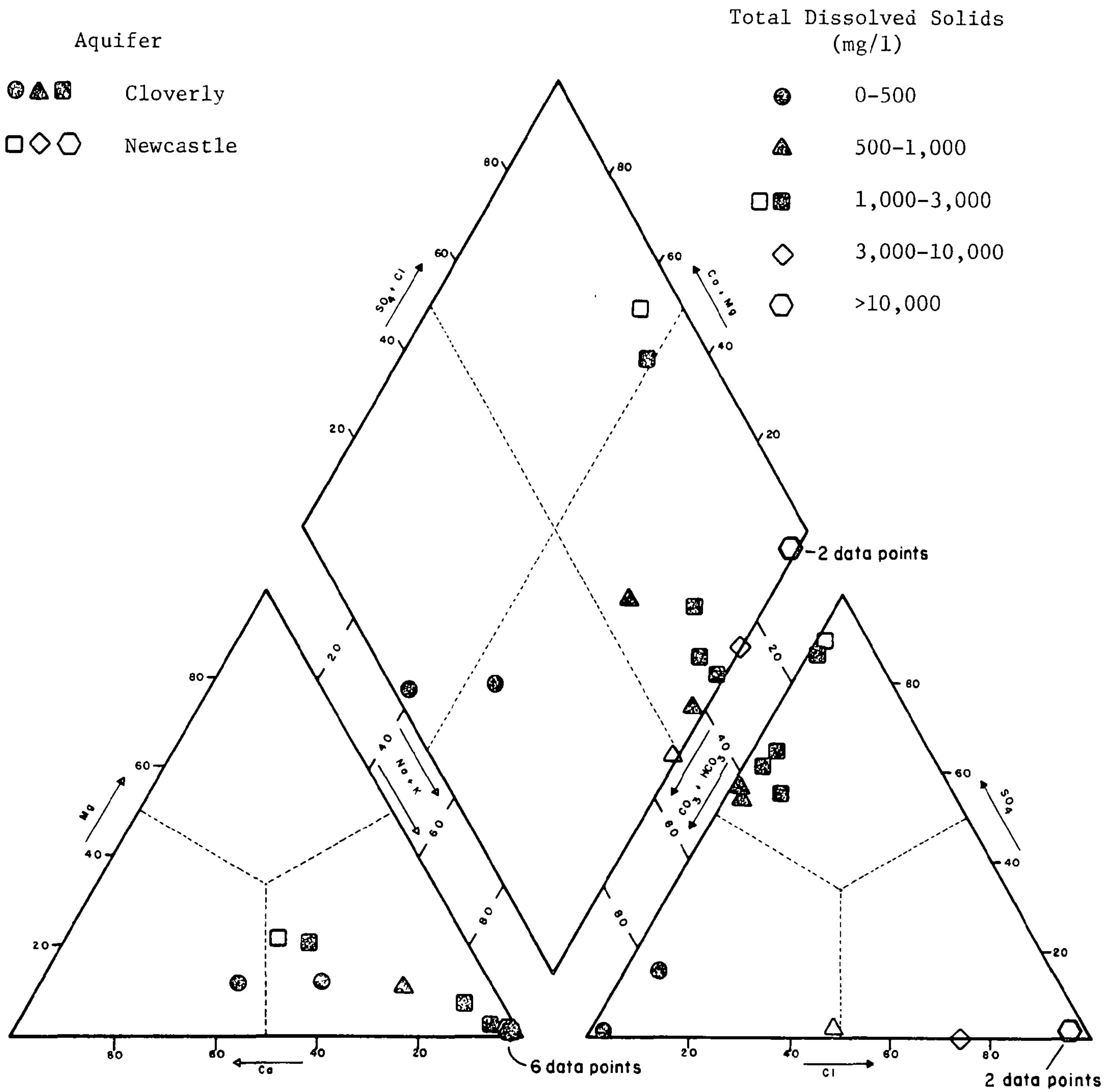

Figure V-2. Major ion composition of representative waters from Mesozoic aquifers, Denver-Julesburg basin, Wyoming.

Hawk Springs (T. 21 N., R. 62 W.) produces water with over 1,000 mg/l TDS. Elsewhere TDS values are between 500 and 1,000 mg/l.

Dilute (<500 mg/l TDS) Lance aquifer waters are calcium bicarbonate to sodium bicarbonate in composition, whereas more concentrated waters typically are enriched in sodium bicarbonate (Figure V-3). Rapp and others (1957) attribute the dominance of sodium to natural softening by ion exchange with clays within the Lance aquifer. They also indicate that sulfate reduction accounts for the dominance of bicarbonate over sulfate.

Increases in TDS and ion composition changes from calcium to sodium dominated water from the southern part of the basin to Goshen Hole indicate ground-water discharge west of Hawk Springs. The lack of potentiometric data for the Lance/Fox Hills prevents verification of this geochemically based conclusion.

Tertiary Aquifer System

The Tertiary aquifer system generally produces good quality calcium bicarbonate rich water with less than 500 mg/l total dissolved solids. Poorer water quality (500-1,000 mg/l TDS) with increased sodium content is primarily limited to the White River aquifer in the Goshen Hole area, which is a regional discharge zone for the Tertiary aquifer system (see Figure IV-2).

White River aquifer water quality is discussed separately from other member aquifers of the Tertiary aquifer system because intra-aquifer chemical differences are present. There are no apparent differences in quality of water derived from the Arikaree and Ogallala aquifers of the Tertiary aquifer system; consequently they are grouped for this discussion.

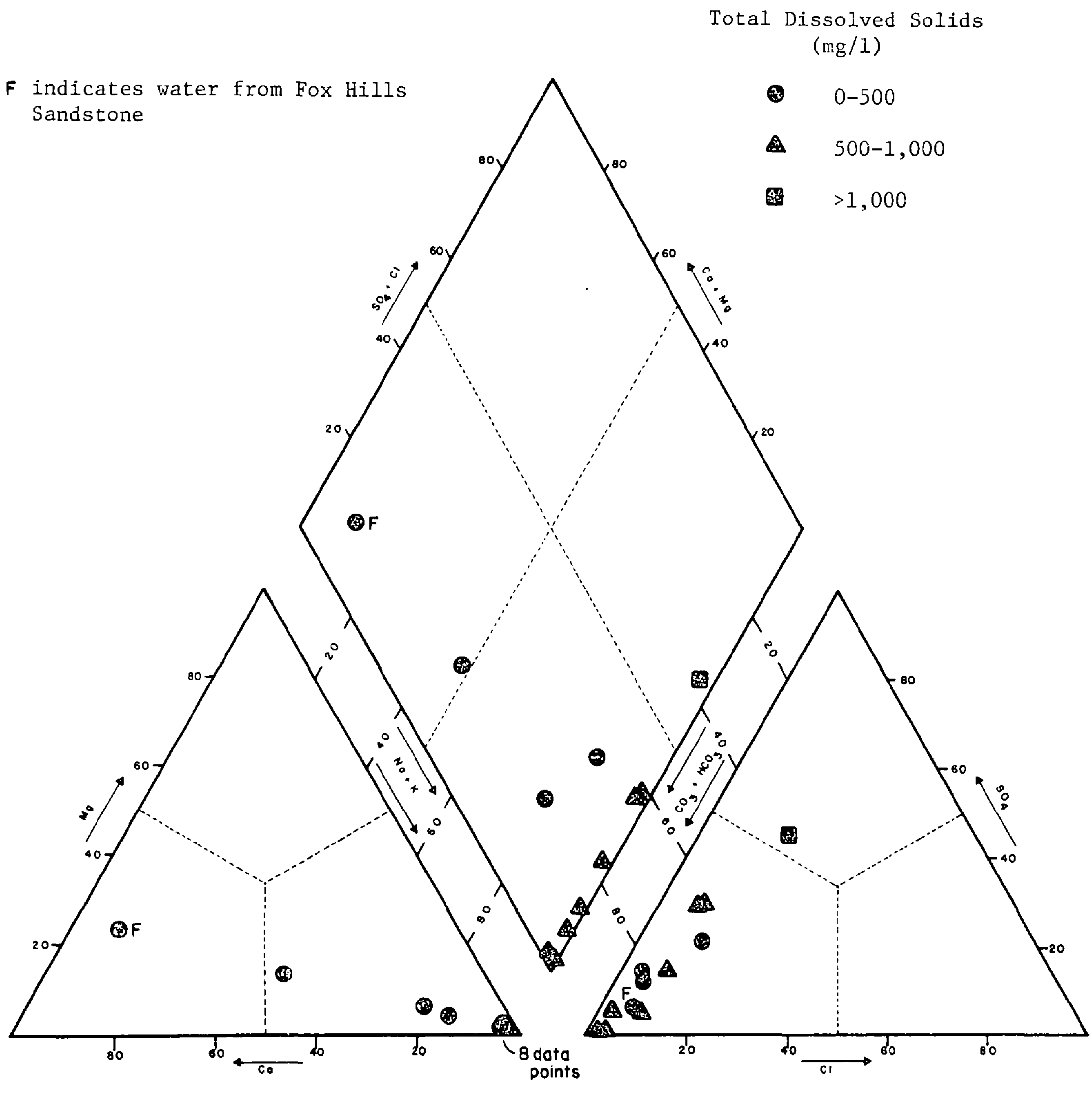

Figure V-3. Major ion composition of representative waters from the Lance/ Fox Hills aquifer, Denver-Julesburg basin, Wyoming.

to a greater degree than the fine-grained sandstones comprising the bulk of these aquifers. Therefore, the channel deposits are likely sources of lower TDS ground water.

There is no apparent regional trend in Arikaree and Ogallala water composition. The absence of an identifiable downgradient trend in water composition is atypical for Wyoming Tertiary aquifers. The relatively higher precipitation rate (recharge) for this basin and more permeable Tertiary sandstones producing more rapid circulation of ground water, result in better water quality relative to other parts of the state.

Quaternary Aquifers

Waters from Quaternary terrace and alluvial aquifers range from 228 to 1,410 mg/l TDS (Plate 8), and most values exceeding 500 mg/l are from central Platte and Goshen counties. In Laramie County and southern Goshen County most waters are calcium-bicarbonate in composition, whereas in the higher TDS waters from Platte and Goshen counties, sodium and sulfate are also significant constituents (Figure V-6).

In Laramie County and southern Goshen County, Quaternary aquifer water composition is similar to that of water in underlying Tertiary aquifers (compare Plates 6, 7, and 8 and Figures V-4, V-5, and V-6). This is due to either good communication between these aquifers or lithologic similarity of Quaternary and Tertiary deposits. In central Platte and Goshen counties there is little similarity between Quaternary and Tertiary aquifer system waters. In central Platte County, water movement is downward from Quaternary aquifers to the Arikaree (Weeks, 1965), whereas in Goshen County, discharge from bedrock aquifers to the alluvial aquifer is considered insignificant compared to other recharge mechanisms (Crist, 1975).

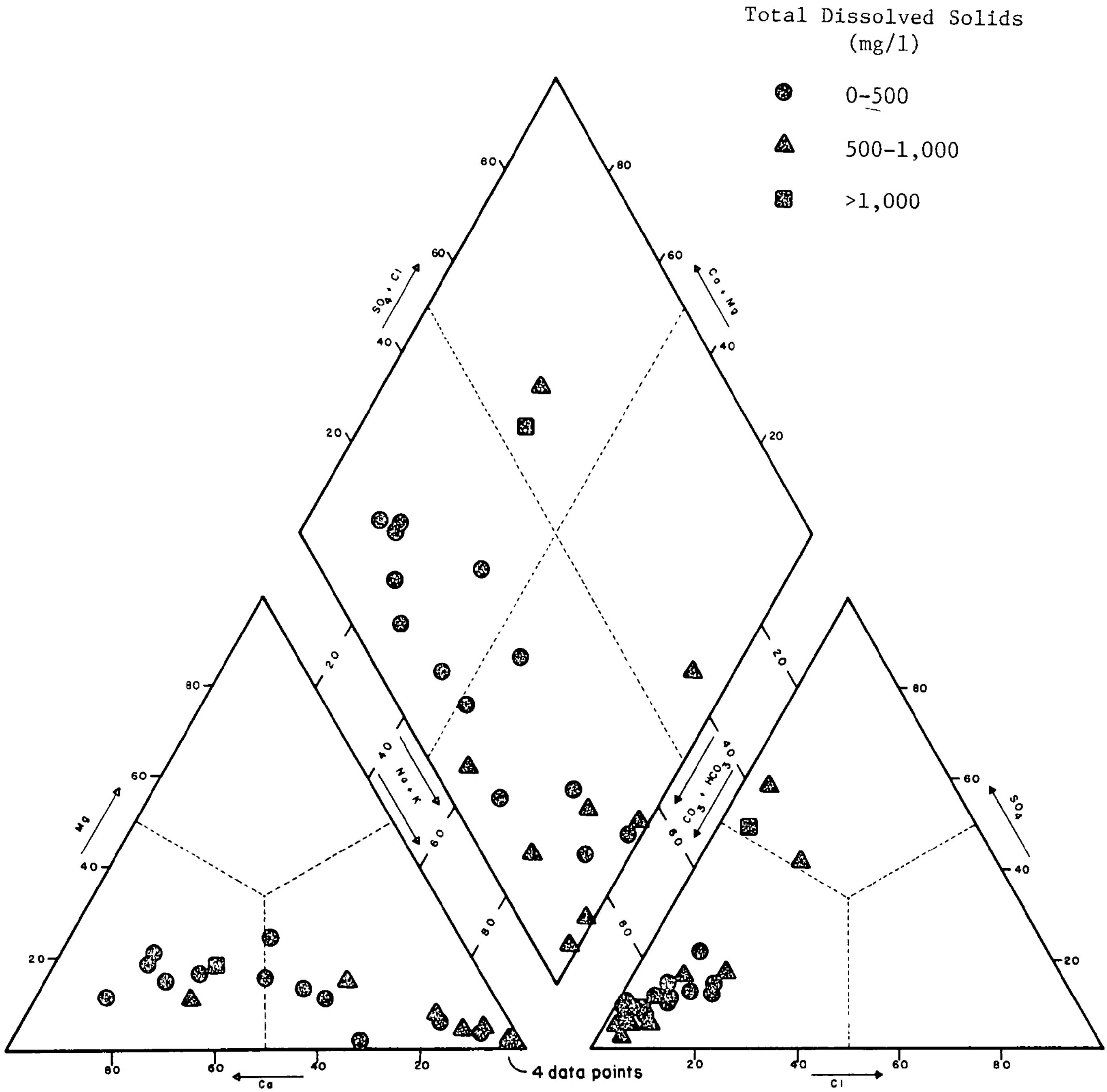

Figure V-4. Major ion composition of representative waters of the White River aquifer, Tertiary aquifer system, Denver-Julesburg basin, Wyoming.

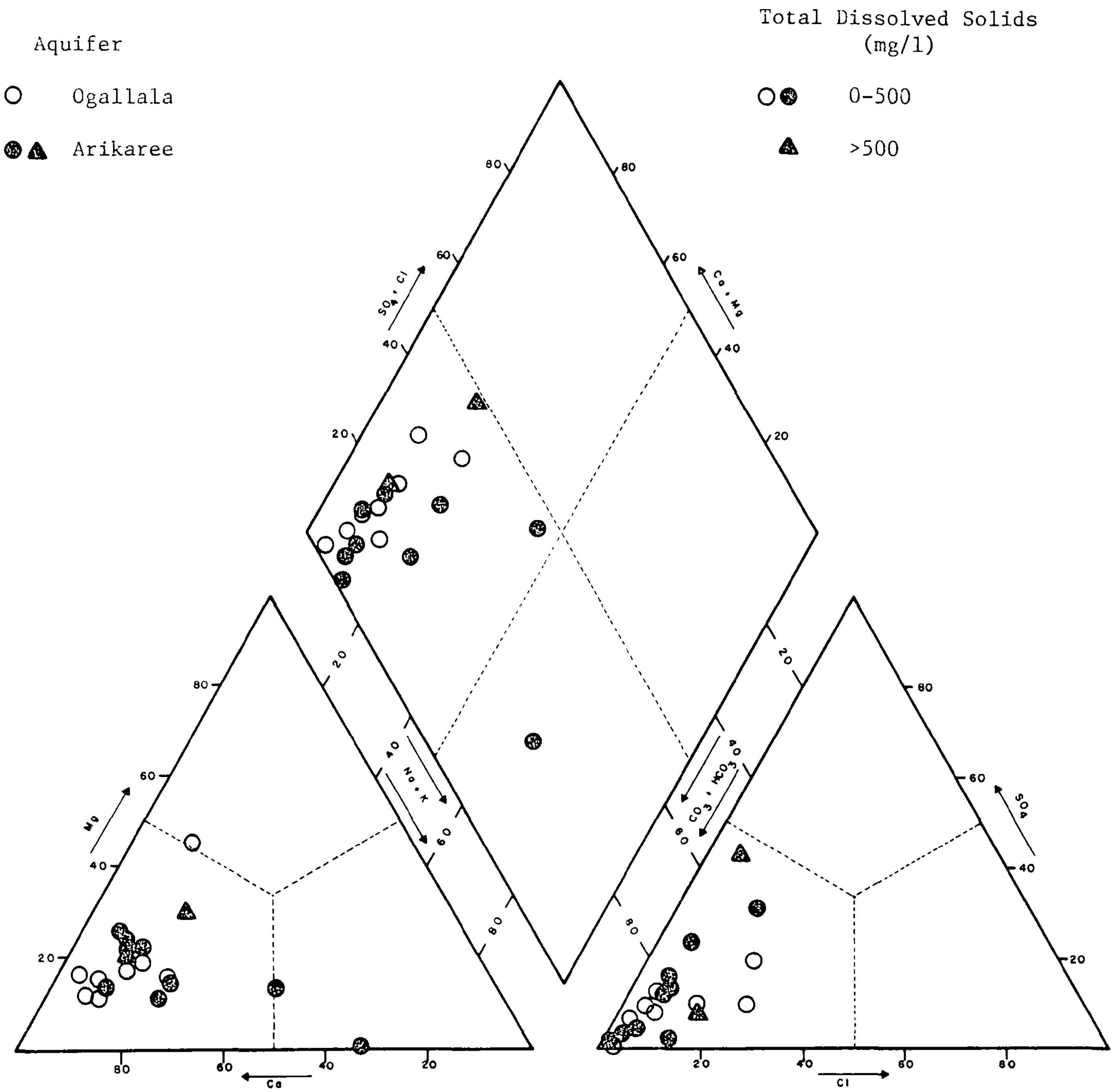

Figure V-5. Major ion composition of representative waters of the Arikaree and Ogallala aquifers, Tertiary aquifer system, Denver-Julesburg basin, Wyoming.

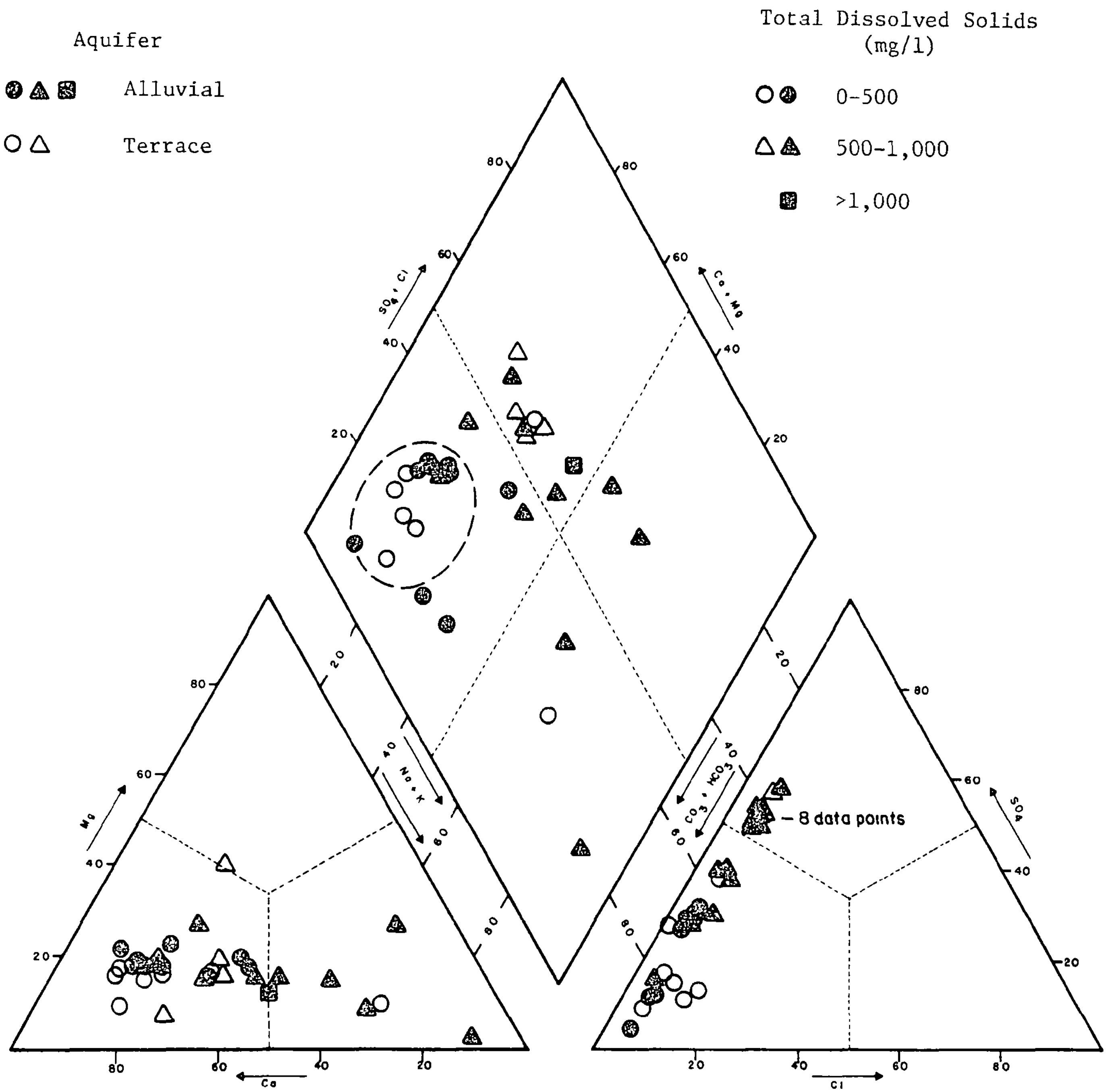

Figure V-6. Major ion composition of representative waters of the Quaternary aquifers, Denver-Julesburg basin, Wyoming. Dashed field represents typical composition of aquifer water in Laramie County.

White River Aquifer

White River aquifer TDS concentrations range from 168 to 1,410 mg/l within the Denver-Julesburg basin (Plate 6). Most reported values greater than 500 mg/l occur in waters from the Chadron Formation in the Goshen Hole Lowland. This area is a regional discharge point for Tertiary ground-water circulation (Figure IV-2).

Waters from the White River aquifer range from calcium to sodium bicarbonate in composition (Figure V-4). Waters with more than 500 mg/l TDS tend to be sodium enriched.

White River water from Laramie County is compositionally similar to other Tertiary aquifers (see below), whereas waters from Goshen County range from typical Tertiary aquifer composition to typical Lance/Fox Hills composition (compare Figures V-3, V-4, and V-5). This water quality variation is a result of downgradient changes in White River water or interaquifer mixing of waters in the Goshen Hole discharge zone.

Arikaree and Ogallala Aquifers

The Arikaree and Ogallala aquifers in the Denver-Julesburg basin generally contain water with less than 500 mg/l TDS (Plate 7). Calcium bicarbonate is the dominant ion composition (Figure V-5).

Total dissolved solids vary on a local basis. In the Cheyenne vicinity, TDS concentrations range from 150 to 2,012 mg/l, with no clear relationship to either well depth or location. Local differences in TDS may be related to the variable lithologies present in these aquifers. Where present, coarse-grained channel deposits allow for rapid transmission of ground water and are likely leached of soluble minerals

In Platte and Goshen counties, there is significant recharge to Quaternary aquifers from streams and irrigation canals (Rapp and others, 1957; Morris and Babcock, 1960; Crist, 1975). Increased sodium and sulfate concentrations in these areas reflect the composition of surface water in the North Platte and Laramie rivers.

Lowry and Crist (1967) report TDS changes with time in Quaternary aquifer water from one well near Pine Bluffs (14/60-11 bcc). TDS concentration increased from 302 mg/l in 1947 to 486 mg/l in 1964. They consider this increase to be due to irrigation. Few wells have multiple analyses reported; therefore this trend of increasing TDS cannot be confirmed.

DRINKING WATER STANDARDS

Primary Standards

Within the Denver-Julesburg basin relatively large amounts of analytical data are available for fluoride and nitrate concentrations in ground water. Few data are available for the remaining eight inorganic species for which primary drinking water standards have been established, and there are no reported exceedences of the standards for these species.

Fluoride

Fluoride concentrations exceed 2.0 mg/l in water samples from several wells completed in the Lance/Fox Hills aquifer in Goshen County, and in water from two wells (36/62-28) completed in the Madison Limestone (Guernsey Limestone equivalent) of the Paleozoic aquifer system. The distribution of reported fluoride concentrations exceeding 2.0 mg/l is shown in Figure V-7. There are no reported analyses with

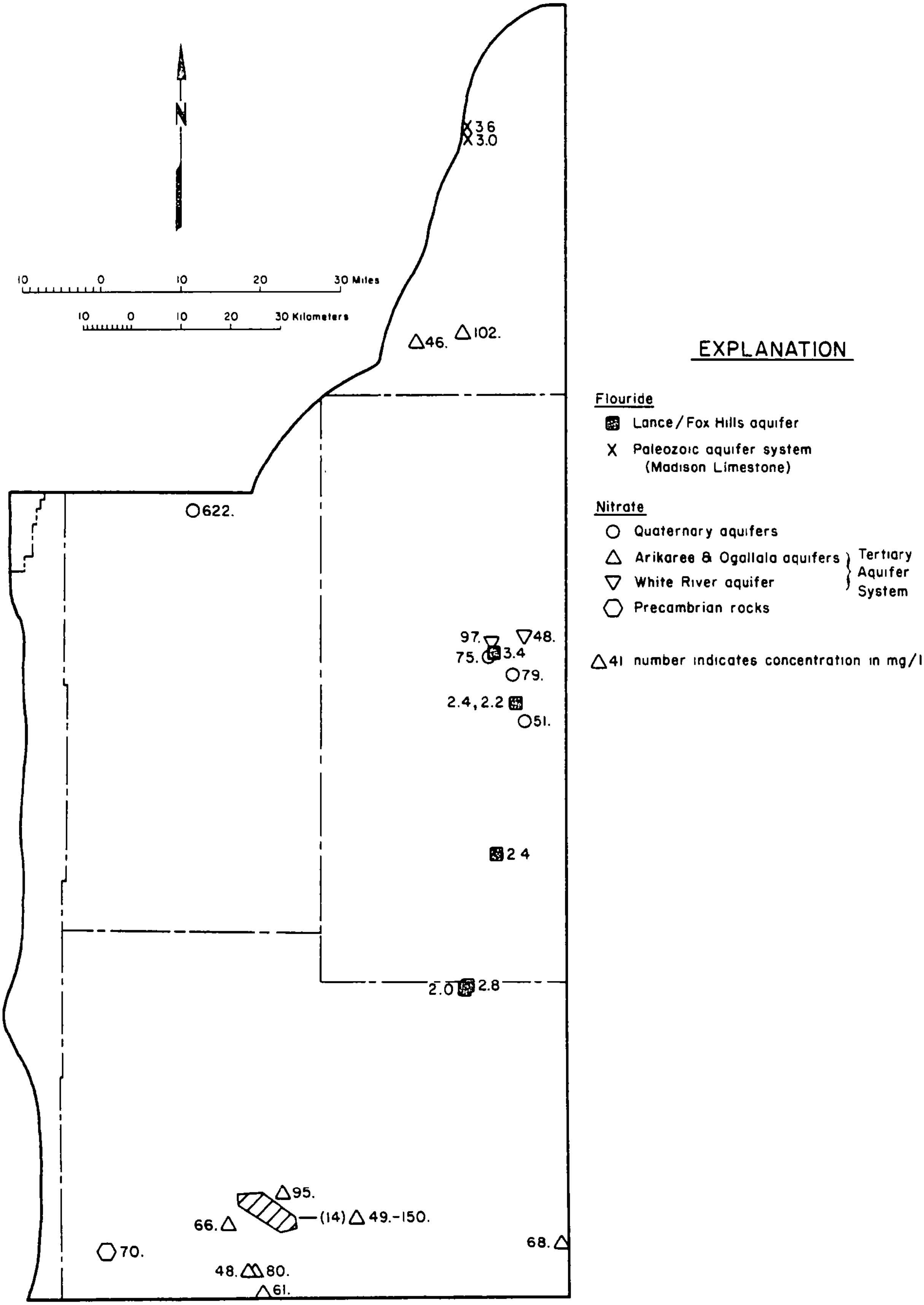

Figure V-7. Locations of high fluoride and nitrate levels in ground water, Denver-Julesburg basin, Wyoming.

fluoride levels in excess of 2.0 mg/l for water from the Tertiary aquifer system or Quaternary aquifers.

Nitrate

The distribution of reported nitrate concentrations in excess of the primary drinking water standard (45 mg/l as $NO_3^=$) is shown in Figure V-7.

About half the reported exceedences of the nitrate standard are from wells less than 200 feet deep in areas north of Cheyenne. In these areas substandard lot size, substandard well-septic tank spacing, and livestock populations all contribute nitrates to the shallowest part of the Tertiary aquifer system (Don Peck, Cheyenne/Laramie City/County Division of Environmental Health, personal communication, September, 1981). Use of these wells for drinking water supply is being phased out, as the areas are being annexed to Cheyenne, with city water supply provided.

The nitrate standard is also exceeded in water from some wells in the Tertiary aquifer system and Quaternary aquifers in other parts of the basin (see Figure V-7). Most of these reported high nitrate levels occur in areas of extensive farming and irrigation. In Laramie County, Lowry and Crist (1967) attributed generally higher than expected nitrate concentrations ($\sim$10 mg/l) to chemical and organic fertilizer derived nitrate.

Secondary Standards

The secondary drinking water standards for which water analyses are available in the Denver-Julesburg basin include sulfate, chloride, iron, and total dissolved solids. Total dissolved solids concentration ranges are displayed spatially on Plates 3 to 8. Table V-1 summarizes sulfate, chloride, and iron concentration ranges by county. Waters from most aquifers generally do not exceed the secondary drinking water standards for these constituents. However, central basin composition of ground waters from pre-Pierre Shale aquifers is poorly known.

Sulfate concentrations consistently exceed the recommended maximum (250 mg/l) in Cloverly aquifer waters from Niobrara County, and some Newcastle aquifer waters in Laramie County. Waters from shallow aquifers in Platte and Goshen counties occasionally exceed the standard.

Chloride concentrations consistently exceed the recommended maximum (250 mg/l) in waters from the Newcastle aquifer in Niobrara and Laramie counties.

High iron concentrations occur sporadically in waters from most aquifers.

Radionuclear Species

Limited data are available on concentrations for radionuclear species in the Denver-Julesburg basin (Table V-2). Several determinations of dissolved uranium and radium-226, a decay product of uranium-238, have been made. Three determinations of gross alpha radiation are available. Primary drinking water standards have been established for radium-226 (5 pCi/l) and gross alpha radiation (15 pCi/l).

Analysis for radium-226 and gross alpha may 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

Table V-1. Range of reported concentrations (mg/l) of chloride, sulfate, and iron, by aquifer and county, Denver-Julesburg basin, Wyoming.

Aquifer	County	Chloride		Sulfate		Iron	
Paleozoic Aquifer System:							
Madison (Guernsey)	Niobrara	(2)[a]	110-130	(2)	110-120		-
Hartville (Casper)	Laramie	(1)	3	(1)	7	(1)	0.04
	Niobrara	(3)	0.7-29	(3)	7-146	(3)	0.12-1.6
	Platte	(15)	1.7-9	(15)	1.6-118	(14)	0.00-0.04
Mesozoic Aquifers:							
Cloverly	Laramie	(1)	108	(1)	62		-
	Niobrara	(7)	5.9-320	(7)	29-1400		-
	Platte	(1)	3.6	(1)	4.0	(1)	0.04
Newcastle	Laramie	(10)	2360-13600	(8)	0-8823		-
	Niobrara	(2)	9.5-10	(2)	300-1600		-
Lance/Fox Hills	Goshen	(9)	7.5-113	(9)	0.9-405	(8)	0.02-0.97
	Laramie	(6)	5.2-31	(6)	28-54	(4)	0.01-0.11
Tertiary Aquifer System:							
White River	Goshen	(29)	2.7-268	(29)	13-486	(28)	0.00-1.1
	Laramie	(78)	2.0-31	(81)	3.8-74	(44)	0.00-1.1
	Niobrara	(5)	12-70	(5)	25-150	(3)	0.01-3.3
	Platte	(9)	3.5-52	(9)	16-305	(8)	0.00-0.26
Arikaree	Goshen	(11)	2-22	(11)	0.0-73	(12)	0.01-0.26
	Laramie	(16)	2.0-16	(17)	6.0-97	(9)	0.00-0.14
	Niobrara	(8)	2.8-40	(8)	4.8-30	(8)	0.00-0.29
	Platte	(10)	4-25	(10)	6-172	(9)	0.01-0.27
Ogallala	Laramie	(48)	1.0-62	(48)	0.3-87	(32)	0.00-5.8

Table V-1. (continued)

Aquifer	County	Chloride	Sulfate	Iron
Quaternary Aquifers:				
Terrace deposits	Goshen	(7) 1.7-14	(9) 80-200	(11) 0.01-0.11
	Laramie	(10) 4.0-19	(10) 8.6-42	(4) 0.00-0.02
	Platte	(11) 12-21	(11) 155-340	(11) 0.01-0.15
Alluvial deposits	Goshen	(47) 1.7-29	(54) 29-430	(58) 0.01-5.3
	Laramie	(20) 5-27	(20) 16-162	(6) 0.00-0.19
	Niobrara	(6) 4.0-15	(6) 6.6-6600	(1) 0.05
	Platte	(14) 3.0-27	(14) 2.4-634	(14) 0.02-2.8

[a]Number of analyses represented by range.

Table V-2. Reported analytical data for radiometric species in ground water, Denver-Julesburg basin, Wyoming.

Location	Aquifer	Gross Alpha (pCi/l)	Radium 226 (pCi/l)	Uranium (as U) (μg/l)	Source
21/61-15 cdd	Lance	-	0.01	15	a
21/61-32 adc	Lance	-	0.20	140	a
22/62-5 cdc	Lance	-	0.28	270	a
22/62-10 bbc	White River	-	0.10	97	a
23/61-16 bbb	White River	-	0.24	120	a
23/62-26 ddd	White River	-	0.14	160	a
23/63-6 ddd	White River	-	0.15	38	a
24/62-26 dad	White River	-	0.10	200	a
Town of Fort Laramie	Quaternary	9.8±2.8	0.2±0.4	-	b
Town of Guernsey	Quaternary	2.2±1.5	-	-	b
Town of Hartville	Quaternary & Arkiaree	7.0±2.5	0.0±0.5	-	b

Sources: a - U.S. Geological Survey Water-Data Report #WY-78-1.
b - U.S. Environmental Protection Agency, information files, Denver, Colorado

confidence interval is large relative to the given absolute value, interpretation of results is difficult.

Gross alpha data are from tested community supplies deriving their water principally from Quaternary aquifers. All three determinations of gross alpha are below the primary drinking water standard.

Radium-226 determinations exist for Platte Valley Quaternary aquifers and the White River and Lance/Fox Hills aquifers in Goshen Hole. Reported values are all less than 0.28 pCi/l, well below the primary drinking water standard.

Eight dissolved uranium determinations, made in 1978 by the U.S. Geological Survey, for water from the Lance/Fox Hills and White River aquifers in Goshen Hole range from 15 to 270 μg/l dissolved uranium. These uranium levels are higher than the typical range for natural water (0.1 to 10 μg/l; Hem, 1970), and radium values from the same samples are well below typical concentrations (<1 pCi/l; Hem, 1970). The source of high uranium levels in these waters is unknown. Equivalent strata contain economic uranium deposits elsewhere in the state, although no commercial uranium deposits are known in Goshen Hole.

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

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APPENDIX A

GROUND-WATER USE BY MUNICIPAL AND NONMUNICIPAL SYSTEMS AND BY INDUSTRY IN THE DENVER-JULESBURG BASIN, WYOMING

Table A-1. Water use by municipalities in the Denver-Julesburg basin, Wyoming.

County/Municipality	Location	Number of Operating Wells	Primary Source: Source Type	Primary Source: Source	Secondary Source: Source Type	Secondary Source: Source	Average Production[b] gal/day	Average Production[b] ac-ft/yr	Population Served	Average gal/cap/da[a] Production	Supplementary Information
Goshen											
Fort Laramie	T24N, R64W, Sec. 23	2	ground	Quaternary	-	-	247,500	277.4	300	825	
Lingle	T25N, R62W, Sec. 18	3	ground	Quaternary White R.	-	-	130,000	145.7	460	282	
South Torrington Water District							33,000	37.0	600	52	Purchases water from Torrington.
Torrington	T27N, R61W, Sec. 3, 9,10,15	12	ground	Quaternary White R.	-	-	4,300,000	4,820.2	4,000	1,075	
Yoder	T23N,R62W, Sec. 34	2	ground	Lance	-	-	11,250	12.6	102	110	
Laramie											
Albin	T17N,R60W, Sec. 29	3	ground	Arikaree	-	-	61,200	68.6	125	489	
Burns	T14N, R62W, Sec. 7	4	ground	Arikaree	-	-	60,000	67.3	300	200	
Cheyenne	T13-15N, R68-69W	47	surface	Douglas Creek	ground	Ogallala White R.	13,000,000	14,572.8	50,000	260	12 of the 47 wells are for emergency and standby use.
Orchard Valley	T13N, R66W, Sec. 18	2	ground	Ogallala	-	-	40,000	44.8	400	100	
Pine Bluffs	T14N, R60W, Sec. 14,15	6	ground	Quaternary White R.	-	-	425,000	476.4	1,000	425	
South Cheyenne Water District							411,000	460	6,000	69	Purchases water from Cheyenne; total is included in Cheyenne figures.
Niobrara											
Lusk	T32N, R63W, Sec. 7,8	7	ground	Arikaree	-	-	163,000	182.7	1,600	102	
Platte											
Chugwater	T21N, R66W, Sec. 30	3	ground	White R.	-	-	14,000	15.7	200	70	
Glendo	T29N, R68W, Sec. 19	?	ground	White R.	-	-	20,000	22.4	450	44	
Guernsey	T27N, R66W, Sec. 35	1	ground	Quaternary	-	-	220,000	246.6	1,115	197	
Hartville	T27N, R66W, Sec. 12,13	3	ground	Quaternary Arikaree	-	-	40,000	44.8	246	163	
Wheatland	T24N, R68W, Sec. 12-14	12	ground	Arikaree	-	-	1,750,000	1,961.7	4,600	380	

[a]Average gallons/capita/day production = $\frac{\text{(average production gallons/day)}}{\text{(population served)}}$

[b]Figures include some industrial use.

SOURCES: U.S. Environmental Protection Agency, Region 8, Water Supply Division, 1979, Public Water System Inventory; Wyoming State Engineer Permit Files.

Table A-2. Non-municipal community public drinking water supplies in the Denver-Julesburg basin (supplied by ground water).

County	Location	EPA PWS ID Number	Aquifer	Average Production gallons/day	Average Production AF/y	Population Served	Service	Facility Name
Goshen		5600171		2,500	2.8	50	Mobile Homes	Potlach Trailer Court
	T24N, R61W, Sec. 5 DD	5600170	Quaternary	1,550	1.7	31	Mobile Homes	Westwood Mobile Home Court
Laramie		5600268		8,750	9.8	175	Mobile Homes	A & A Mobile Home Park
	T13N, R66W, Sec. 4 CD	5600266	Ogallala	4,250	4.8	85	Mobile Homes	Avalon Trailer Park
		5600057		13,350	15.0	267	Mobile Homes	Cimmaron Village
		5600264		4,200	4.7	84	Mobile Homes	Circle ER
		5600272		2,600	2.9	52	Mobile Homes	Continental
		5600263		7,875	8.8	105	Mobile Homes	Hideaway Mobile Home Park
	T14N, R66W, Sec. 22	5600085	Ogallala	3,225	3.6	43	Mobile Homes	Hilltop
	T14N, R67W, Sec. 36 DC	5600267	Ogallala	8,700	9.7	174	Mobile Homes	Hyland Mobile Home Park
	T14N, R66W, Sec. 15 CA	5600051	Ogallala	3,500	3.9	90	Mobile Homes	Miller Lower Mobile Home Park
	T14N, R66W, Sec. 15 AD	5600282	Ogallala/ White River	5,300	5.9	108	Mobile Homes	Mountain View Mobile Home Park
	T14N, R66W, Sec. 26 AD	5600021	Ogallala	1,600	1.8	32	Mobile Homes	Pines Mobile Home Park
	T16N, R65W, Sec. 17 BB	5600260	Arikaree	3,750	4.2	51	Mobile Homes	Prairie Haven Mobile Ranch
	T14N, R66W, Sec. 22 AA	5600265	Ogallala	5,250	5.9	70	Mobile Homes	Shannon Heights
		5600261		9,000	10.1	120	Mobile Homes	Town and Country Mobile Park
	T13N, R66W, Sec. 5 DB	5600262	Ogallala	5,625	6.3	75	Mobile Homes	Trails End Mobile Home Park
Platte	T27N, R65W, Sec. 7 AC	5600024	Precambrian	70,000[a]	78.5	230	Company Town	CF&I Steel Corporation

[a]Industrial and non-municipal community use.

Sources: U.S. Environmental Protection Agency, Region 8, Water Supply Division, 1979, Public Water System Inventory, Wyoming State Engineer Permit Files.

Table A-3. Non-community public drinking water supplies in the Denver-Julesburg basin (supplied by ground water).

County	Location	EPA PWS ID Number	Aquifer	Average Production gallons/day	AF/y	Population Served	Facility Name
Albany				?	?	?	Buford Store and Tavern
Goshen		5600415		2,500	2.8	500	Asmeria Oil Inc.
	T19N, R61W, Sec. 2	5600491	White River	350	.39	60	Bear Mountain Station
	T19N, R61W, Sec. 2 CD	5600412	Quaternary	4,000	4.5	100	Frontier School of the Bible
		5600237		7,000	7.8	220	Huntly School
	T29N, R63W	5600411	Arikaree	950	1.1	30	Jay Em Campground
	T19N, R61W	5600676	Quaternary	250	.30	25	La Grange Bar
	T19N, R61W, Sec. 8	5600420	White River	7,000	7.8	175	La Grange School
	T21N, R62W, Sec. ?	5600734	Lance	250	.30	25	Little Maverick Cafe
		5600696		500	.60	50	Little Moon Supper Club
	T21N, R62W, Sec. ?	5600711	Lance	1,000	1.1	100	Longbranch
		5600416		1,000	1.1	25	Maverick Motel
		5600489		3,000	3.3	160	Scotts Cafe
		5600414		350	.39	50	Stateline Oasis
		5600413		400	.45	40	Valli Hi Supper Club
		5600409	White River	3,250	3.6	130	Veteren School
		5600410		1,400	1.6	35	Western Motel
		5600170		300	.33	150	Wheelers
	T25N, R62W, Sec. 20 AD	5600418	Quaternary	2,500	2.8	500	Wyoming State Highway Department - Rest Stop 22
Laramie		5600427		1,000	1.1	200	All the Kings Men
		5600428		3,750	4.2	375	Antelope Cafe and Station
	T13N, R67W, Sec. 14 AA	5600298	White River Ogallala	25,000	28	800	Arts Truck Terminal
	T13N, R69W, Sec. 13 AA	5600593	White River	2,000	2.2	200	Bar 13
	T14N, R63W, Sec. 6 BC	5600494	Ogallala	1,500	1.8	75	Carpenter Elementary School

Table A-3. (continued)

County	Location	EPA PWS ID Number	Aquifer	Average Production gallons/day	AF/y	Population Served	Facility Name
Laramie (cont.)	T14N, R70W, Sec. 22 BB	5600648	Precambrian	750	.84	25	Curt Gowdy State Park
		5600426		2,000	2.2	200	Fern and Rays Drive-In
	T14N, R69W, Sec. 23 CA	560082	White River	1,375	1.5	55	Gilchrist School
		5600561		12,000	13.4	1,200	Hillsdale Bingo
	T14N, R63W, Sec. 6	5600481	Ogallala	2,000	2.2	80	Hillsdale School
	T13N, R67W, Sec. 2 BA	5600485	Ogallala	42,000	47.1	3,000	Holdings Little America
		5600425		700	.78	70	Husky Terminal
	T14N, R66W, Sec. 27 DA	5600293	Ogallala	12,096	13.6	346	KOA Campground
		5600740		1,500	1.8	100	Little Bear Inn
		5600621		250	.30	25	Maxwells Trading Post
	T13N, R69W, Sec. 18 BB	5600424	White River	480	.54	48	Morrison-Knudsen Co.
	T14N, R66W, Sec. 36 DA	5600292	Ogallala	750	.84	1,000	Rock Crest Water Co.
		5600608		1,000	1.1	100	Stateline Cafe
	T13N, R66W, Sec. 11 DD	5600622	Ogallala	750	.84	150	Wyoming Information Center
		5600609	Quaternary/ White River	400	.45	40	Wyoming Potatoes Inc.
		5600700		4,000	4.5	400	Wyoming Truck Plaza
Niobrara	T32N, R64W, Sec. 13 BD	5600735	Arikaree	300	.33	30	Lusk Drive-In Theater
		5600731		750	.84	25	Lusk Municipal Golf Course
	T32N, R64W, Sec. 13 AC	5600646	Arikaree	2,000	2.2	400	Wyoming Highway Department Rest Area 26
Platte		5600580		5,250	5.9	150	Diamond Guest Ranch
	T26N, R68W, Sec. 12	5600551	Arikaree	300	.33	30	El Rancho
		5600509		2,250	2.5	45	Frontier Recreations Inc.
		560039		13,500	15.1	300	Glendo Marina
	T27N, R66W, Sec. 17 CD	5600693	Hartville	50	.06	50	Guernsey State Park - Sandy Beach 1

Table A-3. (continued)

County	Location	EPA PWS ID Number	Aquifer	Average Production gallons/day	AF/y	Population Served	Facility Name
Platte (cont.)	T27N, R66W, Sec. 18 DD	5600694	Arikaree	25	.03	25	Guernsey State Park - Sandy Beach 2
	T27N, R66W, Sec. 21 CB	5600692	Hartville	4,000	4.5	200	Guernsey State Park - Dump Station
	T27N, R66W, Sec. 9 AB	5600691	Hartville	50	.06	50	Guernsey State Park - Long Canyon
	T27N, R66W, Sec. 27 BA		Hartville	2,000	2.2	200	Guernsey State Park - Headquarters
	T24N, R68W, Sec. 1 CD	5600569	Arikaree	1,200	1.3	120	Rompoon Saloon and Steak House
		5600568		500	.6	50	Shamrock Station
	T26W, R68W, Sec. 21 BB	5600644	Arikaree	2,500	2.8	500	Wyoming Highway Department - Dwyer Junction Rest Area
		5600645	Arikaree	2,000	2.2	400	Wyoming Highway Department - Rest Area 19
	T28N, R68W, Sec. 17 CC	5600643	Arikaree	2,500	2.8	500	Wyoming Highway Department - Rest Area 20
	T22N, R65W, Sec. 6 AA	5600642	Arikaree	2,500	2.8	500	Wyoming Highway Department - Rest Area 21
		5600586	Arikaree	500	.6	100	7 Flags Drive-In

Table A-4. Industrial water use, Denver-Julesburg basin, Wyoming.

County	Facility/Industry	Primary Source		Secondary Source		Number of Wells	Average Production (ac-ft/yr)
		Source Type	Source	Source Type	Source		
Goshen	Holly Sugar Co.	surface	North Platte	ground	Quaternary Lance	11	40
	Petroleum Industry[a]	ground	White River	-	-	6	0.5
Laramie	Petroleum Industry	ground	White River	-	-	51	233
	Husky Oil Co. Refinery		purchased from Cheyenne		-	-	1,680
	Wycon Chemical Co.	ground	Ogallala	-	-	19	869
Niobrara	Petroleum Industry			-	-	3	<0.1
Platte	Missouri Basin Power Project	surface	Grayrocks Reservoir	ground	Arikaree	4	23,250[b]

[a]Petroleum water use data from Wyoming Oil and Gas Conservation Commission, 1979. All other data from the respective industry.

[b]Roughly 20,500 acre-feet/year surface water, 2,750 acre-feet/year ground water.

APPENDIX B

LOCATION AND NUMBERING SYSTEM

Location-Numbering System

The location sites of the wells 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 follow the section number and 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, if shown, denotes the quarter-quarter section; and the third letter denotes the quarter-quarter-quarter section, or 10-acre tract (Figure B-1).

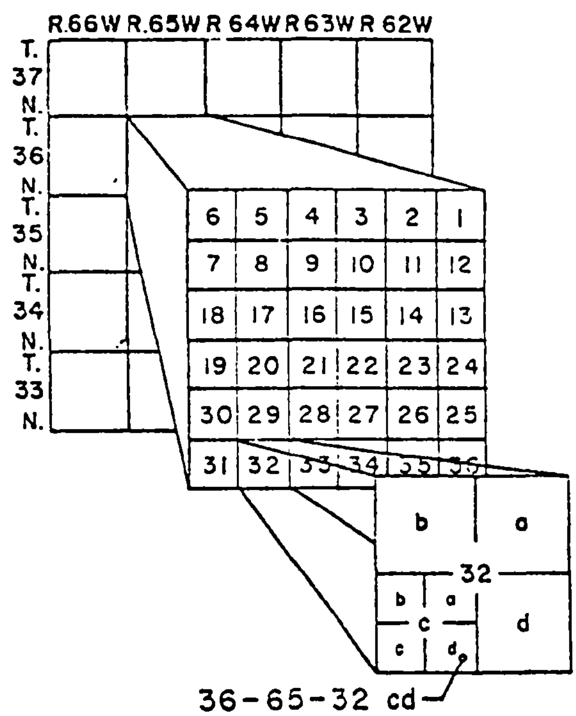

Figure B-1. Well identification system based on township-range subdivisions.