THE DAKOTA AND CHEYENNE AQUIFERS IN THE CHEYENNE WELLS - LAS ANIMAS REGION, COLORADO

by
John C. Romero
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George D. VanSlyke

Prepared by
COLORADO DIVISION OF WATER RESOURCES
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Water Resources Investigation 94-1

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Editor's Note

The report, mapping and research for this study were accomplished by John C. Romero. Unfortunately, prior to publication Mr. Romero fell victim to cancer, which he had fought for the past two years. John had worked for the Colorado Division of Water Resources for over 27 years, during which he conducted numerous studies concerning the ground water resources within the state. He was recognized as an expert in his field and was highly respected by the professional community.

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INTRODUCTION

PURPOSE OF THE INVESTIGATION

This is the final technical report on a work project completed by the Colorado Division of Water Resources (DWR) for the Colorado Oil and Gas Conservation Commission (COGCC). The COGCC is expanding an effort to improve the methodology used to evaluate applications to inject produced water (saline water) in areas underlain by the Dakota and Cheyenne aquifers in the Cheyenne Wells-Las Animas region in southeastern Colorado.

The purpose of the project is twofold. The first part involved the mapping and delineation of the Dakota and Cheyenne aquifers within the 5200 square mile project area. The second part of the investigation centered on evaluating methods for determining water quality within the aquifers. Project results consist of structure contour maps of the top and base of the Dakota and Cheyenne aquifers at a scale of one inch = three miles, four geophysical-log cross sections, four diagrams showing the relationship between formation-water resistivity, total dissolved solids, sodium chloride concentrations, depth and distance from outcrop/subcrop areas, and a computerized data base.

METHOD OF INVESTIGATION

The area of investigation or project area occupies an area approximately 12 townships square with its southern boundary along the Arkansas River between Las Animas and Holly (fig. 1). The top and base of the Dakota and Cheyenne aquifers within the 5,200 square mile area were identified on approximately 500 geophysical logs from oil and gas exploration holes. This work was accomplished at the COGCC office in Denver. Four east-west and north-south E-log cross sections were prepared and are presented on plates 1 and 2. Recorded data were ultimately transferred to 1 inch = 3 mile scale maps (pls. 3,4,5,6). Background or supporting water quality data were obtained from the Colorado Department of Health and from COGCC files.

The Kansas Geological Survey of Lawrence, Kansas supplied the author with a number of geophysical logs with their interpretation of formational boundaries.

The spontaneous potential method was used to generate estimates of formation-water resistivity. Total dissolved solids and sodium chloride concentration were estimated by methods described in Jorgensen (1989). The estimates were ultimately plotted on two Rw/TDS diagrams (figs. 3, 4) and two Rw/TDS determination location diagrams (figs. 5, 6).

ACKNOWLEDGEMENTS

The author extends gratitude to Mr. Ed DiMatteo of the COGCC who located a number of critically important water quality records, and members of the Commission who reviewed this report.

GEOGRAPHY

TOPOGRAPHY AND DRAINAGE

The project area occupies approximately 5,200 square miles north of the Arkansas River in southeastern Colorado (fig. 1). Big Sandy Creek trends diagonally from the northwest toward the southeast and nearly bifurcates the area into two distinct parts: High Plains topography predominates in the area east of Big Sandy Creek, whereas Colorado Piedmont topography occurs west of the High Plains. The High Plains is an eastward-sloping, gently-rolling plain with a surficial cover of eolian sand and loess. It has been cut by numerous ephemeral streams, the principal of which are the Smoky Hill River, Big Timber, White Woman, and Wild Horse Creeks. Slope of the land surface is toward the east and southeast at a rate of 20 to 30 feet per mile. The westward boundary of the High Plains is marked by a low westward-facing escarpment.

The land west of the High Plains escarpment is within the southeastern limit of the Colorado Piedmont. This is an elevated plain characterized by low gently rolling topography but one which has had a significant quantity of unconsolidated material stripped from the underlying bedrock formations. In many areas the eolian deposits which are present have internal drainage. This part of the area of investigation is drained primarily by Big Sandy and Rush Creeks and their tributaries. Regional land surface slope is toward the southeast at a rate of 15 to 20 feet per mile.

CLIMATE

The entire project area is classed as semiarid. Normal precipitation is low with most occurring from May through September. Mean annual precipitation at Cheyenne Wells is 14.23 inches (Boettcher, 1964) and at Holly 15.08 inches (Voegeli and Hershey, 1965). Boettcher indicates that normal or above normal precipitation does not guarantee good crop yields because the crops may wilt during a prolonged dry period. Many storms are accompanied by hail, and summer storms are erratic. Temperatures are usually high during the summer, and winters are mild except for short periods of extreme cold. (Boettcher, 1964.)

CULTURAL DEVELOPMENT

The economy of the area is predominantly agricultural and is based upon dryland farming, irrigation, stock-raising, and minor light industry. Irrigated farming is practiced in the Northern High Plains part of the area and along and near the Arkansas Valley floodplain. Dryland farming is practiced sporadically throughout the project area. Crops produced include wheat, sorghums, sugar beets, alfalfa, corn, oats, barley, and hay. (Boettcher, 1964, Voegeli and Hershey, 1965.) Cattle and sheep grazing is also practiced. Mineral resources are groundwater, raw construction materials, and oil and gas resources. There are approximately 50 petroleum-producing fields within the project area. The area is served by the Missouri Pacific and Union Pacific Railroad Companies, and a number of Federal and State highways, and county roads.

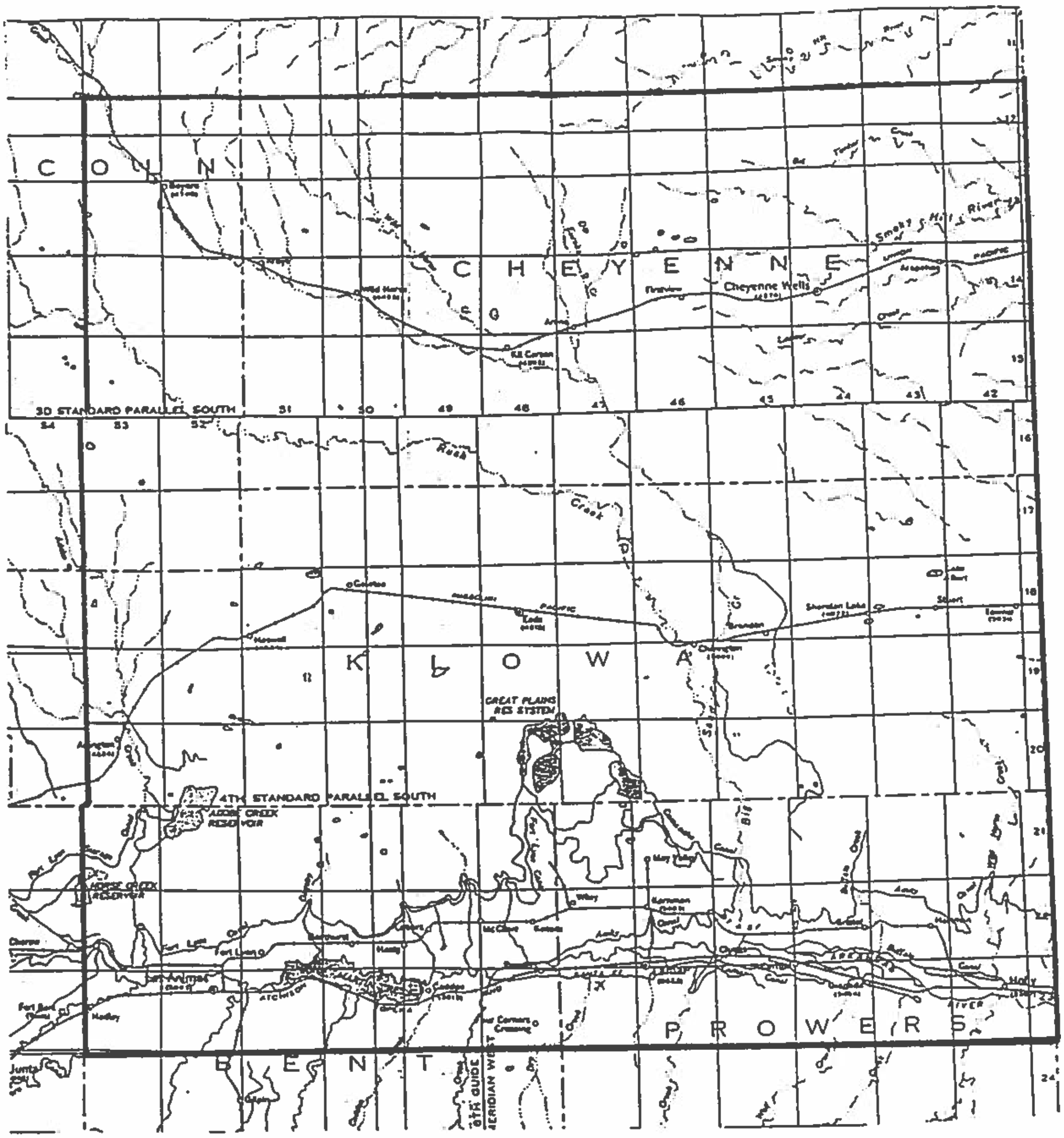

Figure 1. - Location of the project area

GEOLOGICAL FORMATIONS

SUMMARY OF REGIONAL GEOLOGY

All of the project area is underlain by formations of sedimentary origin and range in age from Cretaceous to Recent. The High Plains part of the area is underlain by eolian deposits and the Ogallala Formation. The Ogallala is the principal source of irrigation water throughout the entire High Plains. The Colorado Piedmont part of the area is underlain by eolian deposits, and old and recent valley fill alluvium. Strata of underlying bedrock formations are exposed along the slopes of many hills and in some deeply cut stream channels. Bedrock formations underlying the area of investigation are composed of sandstone, siltstone, shale and limestone; the oldest outcropping bedrock strata are sandstones of the Dakota Sandstone. Outcrops of the Dakota occur intermittently along the banks of the Arkansas River between Las Animas and Holly. Older strata underlie the Dakota and will be discussed in a later section of this report. The Dakota and Cheyenne Sandstones are hereinafter referred to as the Dakota and Cheyenne aquifers.

The project area is nearly bisected by the northeast-trending Las Animas Arch. This structure is responsible for exposing the Dakota and some older strata in the southern part of the project area. A number of faults with up to 200 feet of displacement have been identified and mapped by earlier investigators (Voegeli and Hershey, 1965). In this report no attempt has been made to refine the earlier work because the faults occur in areas where the Dakota and Cheyenne aquifers are generally less than two or three hundred feet from land surface. In these areas they are extensively used as sources of water for domestic and stock purposes. Hence petroleum exploration holes must include cemented surface casing sufficient to protect both aquifers.

SURFICIAL FORMATIONS

Surficial formations of Recent through Pleistocene age include eolian sand and stream alluvium of Recent age, and older deposits of commonly poorly-sorted clay, silt, sand, and gravel. Aggregate thickness of these deposits range from 0 to over 100 feet. The Ogallala Formation is of Pliocene age and is composed of clay, silt, sand and gravel, with caliche and localized deposits of algal limestone (Voegeli and Hershey, 1965, and Boettcher and Horr, 1964). Except for the eolian sand, most of the surficial deposits yield sufficient quantities of water to domestic and stock wells and, when sufficient saturated thickness is available, to large-capacity irrigation wells.

BEDROCK FORMATIONS

Normally, the term Purgatoire Formation is used to describe the geologic unit composed of the Kiowa Shale and the Cheyenne Sandstone. It should be noted that in the following narration the term Purgatoire Formation is dropped and the Kiowa Shale and Cheyenne aquifer are tentatively given formational rank. This follows Kansas nomenclature and simplifies narration.

Figure 2 is a generalized bedrock geologic map of the project area and shows the approximate boundaries of the bedrock formations underlying the surficial deposits and

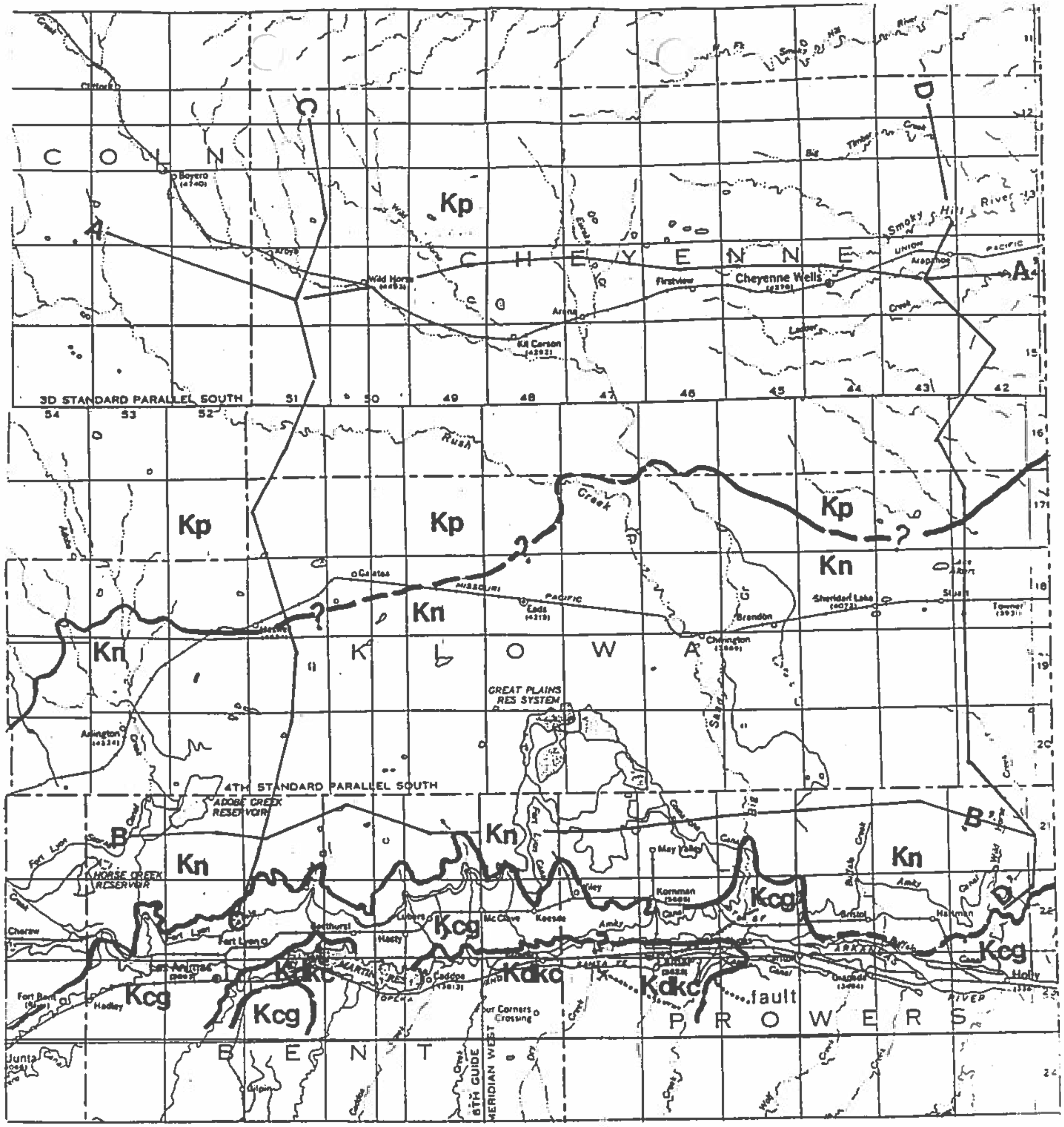

Figure 2. - Generalized bedrock geologic map of the project area. Kp - Pierre Shale; Kn, Kcg - Niobrara through Greenhorn strata undifferentiated; Kd/Kc - Dakota, Kiowa and Cheyenne strata undifferentiated. Three faults in the Lamar area are approximately located. A-A' etc. are locations of geophyscial log cross sections.

major fault traces identified by Voegeli and Hershey (1965). All strata except the Dakota and Cheyenne aquifers and the Kiowa Shale are given only a brief description in this report. Table 1 is a generalized section of the bedrock formations, and plates 1 and 2 illustrate standard geophysical logs from the base of the Pierre Shale to the Stone Corral Formation of Permian age.

The youngest bedrock formation in the project area is the Pierre Shale of Late Cretaceous age. This black to dark gray shale underlies the Ogallala Formation north of the Cheyenne-Kiowa County line (fig. 2). Exposures are limited to steep hill slopes and deep stream cuts. As interpreted from petroleum-exploration holes, the thickness of the Pierre Shale in the project area ranges from about 1,000 to about 1,200 feet. The Pierre Shale is underlain by shaley marls of the Niobrara Formation. Thickness of the Niobrara is approximately 150 feet in the southern part of the project area (Voegeli and Hershey) and approximately 700 feet in the northern part of the project area (Boettcher and Horr). The underlying Carlile Shale includes the Codell Sandstone, Blue Hill Shale, and Fairport Chalky Shale Members. The Codell and Fairport Members yield small quantities of water to wells downdip from outcrop areas. The Blue Hill Shale Member is reported to yield water from springs and seeps. Thickness of the Carlile ranges between 0 and 190 feet. The underlying Greenhorn Limestone ranges from 0 to 130 feet in the project area. Gray to black gypsiferous and bentonitic shale of the underlying Graneros Shale serves as a good marker formation for the underlying Dakota aquifer. One bentonite marker in the Graneros is regional in aerial extent. Thickness range of the Graneros Shale is 0 to 190 feet. Dakota, Kiowa, and Cheyenne strata will be described in the next section of this report. The Morrison Formation (Jurassic) consists of from 50 to 100 feet of multicolored mudstone, shale, and siltstone, with thin interbeds of sandstone and limestone. At localities where uppermost Morrison sandstones are nearly in contact with the overlying Cheyenne aquifer, they have been included with the Cheyenne aquifer.

Geologic strata between the base of the Morrison Formation and base of the Stone Corral Formation (Permian) are approximately 400 to 1,000 feet thick. They are composed predominantly of reddish-brown siltstone and sandstone, pink to yellowish-tan sandstone and dolomite, and generally light-colored gypsum. The only formation known to yield fresh water to wells in this section is the Dockum Group. The Dockum Group is Triassic in age and its red-orange sandstone yields sufficient quantities of water for irrigation purposes in Baca County, Colorado.

Detailed descriptions of strata above the Dakota aquifer and below the Morrison Formation can be found in geologic literature and the reference list at the end of this report.

Dakota Aquifer - The Dakota aquifer underlies the Graneros Shale and overlies the Kiowa Shale. The aquifer consists of 200 to 235 feet of thin to medium bedded sandstone with interbeds of sandy shale and shale. Geophysical log characteristics of the aquifer are shown on plates 1 and 2. The logs reveal that the thicker beds of sandstone usually occur in the lower half of the aquifer. Voegeli and Hershey (1965), McLaughlin (1954), and field experience of this investigator reveals the presence of iron oxide cemented sandstones in many outcrop areas. The cement gives the Dakota a red to brown color and renders the rock hard and brittle. Outcrop colors range from light gray to yellowish-brown and a dark brownish-red, depending upon iron content. Dakota aquifer sandstones are uniformly fine-grained, but grain size may differ widely from bed to bed (Voegeli, and Hershey, 1965).

Table 1. - Generalized section of the bedrock strata within the project area.

System	Series	Stratigraphic unit	Thickness (feet)	Physical character	Water supply
Cretaceous	Upper Cretaceous	Pierre Shale	0-1,100±	Black to dark-gray shale. Contains bentonitic clay and calcareous concretions. Occasionally the upper 4-8 ft is a yellow weathered zone.	Not known to yield water to wells in the project area.

System	Series	Subdivision	Member	Thickness (feet)	Physical character	Water supply
Cretaceous	Upper Cretaceous	Niobrara Formation	Smoky Hill Marl	150±	Chiefly yellowish chalk; contains thin beds of white limestone.	Do.
			Fort Hays Limestone	50-60	Chalky limestone and marl.	Yields water to stock wells and from springs north of the Arkansas River.
		Carlile Shale	Codell Sandstone	22±	Chiefly sandy shale; contains calcareous sandstone.	Yields water to a few stock wells.
			Blue Hill Shale	50-60	Chiefly black noncalcareous fissile shale; contains concretions in upper part.	Yields limited quantities of water from seeps north of the Arkansas River.
			Fairport Chalky Shale	100-125	Chalky shale; contains thin chalky limestone beds in lower part.	Yields water to a few stock wells.
			Bridge Creek Limestone	69-73	Thin-bedded limestone and shale.	Do.
		Greenhorn Limestone	Hartland Shale	20-38	Chalky shale and thin-bedded limestone; contains thin layers of bentonite.	Yields no water to wells.
			Lincoln Limestone	25-37	Thin-bedded hard crystalline limestone and calcareous shale; contains thin layers of bentonite.	Do.
		Graneros Shale		85-100	Gray to black gypsiferous shale and thin layers of bentonite; contains thin-bedded rusty limestone in middle to lower part.	Do.
	Lower Cretaceous	Dakota Sandstone		150-235	Fine-grained thin-bedded to massive sandstone; contains clayey to sandy shale. Color ranges from white to brown.	Yields adequate water for domestic and stock use in most places. In some areas it yields enough water for municipal and industrial supplies.
		Purgatoire Formation	Kiowa Shale	30-140	Gray to black calcareous clayey shale; thin-bedded fine-grained sandstone in upper part.	Yields no water to wells.
			Cheyenne Sandstone	30-200	Massive white to buff fine-grained sandstone.	Yields small to large quantities of water for domestic, stock, industrial, municipal, and irrigation use.
Jurassic	Upper Jurassic	Morrison Formation		20-240	Varicolored marl; locally contains thick sandstone lenses, thin beds of conglomerate, and platy limestone.	Yields water to some domestic and stock wells north of Two Buttes.
		Middle unit of Jurassic age		35-150	Sandstone, limestone, mudstone conglomerate, and chert zones.	Yields no water to wells.
		Entrada Sandstone		100±	Massive white to buff crossbedded fine- to medium-grained sandstone.	Do.
Triassic	Upper Triassic	Dockum Group		150-540	Chiefly sandstone, but locally contains thin beds of conglomerate, limestone, and shale.	Do.
Permian	Upper Permian	Taloga Formation (of Cragin)		100-400	Red siltstone and fine-grained sandstone.	Do.
		Day Creek Dolomite		10-60	Dolomite, anhydrite, or gypsum.	Do.
		Sandstone of Whitehorse age		30-300	Buff to red fine-grained sandstone and red shale.	Do.

The Pierre Shale description is directly from Boettcher and Horr (1964), the Niobrara through Whitehorse strata is directly from Voegeli and Hershey (1965). Strata between the Whitehorse Sandstone and base of the Stone Corral Formation are not described here.

Shales interbedded in the Dakota aquifer are generally gray to black, but can be multicolored in places and, according to Voegeli and Hershey (1965), can be mistaken for shales of the Morrison Formation.

Robson and Banta (1987) discuss the Dakota-Cheyenne aquifer of eastern Colorado and refer to it as a member of the Great Plains aquifer system. In their report, Robson and Banta discuss region-wide stratigraphic characteristics and, to a limited extent, quality of water.

Except in outcrop areas where it may be drained, the Dakota aquifer is a reliable source of water for domestic, stock, and public supplies in much of southeastern Colorado. This property extends westward to outcrop areas along the Front Range of the Southern Rocky Mountains. Depth of existing water wells completed in the Dakota aquifer ranges from 100 to 200 feet along the Arkansas River to approximately 900 to 1,300 feet in the Brandon and Sheridan Lake area.

Depth to the top of the Dakota aquifer ranges from zero in outcrop areas along the Arkansas River to approximately 3,000 feet in the northwestern part of the project area. Plate 3 is a structure contour map of the top of the Dakota aquifer. The Las Animas Arch makes its presence known in the branched ridge which extends northeastward from the Las Animas and John Martin Reservoir area. Plate 4 is a structure contour map of the base of the Dakota aquifer (equivalent to the top of the Kiowa Shale). Plates 3 and 4 can be used to determine depth below land surface by subtracting the structure contour elevations at a specific site from the determined land surface elevation at that site. The Dakota aquifer is underlain by the Kiowa Shale.

Kiowa Shale - The Kiowa Shale consists of 30 to 140 feet of dark gray to black shale with interbeds of sandy shale and thin beds of sandstone. The geophysical logs of plates 1 and 2 show that when the Kiowa is generally 50 feet or more in thickness, a prominent sandy zone normally occurs about midway between the Dakota aquifer and underlying Cheyenne aquifer. Thickness frequently attained by sandstone beds in this zone is 20 to 30 feet. Voegeli and Hershey (1965) report that Kiowa shales are occasionally both calcareous and gypsiferous. The Kiowa Shale is important because it serves as an effective hydrologic barrier between the Dakota and Cheyenne aquifers.

Cheyenne Aquifer - The Cheyenne aquifer underlies the Kiowa Shale and overlies the Morrison Formation. The aquifer consists of from 30 to approximately 200 feet of light gray to white, fine to coarse grained, friable sandstone with thin interbeds of gray shale. Well cemented zones occur locally. The generally light color and friability are two basic characteristics distinguishing it from the usually tightly cemented sandstone of the Dakota aquifer (McLaughlin, 1954; Voegeli and Hershey, 1965). Haun (1959, 1963) reports that the interfingering relationship of the lower Dakota (Cheyenne aquifer included) and upper part of the Morrison Formation renders the Cheyenne-Morrison contact indistinct. Therefore, the base of the Cheyenne aquifer is chosen to be the base of the predominantly sandstone sequence regardless of the classic formational boundary.

The Cheyenne aquifer is a reliable source of water for domestic, stock, and public supplies throughout much of southeastern Colorado. This property extends westward to outcrop areas along the east slope of the Front Range. Depth to the Cheyenne aquifer ranges from 200 to 400 feet along the Arkansas River to approximately 3,300 feet in the northwestern corner of the project area. Plates 5 and 6 are structure-contour maps of the top and base of the Cheyenne aquifer.

The Cheyenne aquifer is underlain by mudstone, shale, siltstone, and thin bedded sandstone and limestone of the Morrison Formation. Morrison colors are red, green, gray, and brown, with green predominating.

QUALITY OF WATER FROM THE DAKOTA AND CHEYENNE AQUIFERS

Most water quality analyses of Dakota and Cheyenne aquifer water have been obtained from wells located within 12 miles from the Arkansas River. Water is withdrawn from domestic, stock, irrigation, and public supply wells. Voegeli and Hershey (1965) obtained groundwater from 28 Dakota, Cheyenne, and Dakota/Cheyenne aquifers. All of the wells checked are located south of Township 20 South. They reported that the quality of water in the Dakota, Cheyenne, and Dakota/Cheyenne combination wells varies considerably from place to place, and that the chemical quality of water from the Dakota in many places does not meet recommended standards for public and domestic water supplies. However, people using such water have reported no adverse effects. Total dissolved solids (TDS) from seven wells range from 478 to 2,090 milligrams per liter (mg/l) from depths ranging from 59 to 1032 feet below land surface. Their table 3 details test results. Voegeli and Hershey report that the hardness of Dakota water ranges from 10-650 mg/l. Weist (1963) reports that in southern Crowley County Dakota and Cheyenne water of the sodium sulfate type is generally soft and that hardness decreases in a northern direction. Weist reports that the hardness of water obtained from 23 Dakota and Cheyenne wells ranged from 8 to 906 mg/l. Weist, Jenkins, and Horr (1965, p.53) graph average composition of groundwater with respect to aquifer.

With the exception of water quality analyses from four wells - one from the Brandon Water Association and three drill stem test results from oil and gas exploration holes - there are no readily available water quality analyses of Dakota and Cheyenne aquifer water between Township 19 South and the northern boundary of the project area.

Two documented methods for determining water quality from geophysical logs were investigated. The first relies on the resistivity log in conjunction with priority and density logs. The second relies on the SP logs. While both methods appear to be useful, overall absence of porosity and density logs of Dakota and Cheyenne intervals, and lack of sufficient chemical quality analyses led to the decision to utilize the spontaneous potential method or SP-method for formation water resistivity (Rw) estimations. Total dissolved solids and sodium chloride (NaCl) concentrations were estimated by the application of methods described by Jorgensen (1989, p.22). TDS and NaCl tolerances are briefly described in the Appendix.

SPONTANEOUS POTENTIAL METHOD

One technique used to estimate formation-water resistivity is the spontaneous potential or SP-method. The SP-method can be used to estimate the Rw of NaCl type water. The method is based on the equation.....

$$SP = -K \log \frac{Rmf}{Rw}$$

Simplifying and rearranging....

$$Rw = \frac{Rmf}{10^{-SSP/K}}$$

Where SSP is the static spontaneous potential in millivolts at formation temperature, K is a constant which is a function of temperature, Rmf is the resistivity of the mud filtrate in ohm-meters, and Rw is the formation-water resistivity in ohm-meters. More detailed descriptions of the method are usually presented in most well-logging manuals and texts such as those by Collier (1992), Jorgensen (1989), Keys (1990), Schlumberger (1989), and Western Atlas International (1985).

Requirements for use of the SP-method in fresh-water formations are:

1) The water contains less than 10,000 (mg/l) dissolved solids.

2) The borehole fluid and formation water must be sodium chloride (NaCl) solutions.

3) The formation water must be distinctly saline.

4) The sand must be relatively clay-free, permeable, and thick enough for an SSP (static spontaneous potential) to be established.

Collier (p. 390) and Keys (p. 52) discuss complications in more detail. Jorgensen (p. 9,10) suggests that the SP-method should be used only if an estimated accuracy of plus or minus one-half order of magnitude is acceptable.

The SP-method is used in this report for three reasons:

1) In an over 3,000 square mile area north of Township 19 South, only three relatively complete Dakota water samples are available.

2) The overall absence of chemical data, and porosity/density data prevents application of various cross-plot methods for determining Rw.

3) The SP-method was tested by comparing SP-method estimations of Rw with the results of commercial/private lab analyses of four drill stem tests obtained from Dakota and Cheyenne water samples from deep oil and gas exploration activities. Results revealed that calculated Rw and TDS lie within 70 to 95 percent of the lab values.

It is believed that the SP-method can be used as a guide to water quality, provided the reader accepts the opinion of Jorgensen that the calculated results may be in error by as much as one-half order of magnitude. Specific conductance and NaCl and TDS concentrations were estimated using techniques described in Jorgensen (1989, p. 2). No corrections were attempted.

RESULTS OF SP-METHOD CALCULATIONS

Colorado State Department of Health data from two analyses indicates that Dakota water withdrawn from the Brandon Water Association has a sodium (Na) concentration of 500-700 mg/l and a TDS of approximately 1,800 mg/l. Drill stem test data from the #4 Grays State oil and gas exploration well in T.12S., R.51W., Section 36, indicates Dakota water at that site has a TDS averaging 8,258 mg/l from a depth of 2,672 feet. Drill stem test data from the #3 Navajo #32-3 well in T.17S., R.46W., Section 3, reveals a chloride (Cl) concentration of 7,800 mg/l and a TDS of 17,036 mg/l from a depth of 1,156 feet. Drill stem test data from the #2

Fallow 43-18 well in T.10S., R.54W., Section 18, reveals Cheyenne aquifer water with a TDS of 2,952 mg/l from a depth of 4,150 feet (table 2).

Results of the calculations for Rw, TDS, and NaCl are plotted on figures 3, 4, 5, and 6. Figures 3 and 4 are plots of estimated Rw versus estimated TDS for the Dakota and Cheyenne aquifers. A single line drawn through the plots of each diagram clearly show the interrelationship between Rw and TDS: low Rw - high TDS, high Rw - low TDS. More importantly, three background data plots for the Dakota aquifer (fig. 3) lie along the distinct lineation of the Rw/TDS plots. These three data points (Brandon W.A., Grays State, and Navajo #32-3) are 20 to 50 miles apart, serve as the basis for a distinct lineation, and the basis for using the SP-method for determining Rw and without applying a correction factor. The Cheyenne aquifer diagram (fig. 4) has the benefit of only one established data point (Fallow #43-18, in 10 South - 54 West - 18); nearly 10 miles north of the project area. It is believed that the Cheyenne plots lie well within the potential plus or minus one-half order of magnitude of error mentioned by Jorgensen (p. 6).

TABLE 2

Average concentrations, in mg/l of pertinent constituents in water obtained from three oil and gas exploration holes and from the Brandon Water Association. SO_4 = sulfate, Kd = Dakota aquifer, KC = Cheyenne aquifer.

Well Name	Location	Na	Cl	SO_4	TDS	Depth (ft)
#4 Grays State	12S-51W-36	2993	4048	175	8,258	2,672 (Kd)
#3 Navajo 32-3	17S-46W-3	-	7300	-	17,036	1,156 (Kd)
Fallow 43-18	10S-54W-18	-	-	-	2,952	4,150 (Kc)
Brandon W.	18S-45W-34	600	-	-	1,760	840 (Kd)

Calculated formation water Rw's for the Dakota aquifer range from 0.28 ohm-meters to 12.57 ohm-meters. Calculated TDS from the 0.28 ohm-meter water is 23,100 mg/l, whereas calculated TDS from the 12.57 ohm-meter water is 603 mg/l. Calculated formation - water Rw's for the Cheyenne aquifer range from 0.31 to 8.31 ohm-meters. Calculated TDS from the 0.31 ohm-meter water is 17,180 mg/l, whereas calculated TDS from the 8.31 ohm-meter water is 906 mg/l. Estimated NaCl concentrations (both aquifers represented) range from 431 to 25,760 mg/l.

Distribution of estimated Rw, and NaCl and TDS concentrations are plotted on figures 5 and 6. Depth to the top of each aquifer is included as a 500 foot contour interval. In general, Rw decreases with depth and NaCl and TDS increases. Since the Dakota and Cheyenne aquifers have an apparent northward dip, it follows that Rw decreases with distance from the outcrop/subcrop area, and NaCl and TDS increases.

On figures 5 and 6, approximate contours have been drawn on 4,000 and 10,000 mg/l TDS. Coincidentally, the position of the 4,000 and 10,000 mg/l NaCl contour is (for this report) identical. A concentration of 4,000 mg/l was chosen because many communities use 2,000-4,000 mg/l water when more suitable supplies are absent (McKee and Wolf, 1978). The 10,000 mg/l concentration is for reference purposes only. In utilizing the two figures the reader will find that low Rw, high TDS, and high NaCl normally occur north and west of the 4,000 mg/l contour. On the opposite side, high Rw's, and lower TDS and NaCl are common. Figures 5 and 6, therefore, can be used to approximate the locations of low and high Rw, and low and high TDS and NaCl. Or, when used with reservation, as a general guide to water quality.

Figures 5 and 6 also show the current northern limit of Dakota and Cheyenne aquifer utilization within the project area. The limit does not represent water quality restrictions as much as it does well construction and pumping economics, and water quantity requirements.

Examination of figures 5 and 6 reveals that water quality trends of both Dakota and Cheyenne water are nearly parallel and that the chemical quality of Cheyenne water is generally poorer than Dakota water lying above it. The reader is advised to compare the positions of the Dakota and Cheyenne 4,000 and 10,000 TDS contours.

SUMMARY

Principal bedrock aquifers in the 5,200 square mile project area are the Dakota and Cheyenne aquifers. These aquifers supply water not only to domestic and stock wells, but also several public supply wells. Most of the useful water quality data within the project area has been obtained from wells south of Township 20 South. North of Township 20 South there are only four useful water quality analyses of Dakota and Cheyenne water; one analyses of Brandon Water Association water, analyses of water from drill stem tests on two widely-spaced oil and gas exploration holes, and the analyses of water from an oil and gas exploration hole 10 miles north of the project area.

The SP-method was used to estimate Rw in the area north of Township 19 South. Total solids and NaCl concentration were obtained by utilizing methods described in Jorgensen (p.22). Results of the calculations were plotted on four diagrams: two Rw vs. TDS diagrams and two Rw, TDS, NaCl vs. distance and depth diagrams. The diagrams support use of the SP-method as a viable means of estimating Rw within the project area, and that relative water quality can be determined by utilization of the four diagrams.

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DATA FROM GEOPHYSICAL LOGS
DAKOTA/CHEYENNE AQUIFERS
EASTERN COLORADO
1994

TWN/RNG	SEC	QTR/QTR	WELL ID	ELEV. GS	ELEV MP	DEPTH TO TOP DAKOTA	DEPTH BASE DAKOTA	DEPTH TO TOP CHEY	DEPTH BASE CHEY	ELEV TOP DAKOTA	ELEV BASE DAKOTA	ELEV TOP CHEY	ELEV BASE CHEY	
17S 45W	36	SWSW	STATE 1-36	4026	4037	1080	1300	1400	1510	2957	2737	2637	2527	
17S 46W	2	SWSW	BETTY 2-1	4068	4078	1155	1370	1415	1445	2923	2708	2663	2633	THIN Kc
17S 46W	8	NWNW	GOLDEN RULE #1	4049	4059	1120	1330	1425	1525	2939	2729	2634	2534	BASE Kc ?
17S 46W	34	SESW	1-34 BUCKLEN	4040	4048	975	1200	1285	1415	3073	2848	2763	2633	
17S 47W	2	NENE	BOWEN #1	4085	4095	1130	1345	1405	1530	2965	2750	2690	2565	
17S 47W	24	NWNW	NEWSHAM HYBRIDS	4038	4038	1004	1210	1284	1394	3034	2828	2754	2644	
17S 47W	28	NWNE	#1 SPOILER 31-28	4125	4135	1040	1275	1335	1480	3095	2860	2800	2655	
17S 47W	31	NENW	HIGHTOWER #1	4158	4168	1150	1370	1470	1600	3018	2798	2698	2568	
17S 48W	2	SWSW	OWENS #1	4193	4203	1030	1250	1350	1580	3173	2953	2853	2623	
17S 48W	8	SWSW	THOMPSON #1	4280	4289	1065	1270	1430	1560	3224	3019	2859	2729	
17S 48W	13	SWNE	WILLIE Jr.1	4210	4220	1155	1360	1430	1530	3065	2860	2790	2690	
17S 49W	21	SWSE	No. 1 U P BERRY	4383	4393	1170	1360	1530	1655	3223	3033	2863	2738	
17S 49W	25	SESE	No. 1 CHAMPLIN-GREENWELL	4340	4350	1320	1520	1605	1710	3030	2830	2745	2640	
17S 49W	36	SESE	FERGUS-STATE 1-36	4301	4310	1250	1455	1540	1640	3060	2855	2770	2670	
17S 50W	14	SWSW	#1 UNITED BANK	4462	4474	1340	1530	1630	1770	3134	2944	2844	2704	
17S 50W	31	SWSE	#1 UPRC-RUST	4467	4479	1255	1435	1515	1595	3224	3044	2964	2884	
17S 50W	32	SWSW	#1 PECK	4453	4465	1230	1430	1515	1625	3235	3035	2950	2840	
17S 51W	18	NWNW	BLAKEMORE 11-18	4647	4657	1520	1680	1725	1855	3137	2977	2932	2802	
17S 52W	1	SWSE	BLAKEMORE 1-1	4662	4672	1530	1685	1800	1865	3142	2987	2872	2807	
17S 52W	12	NWNE	BLAKEMORE 1-12	4656	4667	1540	1705	1800	1845	3127	2962	2867	2822	THIN Kc
17S 53W	6	NWNW	FLB et al 6-1	4627	4636	1880	2000	2130	2215	2756	2636	2506	2421	FAULTED OR LOCATION ERROR
17S 53W	22	NWNW	D-4 RANCH 22-1	4527	4536	1585	1710	1785	1860	2951	2826	2751	2676	
18S 41W	6	SWSW	LAS ANIMAS 1	3958	3967	1210	1405	1520	1610	2757	2562	2447	2357	