Geology and Ground-Water Resources of the Big Sandy Creek Valley Lincoln, Cheyenne, and Kiowa Counties, Colorado

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1843

Prepared in cooperation with the Colorado Water Conservation Board

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By DONALD L. COFFIN

With a section on

CHEMICAL QUALITY OF THE GROUND WATER

By C. ALBERT HORR

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GEOLOGY AND GROUND-WATER RESOURCES OF THE BIG SANDY CREEK VALLEY, LINCOLN, CHEYENNE, AND KIOWA COUNTIES, COLORADO

By Donald L. Coffin

ABSTRACT

This report describes the geology and ground-water resources of that part of the Big Sandy Creek valley from about 6 miles east of Limon, Colo., downstream to the Kiowa County and Prowers County line, an area of about 1,400 square miles. The valley is drained by Big Sandy Creek and its principal tributary, Rush Creek. The land surface ranges from flat to rolling; the most irregular topography is in the sandhills south and west of Big Sandy Creek. Farming and livestock raising are the principal occupations. Irrigated lands constitute only a small part of the project area, but during the last 15 years irrigation has expanded.

Exposed rocks range in age from Late Cretaceous to Recent. They comprise the Carlile Shale, Niobrara Formation, Pierre Shale (all Late Cretaceous), upland deposits (Pleistocene), valley-fill deposits (Pleistocene and Recent), and dune sand (Pleistocene and Recent). Because the Upper Cretaceous formations are relatively impermeable and inhibit water movement, they allow ground water to accumulate in the overlying unconsolidated Pleistocene and Recent deposits. The valley-fill deposits constitute the major aquifer and yield as much as 800 gpm (gallons per minute) to wells along Big Sandy and Rush Creeks. Transmissibilities average about 45,000 gallons per day per foot. Maximum well yields in the tributary valleys are about 200 gpm and average 5 to 10 gpm. The dune sand and upland deposits generally are drained and yield water to wells in only a few places.

The ground-water reservoir is recharged only from direct infiltration of precipitation, which annually averages about 12 inches for the entire basin, and from infiltration of floodwater. Floods in the ephemeral Big Sandy Creek are a major source of recharge to ground-water reservoirs. Observations of a flood near Kit Carson indicated that about 3 acre-feet of runoff percolated into the ground-water reservoir through each acre of the wetted stream channel. The downstream decrease in channel and flood-plain width indicates that floodflows percolate to the ground-water reservoir.

In the project area at least 94,000 acre-feet of water is evaporated and transpired from the valley fill along Big Sandy Creek, 1,500 acre-feet is pumped, 250 acre-feet leaves the area as underflow, and 10,000 acre-feet leaves as surface flow.

Surface-water irrigation has been unsuccessful because of the failure of diversion dams and because of excessive seepage from reservoirs.

Ground-water irrigation dates from about World War I; most of the 30 irrigation wells now in use, however, were drilled after 1937. In 1960 less than 1,000 acre-feet of water was pumped for irrigation, about 500 acre-feet was pumped for municipal use, and less than 10 acre-feet was pumped for rural use (stock and domestic).

Although additional water is available in the valley-fill deposits of Big Sandy and Rush Creeks, large-scale irrigation probably will not develop in the immediate future; soils are unsuitable for crops in many places, and large water supplies are not available from individual wells.

The dissolved-solids content of the ground water in the valley-fill deposits ranges from 507 to 5,420 parts per million. In the Big Sandy Creek valley the dissolved-solids content generally increases downstream, whereas in the Rush Creek valley the dissolved-solids content decreases downstream. Ground water in the Big Sandy Creek valley is suitable for most uses.

INTRODUCTION

PURPOSE AND SCOPE

Investigation of the geology and ground-water resources of the Big Sandy Creek valley was begun in July 1959 by the U.S. Geological Survey in cooperation with the Colorado Water Conservation Board.

The purpose of the study was to determine the availability of ground water, the extent of ground-water development, the chemical quality of water as related to use, and present and possible future ground-water problems.

To accomplish these objectives, basic data were collected and compiled by Coffin (1962) in a report containing logs, water-level measurements of selected wells and test holes, physical properties of unconsolidated material, chemical analysis of ground water, and streamflow measurements.

The collection of these data was also the beginning of a continuing program for water-data collection. This program will be useful in monitoring problems pointed out by this study and in the early detection of new water problems.

LOCATION

The project area (fig. 1), in east-central Colorado, is in the Colorado Piedmont section of the Great Plains province. Its east boundary roughly follows the west boundary of the High Plains section of the Great Plains province, as defined by Fenneman (1931, p. 5–7). The project area is at a lower altitude than the terrain along the west boundary of the High Plains and, as is typical of the Colorado Piedmont, has a gently rolling topography. It includes 420 square miles of Lincoln, 735 square miles of Cheyenne, and 280 square miles of Kiowa Counties, a total of 1,435 square miles. The 1960 populations of the principal towns are: Hugo, 811; and Kit Carson, 356.

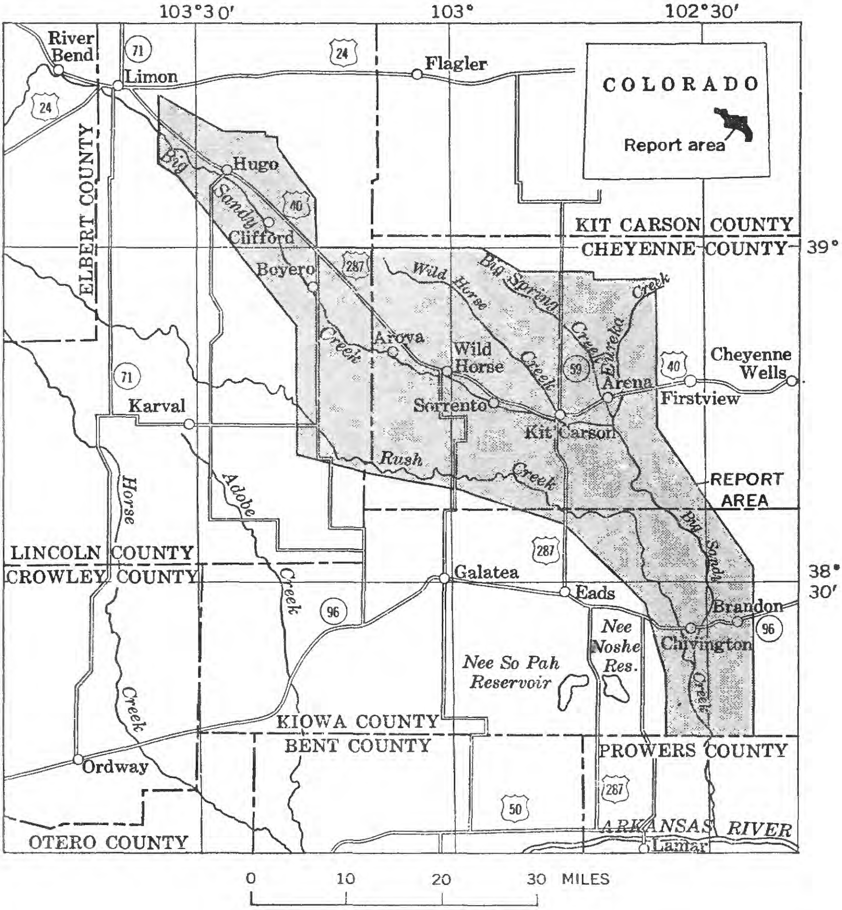

FIGURE 1.—Location of report area.

The Big Sandy Creek drainage basin includes about 3,400 square miles. The project area includes the middle and lower parts of the basin and is drained by Big Sandy Creek and its principal tributaries—Rush, Wild Horse, and Big Spring Creeks. Big Sandy Creek enters the Arkansas River about 8 miles east of Lamar, Colo.

IMPORTANCE OF WATER TO THE ECONOMY

Water is one of the area's most important resources. The economy, based on farming and ranching, is dependent on obtaining enough water for domestic, stock, and irrigation uses. Aquifers extend under much of the area and can be tapped at the convenience of the landowner. Surface water has been comparatively undeveloped, although in many places of ground-water deficiency stock ponds provide dependable water supplies.

The water resources in the Big Sandy Creek basin are relatively small; therefore, their better utilization is of major importance to the economy. Development of the water resources without proper planning and management could result in water shortages. Knowledge of the hydrologic system, proper water management, and conservation practices will provide maximum benefit from the water resources. For example, better use of floodflows could be made by recharge to the ground-water reservoir, and better use of the ground-water reservoir could be made by creating additional storage space, by artificial recharge, or by decreasing natural discharge.

WELL-NUMBERING SYSTEM

The well and test-hole numbers in the tables indicate their locations. The numbering system is based on the U.S. Bureau of Land Management system of land subdivision. The number shows the location of the well or test hole by quadrant, township, range, section, and position within the section. A graphical illustration of this method of well location is shown on figure 2. The capital letter at the beginning of the location number indicates the quadrant in which the well is located. Four quadrants are formed by the intersection of the base line and the principal meridian—A indicates the northeast quadrant; B, the northwest; C, the southwest; and D, the southeast. The first numeral indicates the township; the second, the range; and the third, the section in which the well is located. Lowercase letters following the section number locate the well within the section. The first letter denotes the quarter section; the second, the quarter-quarter section; and the third, the quarter-quarter-quarter section. The letters, beginning with "a" in the northeast quarter of the section, are assigned within the section in a counterclockwise direction. Letters are assigned within each quarter section and within each quarter-quarter section in the same manner. Where two or more locations are within the smallest subdivision, consecutive numbers beginning with 2 are added to the letters in the order in which the wells or test holes were inventoried. For example, C10–55–27cca2 indicates a well in the northeast quarter of the southwest quarter of the southwest quarter of sec. 27, T. 10 S., R. 55 W., and shows that this is the second well inven-

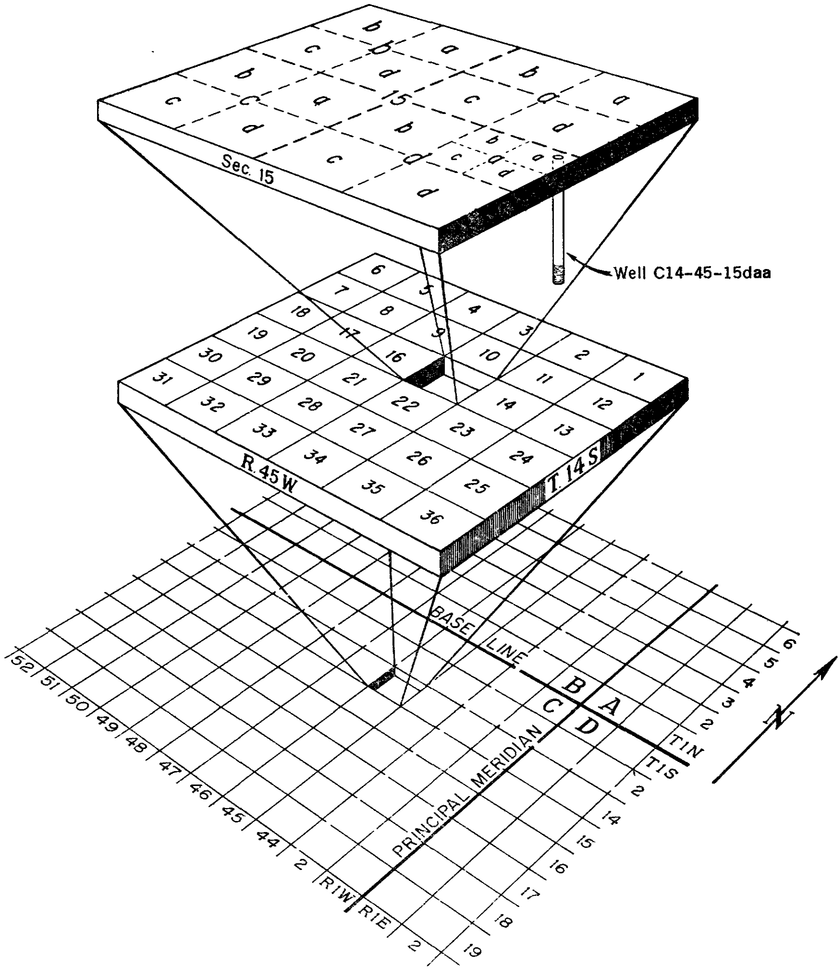

FIGURE 2.—System of numbering wells and test holes.

toried in the quarter-quarter-quarter section. The capital letter C indicates the township is south of the base line and that the range is west of the principal meridian.

ACKNOWLEDGMENTS

The writer is indebted to the many people who supplied information about their wells and permitted test drilling on their land. Thanks are extended to Messrs. V. George, B. Hallowell, and Lloyd Philpy, who permitted the use of their wells for pumping tests, and to the city officials of Hugo, Kit Carson, and Eads, who furnished information concerning municipal wells. Thanks are also extended to the county officials, who gave permission for test drilling along road right-of-ways, and to the members of the Soil Conservation Service, who cooperated in every way possible to expedite the work.

GEOLOGY AND WATER-BEARING PROPERTIES OF THE ROCKS

Topographic position and physical characteristics of the rocks are the major controls of water availability in the Big Sandy Creek valley. Rocks of Late Cretaceous and Quaternary age crop out. In general, the Cretaceous bedrock is relatively impermeable and forms barriers to the downward movement of water. Therefore, the bedrock allows water to accumulate in the overlying unconsolidated deposits of Quaternary age. The rocks of Quaternary age are relatively permeable in comparison with the Cretaceous bedrock and allow water to move through them. The Quaternary rocks constitute the major water-bearing units (aquifers). Table 1 shows a generalized section of the geologic formations and a summary of their water-bearing properties.

ROCKS OF LATE CRETACEOUS AGE

The rocks of Late Cretaceous age—the Carlile Shale, the Niobrara Formation, and the Pierre Shale—are primarily shale but contain a few thin limestone beds; their maximum thickness is about 4,300 feet. Their outcrop pattern has been affected by regional structural movement. The most pronounced geologic structure is the Las Animas arch, which has caused the Carlile and Niobrara to be exposed in the southern part of the area. The Cretaceous rocks are exposed as small isolated patches, except for the Pierre Shale, which is widely exposed.

TABLE 1.—*Generalized section of the geologic formations*

System	Series	Stratigraphic unit		Thickness (feet)	Physical character	Water supply
Quaternary	Recent and Pleistocene	Dune sand		0-70±	Fine to very coarse quartz sand; contains silt and clay. In many places basal part contains scattered very fine to fine gravel.	Where saturated, yields 1-10 gpm to stock and domestic wells. The sand dunes are major catchment areas for recharge from precipitation.
		Valley-fill deposits		0-70±	Sand, gravel, silt, and clay, generally intermixed, but also occur as alternating layers. Become coarser near base.	Yield as much as 800 gpm to wells in the Rush Creek and Big Sandy Creek valleys. Average yields of 5-10 gpm to domestic and stock wells in the tributary valleys.
	Pleistocene	Upland deposits		0-40±	Clay, silt, sand, and gravel. Sandy clay predominates in upper part. Thin sand and gravel layer near base. Caliche stringers throughout.	Generally drained except in areas where depressions in the bedrock surface allow ground water to accumulate. Yield less than 10 gpm to domestic and stock wells.
Cretaceous	Upper Cretaceous	Pierre Shale		1,000-3,500+	Black to gray shale; contains gypsum, limonite, limestone, and calcareous concretions.	Not known to yield water to wells in the project area.
		Niobrara Formation	Smoky Hill Shale Member	700±	Dark- to light-gray chalky shale; contains gypsum and chalky limestone; weathers to orange or light yellow.	Yields less than 2 gpm of poor-quality water to stock wells, principally from weathered zones. Yields no water in some places.
			Fort Hays Limestone Member	50±	White chalky limestone; contains thin beds of chalky shale.	Yields less than 10 gpm to stock wells near outcrop.
		Carlile Shale	Codell Sandstone Member	35±	Chiefly calcareous sandy shale; contains beds of very fine calcareous sandstone.	Yields less than 5 gpm to domestic and stock wells.
			Blue Hill Shale Member	50±	Black noncalcareous shale.	Not known to yield water to wells in the project area.

(See pl. 1.) The formations are not discussed in detail in this report because of poor exposures and because, hydrologically, their principal importance is to retard the downward movement of water. Many reports have described these formations in nearby areas; in particular the reader is referred to Bass (1926, p. 28, 64), Elias (1931, p. 29–131), and Scott (1963, p. 95–104) for excellent discussions of the Carlile, Niobrara, and Pierre.

CARLILE SHALE

The Carlile Shale of Late Cretaceous age contains the Fairport Chalky Shale Member, the Blue Hill Shale Member, and the Codell Sandstone Member. The Carlile can be traced from western Kansas to the Front Range. However, the only member exposed locally is the Codell Sandstone Member, which crops out in a small area near the Prowers County line (pl. 1).

CODELL SANDSTONE MEMBER

CHARACTER

Where the Codell Sandstone Member crops out it consists of about 26 feet of sandy shale separating four sandstone beds 1 to 2 feet thick. The sandstone beds are at the surface and at the intervals of 6, 13, and 26 feet below the surface. The shale is grayish to dark blue, is slightly calcareous, and contains lenses less than 6 inches in diameter of very fine grained silty buff to light-yellow soft sandstone. The shale weathers to a gentle slope that generally is covered by its own weathering products and by rubble from the overlying formations. The sandstone is very fine grained, subrounded, well cemented, calcareous, and light gray to light brown. The bedding is flat, and the sandstone fractures into thin slabs. Locally the sandstone is well cemented into quartzite. The topmost 2-foot-thick sandstone bed contains much chalk and weathers to a yellow-brown gnarly surface. The sandstone beds form resistant ledges, especially the topmost bed, which, together with the disconformably overlying Fort Hays Limestone Member, forms a bluff.

WATER SUPPLY

The sandstone beds of the Codell yield less than 5 gpm (gallons per minute) to wells. Little water moves through the Codell, for its permeability is relatively low because of fine grain size and cementation. The Codell is far beneath the surface except near the outcrop.

NIOBRARA FORMATION

The Niobrara Formation of Late Cretaceous age contains the Fort Hays Limestone Member at the base and the overlying Smoky Hill Shale Member (table 1). The Fort Hays is predominantly chalky limestone, and the Smoky Hill is chalky shale. The Niobrara is exposed widely in eastern Colorado and in adjoining States, but exposures in the project area are generally small and widely separated. Discussions of the Niobrara are given by Elias (1931, p. 29–43) and Scott (1963, p. 97–99).

FORT HAYS LIMESTONE MEMBER

CHARACTER

The lower member of the Niobrara Formation, the Fort Hays Limestone Member, crops out in several places near the Prowers County line (pl. 1). It consists of about 50 feet of white chalky limestone separated by thin beds (less than 1 ft thick) of calcareous silty dark-gray shale. The limestone beds are from 4 inches to 2 feet thick; the thicker beds are near the base. The limestone contains small ironstone concretions and, in unweathered outcrops, is fractured into rectangular blocks. In the SW¼ sec. 19, T. 20 S., R. 45 W., structural movement has produced some minor faults in the Fort Hays; some of these faults have been filled with crystalline calcite. Both the limestone and shale contain abundant fossils. The Fort Hays is more resistant than the overlying and underlying formations and therefore generally weathers to a ridge. If the exposure is next to a stream channel, erosion by the stream forms a small bluff. The limestone in the Fort Hays weathers to small white chips, and in places the chips may cover the unweathered limestone.

The interbedded shale becomes thicker and more abundant near the top of the member and grades upward into the overlying Smoky Hill Shale Member.

WATER SUPPLY

The fractures in the Fort Hays allow movement of water; however, less than 10 gpm is obtained from wells tapping the formation. Except near its outcrop, in the southern part of the project area, the Fort Hays is too deeply buried to be a source of potable water.

SMOKY HILL SHALE MEMBER

CHARACTER

The upper member of the Niobrara Formation, the Smoky Hill Shale Member, is about 700 feet thick. It consists of chalky shale that is dark gray to black on a fresh surface; however, it weathers to an orange or light-yellowish orange. The Smoky Hill weathers rapidly and, except in streamcuts, is almost everywhere thinly covered by silty clay. In several exposures along Rush Creek thin chalky limestone beds and thin bentonite beds are common. Large (1.5 to 3 ft diam) calcareous concretions may be seen in many outcrops. Smaller (1 to 2 in. diam) concretions of limonite surrounded by calcite are also common. In many places the shale is fractured at an angle of about 30° to the bedding and thus has produced a false impression of bedding. The fractures are commonly filled with calcite and gypsum.

The conformable contact of the Smoky Hill and Pierre Shale is marked by an upward gradation of the calcareous orange- or yellow-weathering shale into the noncalcareous drab yellowish-brown-weathering shale of the Pierre.

WATER SUPPLY

The Smoky Hill is relatively impermeable and yields water to wells (less than 2 gpm) only in a few places, principally from weathered zones. In Wallace County, Kans., Elias (1931, p. 40) reports permeable zones in the Smoky Hill. These zones have not been reported in the project area and, if present, probably contain highly mineralized water. The Smoky Hill retards downward movement of water.

PIERRE SHALE

The Pierre Shale crops out widely in the Great Plains. It underlies the unconsolidated deposits in most of Cheyenne and Lincoln Counties. The Pierre has been the subject of many geologic investigations, and the reader is referred to Elias (1931, p. 43–131) and Scott (1963, p. 99–104) for a complete description of the formation. The Pierre has been subdivided into several mappable members; however, in this report it is considered to be a single hydrologic unit.

CHARACTER

The Pierre is remarkably uniform lithologically and is composed of noncalcareous shale usually dark gray to black but weathering to lighter shades of brownish gray or yellow. Thin crystals of selenite are scattered through the formation but are most common along bedding planes and fractures. Concretions ranging from a few inches to several feet in diameter are abundant throughout the formation and generally contain many fossils. The concretions are usually impure limestone but in some places are mostly ironstone.

A few thin and nonpersistent limestone beds occur locally. Conical buttes of limestone may be found near and northeast of Boyero. These are called the tepee buttes because the limestone core is conical and weathers out of the surrounding shale as a hill resembling an Indian tepee. The limestone contains large numbers of *Lucina* shells, and, in Kansas, Elias (1931, p. 80) applied the name "Lucina limestone."

The Pierre generally weathers to form gentle slopes because of the lack of resistant beds. Soil that forms from the Pierre is fine grained and relatively impermeable; hence, precipitation runs off the formation quickly and forms many ephemeral washes and gullies.

WATER SUPPLY

The Pierre is not known to yield water to wells in the project area. Its fine grain size makes it relatively impermeable.

The minimum thickness from the base of the Pierre to the first dependable source of water, the Dakota Sandstone, is about 2,000 feet. The Dakota probably contains highly mineralized water. Therefore, a test hole that does not tap potable water above the Pierre Shale should be abandoned.

ROCKS OF QUATERNARY AGE

Rocks of Quaternary age are sand, gravel, silt, and clay that have been deposited by wind and streams. These rocks are composed of reworked material originally deposited during the Pliocene and early Pleistocene. A small part is derived from Cretaceous material. The principal source material is probably the Ogallala Formation of Pliocene age, which forms the High Plains. In this report rocks of Quaternary age are divided into three groups: (1) the upland deposits (mostly north of Big Sandy Creek), which are considerably above stream level, (2) the valley-fill deposits along the streams, and (3) the dune sand, which is generally on the south side of streams. The Quaternary deposits are the major aquifers. Their geologic character, position, and hydrologic properties are described on the following pages. Suggestions for advantageously locating wells in these rocks are given at the end of the description of each unit.

UPLAND DEPOSITS

CHARACTER AND POSITION

The upland deposits east and northeast of Aroya (pl. 1) are the oldest Quaternary deposits in the project area. They are composed chiefly of reworked Pliocene and lower Pleistocene material. Their thickness ranges from 0 near the north project boundary to about 40 feet at the southern contact of the upland deposits and the valley-fill deposits near Big Sandy Creek. They grade from coarse sand and gravel at the base to sandy clay and silt at the top. The lower sand and gravel beds thicken northward, whereas the sandy clay beds thin. Thus the total thickness does not greatly change except for abrupt thinning near the northern edge. For discussion, it is convenient to divide the deposits into a lower unit of sand and gravel, a middle sandy unit, and an upper unit of silt and clay.

The lower unit is 5 to 20 feet thick. It is thickest near the north project boundary and thins southward. It is composed of fine to medium subrounded to rounded quartz and feldspar gravel and fine to very coarse sand. A few well-rounded igneous and metamorphic cobbles are generally present. The sand and gravel unit contains much concretionary material and a few lenses of claystone, which are both derived from the Pierre Shale. Well-rounded and reworked caliche nodules and a few stringers of caliche are scattered throughout the unit. The lower unit is poorly sorted compared with the middle and upper units.

The middle unit, above its gradational contact with the lower unit, is predominantly fine to very coarse sand that contains lenses of very fine gravel. It ranges in thickness from 5 feet near the southern contact to 10 or 15 feet near the north project boundary. Caliche stringers and nodules are abundant and give it a whitish appearance when viewed from a distance. Reworked claystone from the Pierre Shale is much less common than it is in the lower unit.

The middle unit grades upward into the upper unit, which consists of 1 to 15 feet of gray-brown windblown silt and clay or loess. The upper unit is thickest near the southern contact with the valley-fill deposits and thins northward, where it almost disappears near the north project boundary.

The upland deposits overlie a relatively smooth eroded surface of the Pierre Shale. This surface slopes southward at about 20 feet per mile. The surface of the upland deposits also slopes uniformly southward and ranges from about 400 feet above Big Sandy Creek at the north project boundary to about 50 feet above the creek at the southern edge of the deposits. The surface is covered by dune sand in some places and is dissected by streams in others.

Regional extension of the surface of the upland deposits indicates a correlation with deposits southwest of Big Sandy Creek. The deposits southwest of Big Sandy Creek have been mapped as Pliocene Ogallala Formation (Burbank and others, 1935). However, their topographic position, which is generally below the Pliocene surface projected from the High Plains westward to the Front Range, indicates an age younger than Pliocene. An age of Pleistocene for these deposits southwest of Big Sandy Creek may be assumed, primarily because of their position below the projected Pliocene surface and because their caliche content, smaller than that in the Pliocene Ogallala Formation, may indicate a shorter time since deposition. A more specific age may be determined by additional fieldwork southwest of Big Sandy Creek.

WATER SUPPLY

Even though the upland deposits are permeable and receive recharge from precipitation, they are topographically higher than the valleys and are generally drained. Line *G–G′* (pl. 1) illustrates the hydrologic situation in most of the area underlain by upland deposits. Although stock and domestic wells yielding less than 10 gpm have been developed in a few undrained depressions in the bedrock surface, it is not possible to develop irrigation wells in the deposits.

Landowners in the area of upland deposits (pl. 1) desiring to develop domestic and stock-water supplies should first test the valley-fill or dune-sand areas by drilling. If no valley fill or dune sand is nearby, the upland deposits may be tested. However, the chance of obtaining successful wells in the upland deposits is considerably less than it is in either the dune sand or valley fill.

VALLEY-FILL DEPOSITS

The valley fill consists of sand, gravel, silt, and clay resting on the bedrock of the valleys. The deposits along Big Sandy and Rush Creeks will be discussed separately from the deposits in the tributary valleys.

VALLEY-FILL DEPOSITS IN THE TRIBUTARIES

CHARACTER AND POSITION

In the tributaries to Big Sandy and Rush Creeks, the thickness of the valley fill ranges from 0 to about 40 feet. The deposits are predominantly sand, silt, and clay. The valley fill of the larger tributaries may contain a small amount of very fine to fine gravel, usually near the base. The average grain size of the valley fill in the tributaries is smaller than that in the Big Sandy Creek and Rush Creek valleys because most of the valley fill in the tributary valleys was derived primarily from fine-grained sources—Pierre Shale, Niobrara Formation, loess, and dune sand. The sand and gravel are probably derived from the lower upland deposits and the Ogallala Formation. Sorting is much poorer than it is in the deposits of the main valleys,

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mainly because of smaller and more erratic streamflow during the time of deposition.

The bedrock floor of the tributary valleys gently slopes from each side, meeting in a shallow V. The thickest valley fill normally is near the center of the valley. Even though the width of the deposits in the tributaries may be greater than that in the main valleys, the average thickness is less because of the gently sloping bedrock sides. Section lines *G–G′* and *H–H′* (pl. 1) show the configuration of the bedrock and the lithologic characteristics of the tributary valley fill.

Terraces are not well developed in the tributary valleys and were not mapped. In many places there are terrace remnants near the mouths of tributaries, but the remnants cannot be traced upstream.

WATER SUPPLY

The tributary valleys are topographically lower than the surrounding terrain. Thus their valley-fill deposits usually contain water because they collect runoff or ground water draining from the dune sand or upland deposits. Saturated thickness may range from a few inches near the edge to about 20 feet near the center of the larger tributaries. Finer grain size and poorer sorting of these deposits relative to the valley fill in the Big Sandy Creek and Rush Creek valleys result in lower permeability. The maximum well yield in the tributary valleys is estimated to be 200 gpm, which is probably possible only in the lower end of Big Spring Creek and Wild Horse Creek valleys, where the saturated section is thickest and permeability is highest. In the other tributary valleys maximum yield of wells is about 50 gpm, and average yield is 5 to 10 gpm.

When prospecting for water in the tributary valleys, test holes should be drilled in a line at right angles to the long axis of the valley. The first test hole should be drilled near the center of the valley. The well owner should locate his well in the thickest saturated section to obtain the greatest well yield and to minimize the chance of the well going dry in drought.

VALLEY-FILL DEPOSITS IN BIG SANDY CREEK AND RUSH CREEK VALLEYS

CHARACTER AND POSITION

The valley fill along Big Sandy and Rush Creeks is composed of sand, gravel, silt, and clay and ranges from 0 to about 70 feet in thickness. The average thickness is 25 to 30 feet. The sand and gravel were derived mostly from igneous and metamorphic rocks but to some extent from limestone and sandstone. The grains and pebbles are subangular to well rounded, and the pebbles generally are more rounded. Compared with the upland deposits, the valley fill contains only small amounts of caliche and is well sorted. Crossbedding is apparent in most exposures of the valley-fill deposits.

Test-well logs (Coffin, 1962) and the outcrops of the valley-fill deposits show a vertical gradation from very fine to fine gravel and sand near the base to silt and clay or very fine to fine sand near the top. The basal valley-fill deposits also grade downvalley from cobble-size material near the headwaters of Big Sandy Creek (McLaughlin, 1946, p. 94) to very fine gravel near the Kiowa County and Prowers County line.

At least four terraces and the flood plain are developed on the valley fill along Big Sandy Creek. For this report, the mapped units (pl. 1) from youngest to oldest are: the flood plain deposits; younger terrace deposits, which include at least three terrace levels; and older terrace deposits. Figure 3 shows a diagrammatic section of the Big Sandy Creek valley and the relative position of the surfaces.

The flood plain lies at about the same level as the top of the stream channel. It is fairly smooth, although there are some meander scars and discontinuous 1- to 2-foot terraces. The width of the flood plain decreases downstream, as shown on plate 1. This is attributed to the percolation of floodwater into the underlying deposits. As flood discharge decreases downstream because of percolation, the area needed for flow also decreases, and thus the width of the flood plain decreases.

The downstream decrease in discharge, as indicated by the downstream decrease in flood-plain width, implies that the thickness of the fine-grained flood-plain deposits must increase downstream. If most of the suspended load originates from the drainage basin rather than from the flood plain, then a decrease in discharge by percolation results in a concentration of the suspended load. As the concentration increases some of the load may be deposited, for the slope of the stream profile decreases downstream (fig. 4).

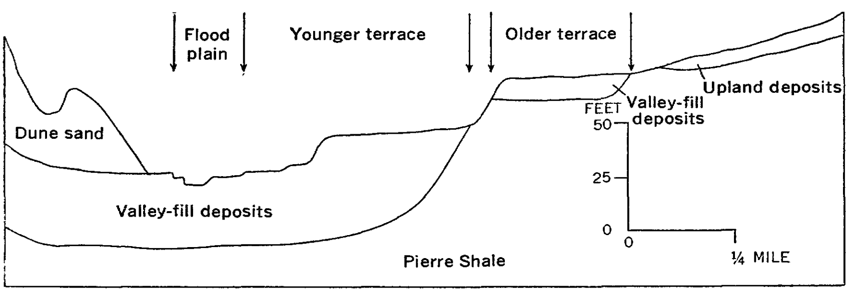

FIGURE 3.—Diagrammatic north-south section across the Big Sandy Creek valley.

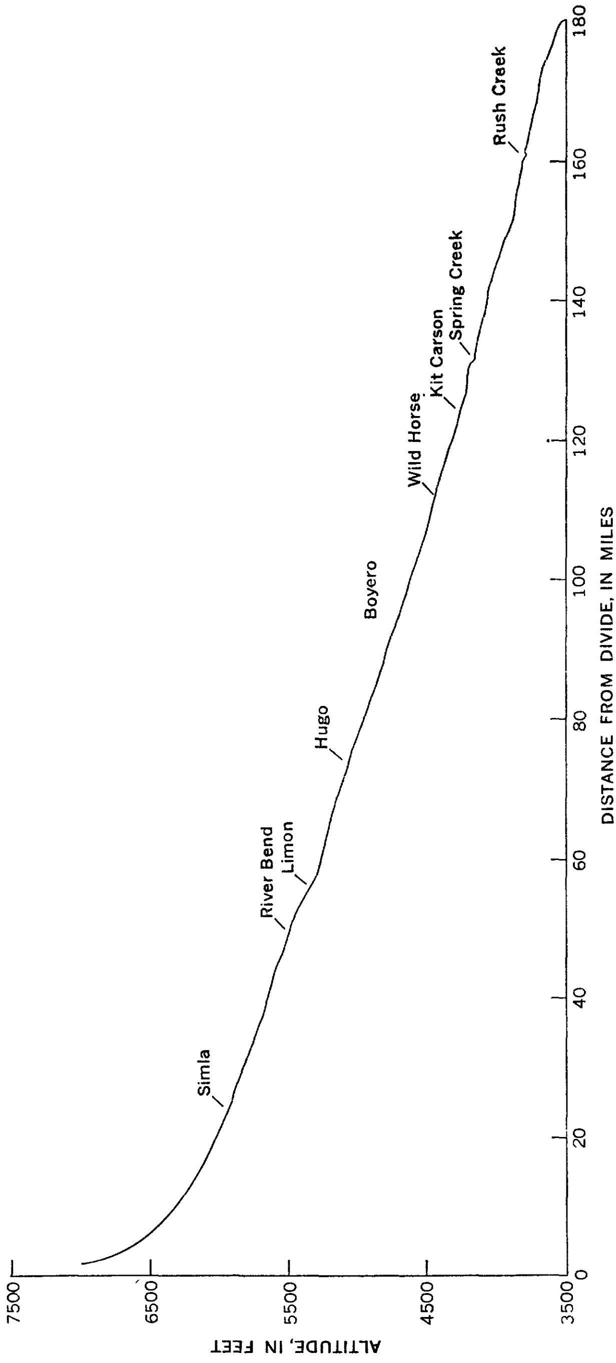

FIGURE 4.—Profile of Big Sandy Creek.

The increase in thickness of the fine-grained deposits beneath the flood plain is shown by section lines *A–A′*, *B–B′*, *C–C′*, *E–E′*, and *F–F′* (pl. 1). The deposits increase in thickness from Hugo to about the Cheyenne County and Kiowa County line. Downstream from the county line there is little increase in thickness of the fine-grained deposits because most floods originate above Wild Horse and are absorbed before they reach the county line.

The younger terrace includes at least three unmapped units. Although the heights above the flood plain differ from place to place, the first unit is about 3 feet above the flood plain, the second is about 3 feet above the first, and the third is from 10 to 20 feet above the second. The three units are not everywhere present where the youngest terrace is shown. The lowest unit commonly has been removed, and in many places the highest unit is poorly developed or covered by dune sand.

The older terrace ranges in height above the flood plain from about 100 feet near Hugo to about 35 feet downstream from Kit Carson. Both the terrace and its deposits are discontinuous, and its wide range in height above the flood plain makes correlations between outcrops tentative.

HISTORY OF DEVELOPMENT OF TERRACES

The valley fill is reworked Pliocene and lower Pleistocene deposits that were originally derived from the mountains, as shown by the abundance of igneous and metamorphic rock fragments. These fragments were deposited by eastward-flowing Pliocene and early Pleistocene streams in and along channels. In many places the material along adjacent streams may have coalesced to form sheet deposits. As the southeastward-flowing Big Sandy Creek began to develop its drainage area, it destroyed the early topography and incorporated the older sand and gravel into the present valley fill.

The above brief and oversimplified summation of the Quaternary shows that sand and gravel in the valley fill have undergone at least two cycles of erosion and deposition. The reworking during the second cycle of erosion and deposition is the principal reason that a well penetrating 20 to 30 feet of saturated material may yield 300 to 500 gpm from the valley fill of Big Sandy Creek, whereas a similar well may yield only 50 to 100 gpm from the Pliocene Ogallala Formation or lower Pleistocene deposits. Reworking and redeposition of the valley-fill deposits have increased the rounding and sorting of the constituent particles and, consequently, the water-yielding capabilities.

In the Big Sandy Creek valley all terraces do not necessarily have the same genetic relations with the deposits beneath them; that is, terraces may be formed either by deposition or by erosion. The presence of 20 to 30 feet of valley fill does not necessarily imply that the terrace is depositional. The sand and gravel of the valley fill could simply have been exchanged for the siltstone and claystone of the bedrock by the downcutting stream. On the other hand, the valley-fill deposits may have once filled the valley to the height of the uppermost terrace, and successive downcutting and planation by the stream may have produced the present terrace levels.

Most of the valley fill beneath the flood plain and the younger terrace was probably deposited as a unit; that is, the valley was probably filled to an altitude 20 or 30 feet above the present channel, and, therefore, the highest level of the younger terrace is a surface of deposition. This is indicated throughout the unit by (1) the uniform upward gradation from sand and gravel to silt and clay, as shown by test-hole logs, (2) the uniform downstream gradation from cobbles to very fine gravel in the lower 5 feet of the valley fill, and (3) the fact that both the upward and downstream gradation are continuous throughout the valley. The two lower levels of the younger terrace may represent periods of downcutting and planation; thus they may be surfaces of erosion. This is indicated by the absence of a silt and clay layer immediately below the surface; the layer probably has been removed by erosion.

The scattered outcrops of the deposit beneath the older terrace makes the origin of the terrace difficult to interpret. In the Hugo area the base of the valley fill beneath the older terrace is several feet above the younger terrace, and the valley fill grades from gravel at the base to silt and clay near the top. Downstream, north of Chivington, the older terrace merges into the younger terrace; the deposit beneath the older terrace is primarily sandy clay. The dissimilarity of lithologic characteristics and the wide variation in height of the remnants above the channel permit speculation that perhaps the remnants of the older terrace deposit result primarily from downcutting and exchange of sand and gravel for fine-grained bedrock.

The valley fill of Rush Creek is lithologically similar to that of Big Sandy Creek. Terrace relations are not evident because most of the valley-fill deposits of Rush Creek are covered by dune sand; therefore, the valley-fill deposits are undifferentiated on the map (pl. 1).

WATER-SUPPLY AND HYDRAULIC CHARACTERISTICS

The valley-fill deposits in the Big Sandy and Rush Creek valleys are the principal aquifers in the area. As much as 800 gpm may be obtained from wells tapping them; however, the average yield of irrigation wells is about 400 gpm.

The coefficient of transmissibility of the valley fill was determined in four places by pumping tests. See Ferris, Knowles, Brown and Stallman (1962, p. 91–122) for definitions and methods of making pumping tests. These tests are useful in assessing the ability of the aquifer to store and transmit water. Results of the pumping tests are summarized in table 2.

TABLE 2.—*Summary of the results of pumping tests in valley-fill deposits*

Well	Owner	Depth of well (feet)	Depth to bedrock (feet)	Depth to water (feet)	Saturated thickness (feet)	Duration of pumping (minutes)	Average pumping rate (gpm)
C10-55-27cca	B. Hallowell	36	36	6.4	30	2,910	117
C14-51-6ddd	V. George	16	20	6.6	13	1,425	53
C17-45-30cbd	E. Rutledge	23	28	6.6	21	1,440	78
46-18cdd	Town of Eads	46	46	10.9	35	2,880	565

Well	Owner	Drawdown in pumped well at end of pumping (feet)	Specific capacity (gpm per ft of drawdown)	Coefficient of transmissibility (gpd per ft)	Average coefficient of permeability (gpd per sq ft)	Number of observation wells	Date
C10-55-27cca	B. Hallowell	5.3	22	40,000	1,300	3	7-15-60
C14-51-6ddd	V. George	4.2	13	45,000	3,500	1	7-20-60
C17-45-30cbd	E. Rutledge	4.5	17	55,000	2,600	1	7-29-60
46-18cdd	Town of Eads	32.0	18	48,000	1,400	2	7-23-55

The coefficient of transmissibility was determined near well C17-45-30cbd by a mathematical model that assumes, among other factors, steady state and uniform recharge (Ferris and others, 1962, p. 131). If at several places the altitude of the water table, with respect to the mean stream level and distance to the ground-water divide, is known, the ratio of transmissibility and recharge can be calculated. By further assuming that during the winter, when evapotranspiration is low, the effective recharge is discharged into the stream where it can be measured, then recharge and, hence, transmissibility may be calculated. This method resulted in a transmissibility of 13,000 gpd (gallons per day) per ft. This transmissibility is much lower than that calculated from pumping tests—a result probably due to the fact that different volumes of aquifer were sampled by the two methods. A pumping test samples a roughly cylindrical volume with the well at its center, whereas the other method samples a unit width of the saturated zone extending from the stream to the ground-water divide or valley wall. Therefore, fine-grained material eroded from the valley walls and redeposited within the valley fill would decrease the transmissibility over a large part of the unit width of the aquifer. The higher transmissibility, as determined by pumping tests, may apply only to a volume of well-sorted material relatively near the well.

The average coefficient of permeability of the valley fill (for horizontal flow) may be determined by dividing the coefficient of transmissibility by the saturated thickness. Permeability determined in this manner, however, is an overall average of an ideal aquifer assumed in the mathematical model and may not represent the aquifer tested. Average permeability should therefore be used with caution.

Permeability, as determined in the field or in the laboratory by permeameter, is likewise subject to limitations, especially because permeability depends on the geometry of the pore space or packing. The act of collecting a sample disturbs and often completely changes the packing. The sample is repacked, but the pore spaces in the disturbed sample differ from those in the aquifer.

An alternate method for estimating the coefficient of permeability is to calibrate a driller's log of a well where the coefficient of transmissibility was determined by a pumping test. Not only can the permeability of the undisturbed aquifer be estimated by this method, but also the determined permeability values can be used with a driller's log to estimate the potential yield of other test holes.

Table 3 shows the permeability of various intervals of valley-fill deposits, as determined by solving for P_i in the formula

$$T = \Sigma\, P_i m_i$$

where T = coefficient of transmissibility, as determined by a pumping test, in gallons per day per foot;
P_i = field coefficient of permeability of the interval described in the driller's log, in gallons per day per square foot; and
m_i = thickness of the interval described in the driller's log, in feet.

The field coefficients of permeability corresponding to the intervals described in the driller's log may be obtained from table 3. These coefficients multiplied by the thickness of the interval can then be added to obtain transmissibility. The transmissibility thus estimated may be substituted in the following approximation of the steady-state Theim equation (Ferris and others, 1962, p. 91)

$$Q = \frac{Ts}{2{,}000}$$

where Q = discharge, in gpm;
T = transmissibility, in gpd per foot; and
s = drawdown, in feet.

The permissible drawdown is also estimated from the driller's log. Solution of the above equation gives a rough estimate of the test-hole yield.

TABLE 3.—*Field coefficient of permeability of the valley-fill deposits in the Big Sandy Creek valley*

Description	*Field coefficient of permeability (gpd per sq ft)* Range	Average
Sand, medium to very coarse, and very fine to fine gravel	1,500–2,500	1,900
Sand, very fine to very coarse	200–1,000	500
Clay, contains silt and fine sand	----------	<100

The average coefficient of permeability to vertical flow was roughly estimated for very fine to very coarse sand of the valley-fill deposits between the stream-channel floor and the water table by flood-discharge measurements and by applying Darcy's law. The total flood discharge on July 6, 1960, at Wild Horse was estimated to be 300 acre-feet. The flood was almost completely absorbed during 1 day in 22 miles of stream channel, or an area of about 110 acres. If it is assumed that the zone between the water table and the channel floor (about 2 ft) becomes saturated and that the vertical gradient during the flood is relatively constant, Darcy's equation may be solved for the coefficient of vertical permeability. A vertical permeability of 7 gpd (gallons per day) per sq ft was determined by this method. Because of the broad assumptions and the errors in measuring total discharge and area of infiltration, this method should be considered indicative only of the order of magnitude. Comparison of the vertical to horizontal permeability for very fine to very coarse sand results in a ratio of 1 to 70.

The storage coefficient, as determined by a 2-day pumping test, was about 0.15. For short periods of pumping, two-dimensional flow and instantaneous drainage, which are assumed in the analysis of the data, may not have been attained. To more closely determine the storage coefficient, much longer (60 to 90 days) durations of pumping are necessary. The calculated storage coefficient seems to increase as pumping time increases. Thus, 0.15 is probably a minimum.

The coefficients of storage and transmissibility determined during this study will aid in predicting effects of additions or withdrawals of water from the aquifer. For example, if the coefficients of storage and transmissibility are known, declines of water levels near a pumping well may be predicted, and proper spacing of additional wells may be determined. Also, water-table declines due to increased evapotranspiration may be predicted. These coefficients would also aid in predicting water-level rises due to increased recharge. Thus, knowledge of the aquifer's hydraulic characteristics is a prerequisite to proper planning and management of the area's water supply.

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Test drilling is advisable in locating a site for a large-capacity well because of variations in thickness and saturation of permeable sand and gravel and differences in amounts of fine-grained material. As in the tributary valleys, test holes should be spaced about 500 feet apart on a line extending across the valley. During drilling, careful attention should be given not only to the largest grain size in the cuttings but also to amounts of clay and silt. The well should be located at the test hole penetrating the thickest section of saturated sand and gravel and the least amount of clay and silt. For a more complete discussion of test drilling in valleys similar to the Big Sandy Creek valley, the reader is referred to McLaughlin (1946, p. 60–63; 1954, p. 138–139).

DUNE SAND

CHARACTER

The dune sand consists of very fine to very coarse angular to well-rounded quartz grains. Generally about 75 percent of the sand is very fine to medium. Thickness ranges from 0 to about 70 feet, but is generally 10 to 20 feet. Silt and clay may be intermixed but are generally in layers. In many places the basal part of the dune sand contains some very fine to fine gravel.

The dune sand south of Big Sandy Creek is derived from the valley-fill deposits. The lineation of the dunes (N. 20° W. to N. 30° W.) indicates wind direction from the northwest, and the occurrence of the sand on the south side of the streams indicates that its source is the valley-fill deposits. The increase in the silt and clay content southward from the Big Sandy (fig. 5) is further evidence for the valley-fill source because the wind carries the finest material the farthest distance. In places, sand derived from the north side of the valley covers the valley-fill deposits on the south side of the valley.

The dune sand north of Big Sandy Creek in Cheyenne County is probably obtained from the valley fill in tributaries of Big Sandy Creek and from sand carried southward from the Ogallala Formation.

WATER SUPPLY

Dune sand is a catchment for recharge because it absorbs a large percentage of the precipitation. Where it overlies the valley-fill deposits, as along the south side of Big Sandy Creek, much of the precipitation recharges the valley-fill deposits. Where the dune sand overlies the Pierre Shale or the Niobrara Formation, water accumulates above the bedrock and slowly moves toward either Big Sandy or Rush Creeks.

Wells yielding 1 to 10 gpm can be developed in the dune sand; however, the relatively low permeability of the sand and its thin section of saturation make larger yields unlikely. Usually test drilling is necessary to find sites where the saturated section is thickest and to detect any valley-fill deposits that may underlie the dune sand. Test drilling should be in a line at right angles to the general slope of the land (not at right angles to the dune lineation). Test-hole spacing may be greater than in the valley fill because of more uniform bedrock topography; however, 1,000 feet should be the maximum.

Wells in the dune sand may go dry during years of below-normal precipitation or perhaps during dry seasons in an otherwise normal year. For this reason, sites in the valley fill should be tested by drilling before the dune sand is tested.

GEOLOGY IN RELATION TO LAND USE

The characteristics of the rocks have been briefly described in the previous discussion. These characteristics have a marked effect not only on the hydrology but also on the land use.

The area's economy is based on agriculture, principally stock raising and dryland farming, the main crops being winter wheat, grain sorghums, and maize. The areal distribution of these two activities is based in large part on geology. Almost all dryland farming is confined to Cheyenne and Kiowa Counties east of Big Sandy Creek because of large areas of upland and valley-fill deposits and, more important, because much of the area has a thin cover of windblown sandy silt. The sandy silt provides a good soil that is easily tillable and is capable of storing water for plant use. The upland deposits northeast of Aroya and north of Wild Horse (fig. 1) have the greatest thickness of fine-grained material and, hence, are the best farmland. Elsewhere, the fine-grained material is much thinner, and special precautions must be taken to prevent serious wind erosion.

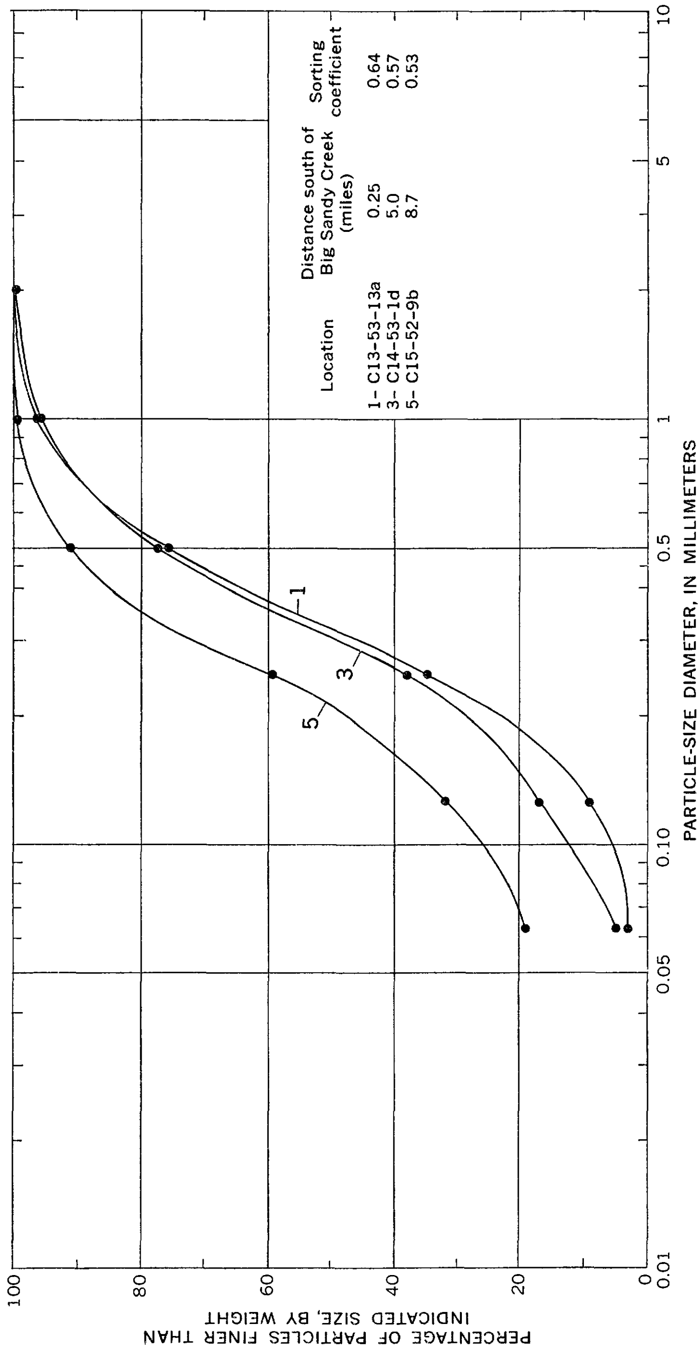

FIGURE 5.—Particle-size distribution curves of dune sand south of Big Sandy Creek.

The rest of the project area is devoted primarily to ranching, where the Pierre Shale and dune sand are at the surface. The Pierre is relatively impervious, allows rapid runoff, does not form a thick soil, and generally is not suitable for cultivation. However, perennial short grasses, principally buffalograss and grama, are abundant. If the thin soil cover is disturbed by cultivation or overgrazing, less desirable plants such as annual grasses, weeds, and cactuses infest the land. Thus, the most economical land use is based on conservation and utilization of the native grasses. Dune-sand areas do not allow rapid runoff; however, soils suitable for cultivation generally are not present. Cultivation destroys the native grasses, and during years of below-normal precipitation, wind erosion may be serious. The native grasses grow well in the dune sand and, while stabilizing the land, generally provide a dependable source of feed for livestock.

Although few detailed soil maps have been prepared, it seems that only a small part of the valley fill is suitable for cultivation in Big Sandy Creek and Rush Creek valleys. Most of the soil is sandy and thin. The thinness of the soil prevents leveling the land for irrigation, and the sandy texture causes difficulties in the construction and maintenance of ditches. Soils suitable for cultivation occur in small patches surrounded by sandy soil; this increases the cost of cultivation. If the sandy soils are flood irrigated, their porous nature requires application of larger amounts of water than generally can be obtained from one well. Although moderate quantities of water are available from the valley-fill deposits, expensive agricultural practices are necessary to insure sustained dependable crop production.

HYDROLOGY

HYDROLOGIC CYCLE

The hydrologic cycle consists of the movement and exchange of water from the atmosphere, from the earth's surface, and from beneath the earth's surface (fig. 6). In the Big Sandy Creek basin the cycle begins with precipitation, which is the only source of water in the basin. Most of the precipitation is evaporated shortly after it reaches the ground, but part infiltrates the soil and part runs off.

A large part of the water that infiltrates is held in the soil and is subsequently used by vegetation; however, some of it percolates downward and reaches the ground-water reservoir. When the rainfall intensity exceeds the infiltration capacity of the soil, the excess water runs off. Runoff travels down the stream channels, where it may be absorbed into the ground-water reservoir, or it may continue to the Arkansas River and eventually the ocean. Except after unusually intense storms, runoff is absorbed into stream channels and ground-water reservoirs before it reaches the Arkansas River.

Water is returned to the atmosphere by evaporation from the land surface and from free-water surfaces and by transpiration by plants. Man pumps water from greater depths than those where the processes of evapotranspiration are operative; thus man's use of water generally results in hastening the return of water to the atmosphere.

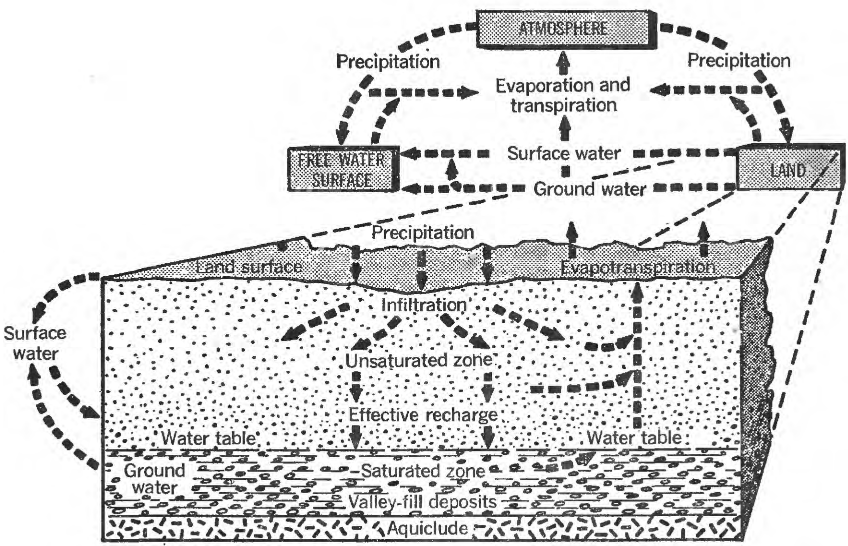

FIGURE 6—Hydrologic cycle.

PRECIPITATION

The average annual precipitation is about 12 inches. Thundershowers from May through September account for about 70 percent of the average annual precipitation. Evaporation is high during these months, and much of the rain is evaporated before it can soak into the soil or become runoff. During the winter, precipitation generally is windblown snow. In the early spring, rainfall may be of long duration but low intensity.

RECHARGE

All recharge to ground-water reservoirs results from precipitation within the Big Sandy Creek basin. The valley-fill deposits may be recharged by percolation of water into the beds of ephemeral streams during floods, or water may infiltrate through the soil. Most of the water entering the soil is stored for subsequent use by vegetation; however, some eventually makes its way to the water table. Ground water then slowly flows downvalley, but is evaporated or transpired before it reaches the Arkansas River.

Recharge is greatest during the spring and summer, when precipitation is greatest. Rainfall in early spring commonly is gentle and of long duration. In contrast, late spring and summer thundershowers are intense and of short duration. Gentle rainfall produces little runoff and may be most effective in replenishing soil moisture. Thundershowers may provide the most recharge to the valley-fill deposits, for water is readily absorbed through the relatively permeable stream channels.

Recharge was estimated east of Wild Horse during a flood on July 6, 1960. The flood originated upstream, so the streambed at Wild Horse was dry before the flood. The total flow passing Wild Horse was estimated to be 300 acre-feet by stage measurements made during the flood and by slope-area computations. The flood was almost completely absorbed during 1 day in 22 miles of stream channel—an absorption of about 14 acre-feet per mile of channel. The area of channel over which the flood spread (calculated from fig. 7) was about 110 acres. Therefore, about 3 feet of water was recharged.

Further evidence for percolation of floodflows into the valley fill is the downstream decrease in channel width, as shown on figure 7. The scatter of the points is largely due to tributary inflows, which require a wider channel for short distances below the tributary mouths. Whereas measurements of channel width were made of a well-defined channel and were fairly accurate, the measurements of distance from the point of origin of Big Sandy Creek in El Paso County were made from small-scale maps and may have considerable error. The rate of decrease of channel width shown on figure 7 should be considered indicative of a trend rather than of absolute magnitude.

As floods decrease in discharging downstream, the cross-sectional area needed for flow also decreases. Channel depth and other characteristics do not change greatly downstream; therefore, the stream adjusts its cross-sectional area by adjusting its width.

The relation between channel width and distance from the point of origin of Big Sandy Creek can be expressed as

$$W = aD^b$$

where W = channel width,
a = an undetermined constant,
D = distance from the point of origin, and
b = slope of the curve or rate of downstream decrease in width (fig. 7).

For the Big Sandy, the value of b is -1.6.

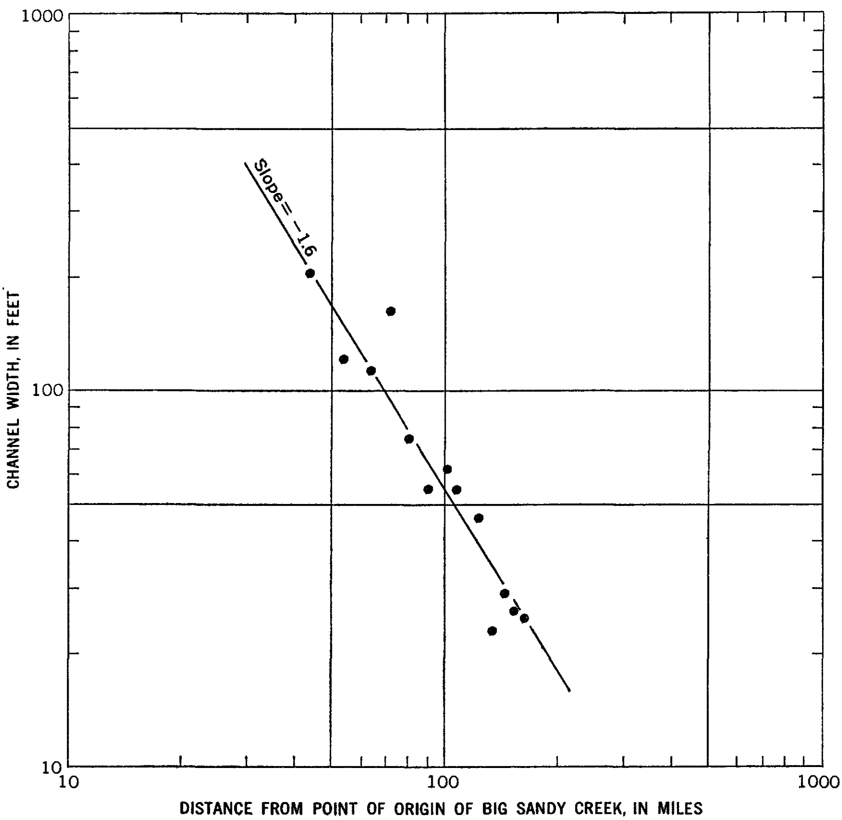

FIGURE 7.—Relation of channel width with distance from point of origin of Big Sandy Creek.

Because the rate of decrease of channel width downstream is largely a function of the amount of water recharged from the channel to the ground-water reservoir, the slope (b) provides a simple means of comparing recharge rates in ephemeral streams of similar geologic settings. This brief discussion points out that a relation exists between channel width and recharge. Further study will be needed to define even an empirical relation between rate of decrease of channel width and amount of recharge. Such study may be warranted because channel width may be easy to measure, whereas recharge measurements are time consuming and expensive. The above relation possibly may be used to estimate recharge over a long period.

Total recharge may be roughly estimated by an approximation of the water budget, which is an accounting of the inflow to, outflow from, and storage in the valley-fill deposits. For the project area the water budget may be written:

$$\text{Recharge} = \text{discharge} - \text{inflow} \pm \text{change in storage.}$$

The reader is cautioned that the values are tentative and merely indicate the order of magnitude of recharge. These values are the best available, however, and provide a first approximation of recharge.

If the water budget is computed over as long a period as a year, the assumption may be made that recharge equals discharge minus inflow or that there is no net change in storage of water. Discharge from the valley-fill deposits is the sum of evapotranspiration (94,000 acre-ft per year, p. 31), pumpage (1,500 acre-ft per year, p. 33), and outflow (250 acre-ft per year, p. 31). Inflow is about 200 acre-feet per year in the valley fill along Big Sandy Creek and about 100 acre-feet per year in the valley fill along Rush Creek. Therefore, recharge is at least 95,000 acre-feet per year.

DISCHARGE

Discharge includes water that reaches Prowers County by outflow and evapotranspiration in the area. For discussion, outflow may be divided into runoff and ground-water underflow.

Runoff is controlled by factors such as climate, topography, soils, geology, and intensity and duration of storms. The Big Sandy Creek basin is semiarid and evaporation is great; thus most precipitation is evaporated before it can run off. The basin generally is gently rolling, although slopes are steeper upstream about Aroya than they are downstream. All other factors being equal, the steeper the slope the greater the runoff. Geology influences runoff in part by determining type of soil and its infiltration capacity. The infiltration capacity of dune sand and valley-fill and upland deposits is much greater than that of the Pierre Shale or Niobrara Formation. Thus, almost all runoff originates upstream from Aroya and north of Big Sandy Creek, where the Pierre Shale crops out and slopes are steepest. Intensity and duration of a storm are critical for 2 inches of precipitation in an hour will result in several times the runoff of 2 inches of precipitation in a day.

The average annual runoff from the drainage basin, as determined from 6 years of streamflow records near the mouth of Big Sandy Creek, is 10,000 acre-feet per year (0.5 percent of the average annual precipitation on the basin). Average runoff is useful in roughly comparing runoff in the Big Sandy Creek basin with that in other basins, but it should be used cautiously principally because (1) records are short (6 yr) and therefore may not be representative and (2) the gaging station was on a perennial stretch of stream that for the most part is ephemeral and, thus, runoff measured at this station was probably greater than average for the basin.

Big Sandy Creek generally flows only in response to storms of late spring and summer except for short perennial stretches near the mouths of Rush Creek, Big Spring Creek, near Hugo, and about 8 miles north of Chivington. Flows near the junctions are caused by additional ground water entering the valley fill as underflow from tributaries. Excess water flows at the surface until it is evaporated and transpired or until it reaches a stretch where the valley fill is more permeable. Perennial flows at Hugo and northeast of Chivington are caused by reduction in cross-sectional area of the valley fill, by lower transmissibility, or by above-normal recharge from dune sand that overlies the valley-fill deposits. Records of streamflow measurements made during this study are shown in table 6 of the basic-data report by Coffin (1962).

Water is discharged from the valley fill principally by evapotranspiration and by wells. The pumpage by wells is discussed on pages 32–34. Along Big Sandy Creek, evapotranspiration is greatest from the surface of the flood plain and younger terrace (pl. 1). The water table is less than 5 feet below the flood plain and is 5 to 15 feet below the younger terrace. Evapotranspiration from the older terrace is slight because depths to water are greater than 15 feet. In the tributary valleys depths to water are less near the stream channels, where they range from less than 5 to about 20 feet.

Areas where evapotranspiration is operative have an abundance of cottonwood, saltcedar, and other plants common to areas of shallow water table.

An estimate of evapotranspiration was made near well C10–55–27cca in a field covered primarily by annual grasses and weeds but sparsely by alfalfa. The depth to water was about 6 feet. The method of estimation was suggested by White (1932) and is based on the diurnal fluctuation of the water level in a well. A representative period of fluctuation is shown on figure 8. It is assumed that evapotranspiration is negligible from midnight to 4 a.m. and that during this time the depth to water is not greatly different from the average for the 24-hour period. Evapotranspiration from the ground-water reservoir (E) is approximated by

$$E=S(24h\pm n)$$

where S = specific yield of the aquifer near the water table,
h = hourly rate of rise of the water table from midnight to 4 a.m., and
n = net rise or fall of the water table during the 24-hour period.

Assuming the specific yield to be 0.15, the continuous record of water levels during August 1962 indicated the monthly evapotranspiration to be 0.4 foot. If this figure is representative for June, July, and August, the evapotranspiration during the growing season or frost-free months is greater than 1.2 feet. Evapotranspiration probably is even greater from the surface of the flood plain and younger terrace because much of this area is more densely covered by phreatophytes and the depth to water commonly is less. Accordingly, it is conservatively estimated that 2 feet of water per year is evaporated and transpired from the 47,000 acres of flood plain and younger terrace. Roughly, then, 94,000 acre-feet per year, or about 4 percent of the total average annual precipitation in the basin, is evaporated and transpired from the Big Sandy Creek valley.

Ground water moving down the Big Sandy Creek valley leaves the project area as underflow which is estimated to be 220,000 gpd, or 250 acre-feet per year—about 0.01 percent of the average annual precipitation on the Big Sandy Creek basin.

GROUND WATER IN STORAGE

Ground water in the valley fill is moving slowly downvalley and eventually is discharged into the Arkansas River. The movement probably is less than 2 feet per day; therefore, the ground-water reservoir acts as a storage reservoir. The ground-water reservoir is constantly being replenished by recharge and depleted by evapotranspiration, pumping, and underflow. During a normal year, additions about balance withdrawals so that storage changes little. In the winter and spring, recharge may be more than discharge, a condition resulting in water-level rises. Withdrawals by pumping and evapotranspiration decrease the water in storage and cause water levels to decline. Water levels in the valley fill generally rise during the winter and reach a peak during the early spring. Evapotranspiration then becomes dominant, and water levels decline until September or October. Measurements of ground-water levels made during this study are shown in table 5 of the basic-data report by Coffin (1962).

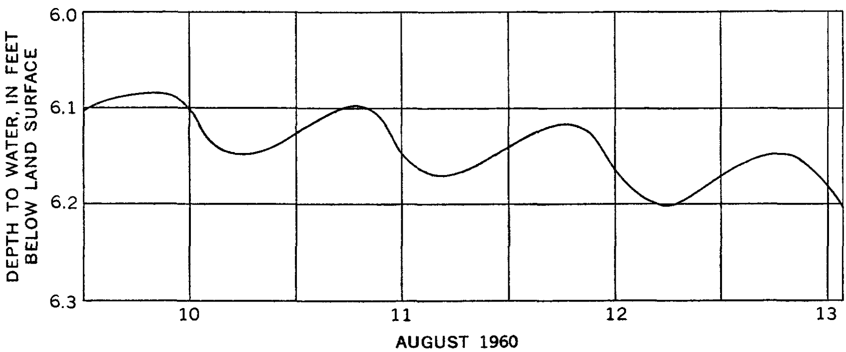

FIGURE 8.—Diurnal water-level fluctuations in well C10–55–27cca.

DEVELOPMENT OF SURFACE WATER

At present (1963), the main use of surface water is for stock ponds. Several attempts have been made to divert water of Big Sandy Creek for irrigation. The following is summarized from Code (1945, p. 8–9), and the reader is referred to his report for a detailed discussion of diversion attempts. Two projects reached construction stage and failed because (1) floods washed out diversion dams, (2) floodflows were infrequent, and (3) the reservoirs leaked. These projects may not offer conclusive evidence about development of surface water; however, they have discouraged surface-water irrigation of large tracts.

DEVELOPMENT OF GROUND WATER

Because flowing water is scarce in east-central Colorado, stretches of perennial flow in Big Sandy Creek valley have been historic watering places. Thus, stretches of the valley near perennial flows were favorite Indian campsites; that stretch northeast of Chivington was a campsite for the Cheyennes of Chief Black Kettle. The site proved to be a poor defensive position, however, for most of the Indians were killed in the 1864 Big Sandy Creek massacre. Later, perennial stretches became watering spots for horses and cattle on the open range, and a stage station was built near a perennial flow on Big Spring Creek.

Irrigation development dates from about World War I (Code, 1945, p. 9). The early developments were short lived, and according to Code, the probable reasons for their failure were (1) soil and topography not suited to irrigation, (2) no preparation of the land for irrigation, (3) poor or unreliable equipment, (4) inadequate water supply, and (5) collapse of prices of farm products.

Irrigation developments after about 1937 have been more successful, largely because of new techniques in well drilling and because more attention was given to soil characteristics and land preparation. In 1944 there were 5 irrigation wells in operation in the project area (Code, 1945); in 1960 there were 30 irrigation wells.

The geographic distribution of wells and data collected from the wells inventoried during the study have been published (Coffin, 1962), and the locations of wells are shown on figure 3 of that report. During this study all known irrigation wells and many of the domestic and stock wells in the valley fill were inventoried. Where domestic and stock wells are closely spaced, generally only one well from the group was inventoried.

Except for seven irrigation wells in an area of about 1 square mile west of Hugo, the irrigation wells are widely scattered throughout the Big Sandy and Rush Creek valleys. This is primarily due to the small extent of areas where soil and topography are suitable for irrigation. About one-third of the irrigation wells are powered by electric motors; the other wells are powered by butane, propane, or gasoline engines.

No exact irrigation-pumpage computations can be made because records of hours of operation of many pumps are not available. By assuming that the nonelectrically powered wells were pumped about the same number of hours as the electrically powered wells, it is estimated that 1,000 acre-feet of water is pumped annually for irrigation.

The 11 municipal wells serving the towns of Hugo, Kit Carson, and Eads (see Gregg and others, 1961, for a description of the water systems) are estimated to pump 500 acre-feet annually. This estimate is based on average-consumption data supplied by water superintendents.

Pumpage for rural use (stock and domestic) is small. Assuming average yield and pumping time of a representative sample of stock and domestic wells, it is estimated that all these wells pump less than 10 acre-feet per year.

Additional irrigation supplies may be developed in the valley fill of Big Sandy and Rush Creeks. Their areal extent and sections of the water-bearing sand and gravel are shown on plate 1. Detailed information based on test drilling is necessary to insure the best location for an irrigation well. Except for greater-than-average saturation at

Clifford (pl. 1), saturation and permeability is fairly uniform in the valley-fill deposits of Big Sandy and Rush Creek valleys. First consideration probably should be given to soil at any proposed irrigation site. After it has been determined that the soil is suitable or can be made suitable for irrigation, test drilling should determine the well site. Yields averaging about 400 gpm from a properly constructed well should be expected at most sites. The owner may desire to drill several irrigation wells, depending on the size of the area to be irrigated.

The 30 irrigation wells in the project area have not lowered the water table permanently. Observation-well records in the area of greatest concentration of irrigation wells show a seasonal low in the fall of each year; which is probably due to pumpage and evapotranspiration. Well owners also report that yields diminish during the late summer, a condition which is probably due to lowering of the water table by pumping. Recharge from precipitation and floods replenishes the ground-water reservoir during the spring and early summer, and the water table returns to its prepumping level. Observation wells in areas where irrigation wells are scattered show no detectable declines in water levels that may be attributed to pumping. Of course, if ground-water discharge exceeds recharge during a year, the excess water must come from storage, thus the water table will decline until recharge exceeds discharge. Capturing water presently discharged either by underflow or by evapotranspiration simply changes the point of discharge and will not cause a rise in the water table.

At present (1963), the quantity of ground water is generally adequate to meet demands. If large-scale changes in land use are made, however, by new farming techniques, by construction of stock ponds, and by range-conservation measures, the hydrologic cycle may be altered, and the water table may decline without additional pumpage. These changes in land use would tend to put more runoff into the soil (to become soil moisture) and ponds, where the water would be transpired and evaporated, and thus reduce the recharge.

Increases in pumping will increase the total beneficial water supply because lowering the water level will decrease nonbeneficial evapotranspiration and will cause some of the present 10,000 acre-feet per year surface-water outflow to be recharged to the ground-water reservoir.

The Big Sandy Creek valley should be considered part of the Arkansas River valley with respect to management practices because part of the Arkansas Valley water supply comes from the Big Sandy Creek valley. Increased use of water in the Big Sandy Creek valley will reduce the contribution of water to the Arkansas Valley.

CHEMICAL QUALITY OF THE GROUND WATER

By C. ALBERT HORR

Samples collected from representative wells (pl. 1) were analyzed by personnel of the U.S. Geological Survey using standard methods (Rainwater and Thatcher, 1960). The chemical analyses were reported by Coffin (1962). The dissolved-solids content of the ground water, calculated from the sum of determined constituents, ranges from 507 to 8,510 ppm (parts per million). Although the analyses indicate that the water is of the sodium calcium sulfate bicarbonate type, sodium and sulfate are the major ions and constitute more than half the dissolved material in 30 of the 41 samples analyzed and are representative of 75 percent of the ground water. The calcium and sulfate in the water were probably derived from gypsum in the underlying shale. Limestone is also a source of the calcium and the bicarbonate in the ground water. Weathered feldspar in the valley fill is probably the source of sodium as well as calcium. High sodium content is also generally associated with ground water in arid and semiarid regions.

DEFINITION OF TERMS

Although terms used in water chemistry are common ones, some have limited usage, and others may convey a variety of meanings. As an aid to clarity, some of the terms used in this report are defined as follows:

Parts per million (ppm). A unit expressing the concentration of a constituent on a weight-to-weight basis, usually in grams of constituent per million grams of solute. For practical purposes, it is nearly equal to milligrams of constituent per liter of water.

Equivalents per million (epm). A unit expressing the concentration of chemical constituents in terms of chemical equivalence and more closely describes the composition of water and the relationship of ions in solution than parts per million. One equivalent of a positively charged ion (cation) will react with one equivalent of a negatively charged ion (anion). Parts per million are converted to equivalents per million by multiplying by the reciprocal of the combining weight of the ion.

Soil amendment. Usually gypsum, limestone, or other material used to improve unfavorable conditions of soil structure, acidity, or alkalinity. It is not used to supply the essential nutrient elements directly but to create a more favorable environment for plant growth.

Specific conductance. A measure of the ability of water to conduct an electric current and is expressed in micromhos per centimeter at 25°C. Because specific conductance is dependent upon the concentration of ions in solution, it can be used as an empirical measure of the degree of mineralization of water. The following approximate relations are used:

$$\text{Specific conductance} \times (0.70 \pm 0.05) \approx \text{ppm dissolved solids.}$$

$$\frac{\text{Specific conductance}}{100} \approx \text{epm cations} \approx \text{epm anions.}$$

Sodium-adsorption-ratio (SAR). A measure of the quality of irrigation water and is related to the adsorption of sodium by soil from applied water. The ratio is determined by dividing the concentration of sodium by the square root of half the concentration of calcium plus magnesium, all concentrations expressed as equivalents per million.

Leaching requirement (D percent). A ratio, expressed as a percentage, of the amount of irrigation water that must pass through the root zone to the amount of applied water needed to maintain soil productivity for satisfactory crop yields.

Salt. A comprehensive term that includes all ionizable material in solution derived from minerals such as gypsum ($CaSO_4 \cdot 2H_2O$), epsomite ($MgSO_4 \cdot 7H_2O$), sylvite (KCl), and others. The term does not refer to common table salt (NaCl) alone.

FACTORS AFFECTING THE WATER QUALITY

Differences in the chemical quality of ground water in the Big Sandy Creek valley are the result of several interdependent factors. The most important are the source and amount of recharge, distribution and amount of discharge, direction and rate of ground-water movement, and composition of the aquifer through which the water moves. Although the general patterns of water quality exist throughout most ground-water provinces, the quality of the water from a specific well may be more dependent on the local environment.

WATER QUALITY IN RELATION TO HYDROLOGY

Variations in water quality are often related to ground-water recharge and discharge. Figure 9 illustrates the changes in specific conductance downstream along Big Sandy and Rush Creeks. Starting at well C10–55–27cca2, one finds that the specific conductance increases at an average rate of 29.6 micromhos per cm at 25°C per mile downstream along Big Sandy Creek. This downstream increase in mineralization is probably due to solution of minerals from the valley fill and bedrock and to evapotranspiration. The sharp decrease in mineralization between wells C14–50–23ccd and C15–49–6abc (fig. 9) indicates dilution by inflow of ground water of better quality from the north along Wild Horse and Big Spring Creeks.

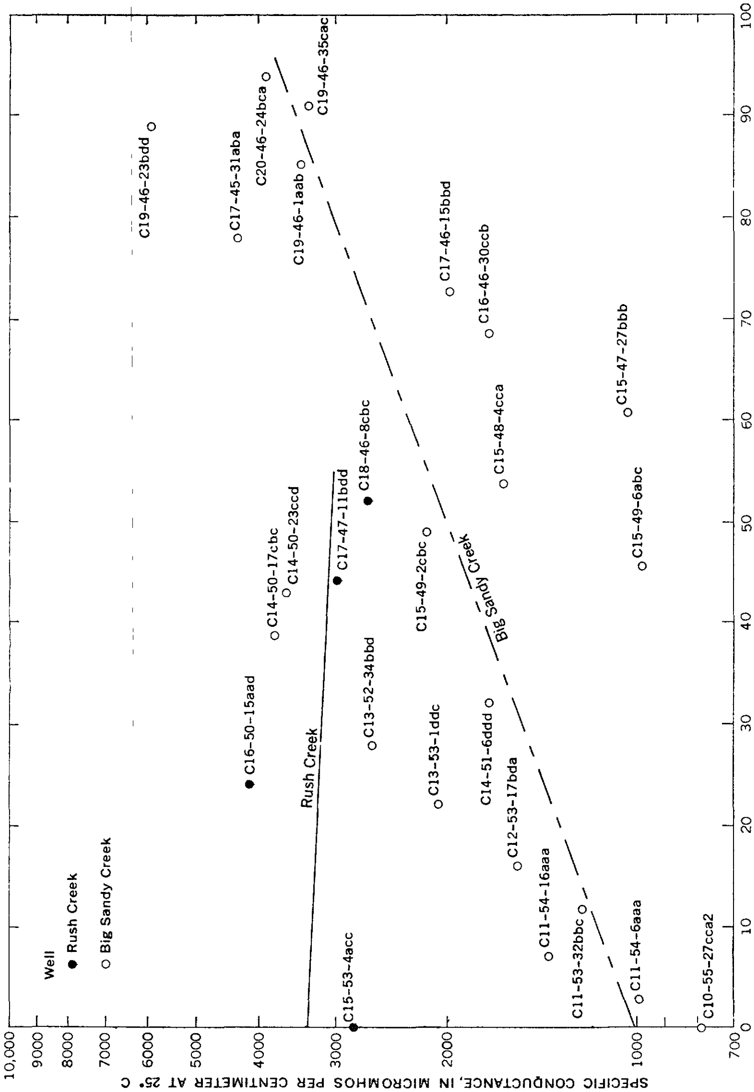

FIGURE 9.—Change in specific conductance downstream along Big Sandy Creek and along Rush Creek.

Along Rush Creek downstream from well C15–53–4acc, the specific conductance decreases at an average rate of 5.4 micromhos per centimeter at 25°C. The decrease in mineralization is probably the result of the overlying dune sand, which allows relatively large amounts of recharge and inhibits evapotranspiration.

WATER QUALITY IN RELATION TO GEOLOGY

The chemical quality of ground water is affected by the type of rocks with which the water is in contact. The valley-fill deposits of Big Sandy Creek are underlain by the Pierre Shale and by the Niobrara Formation in the southern part.

Precipitation infiltrating to the water table dissolves the rocks; the amount dissolved depends on the temperature and dissolved-gas content of the water, the duration of contact with the rocks, and the permeability and solubility of the rocks. The types of minerals dissolved depend on the composition of the rocks that contact the water. Figure 10 shows, in general, the chemical quality of water obtained from valley fill and bedrock in the Big Sandy Creek valley. However, attempts to isolate the effect of any one rock type on water quality are inconclusive.

In general more mineralized water may be often associated with thin zones of saturation and short distances to bedrock outcrops; for example, wells C14–50–17abc and C14–50–23ccd are near the bedrock and valley-fill contact (fig. 9). Changes in lithology, such as at the contact between the Pierre Shale and the Niobrara Formation between wells C17–46–15bbd and C17–45–31aba, also may be identified by changes in the mineralization of the ground water.

WATER QUALITY AND USE

The ground water in the Big Sandy Creek valley generally is of fair to poor quality for most use. Water-quality criteria differ according to use and are presented below.

DOMESTIC USE

Water for domestic use should be clear, colorless, and free of objectionable odor, taste, and disease-causing microorganisms. Standards for water quality have been established by State health departments, but the only nationwide standards for potable water are those established by the U.S. Public Health Service (1962). The American Water Works Association has adopted these standards as recommended limits for all public water supplies. Recommended maximum limits for some of the chemical constituents are listed below:

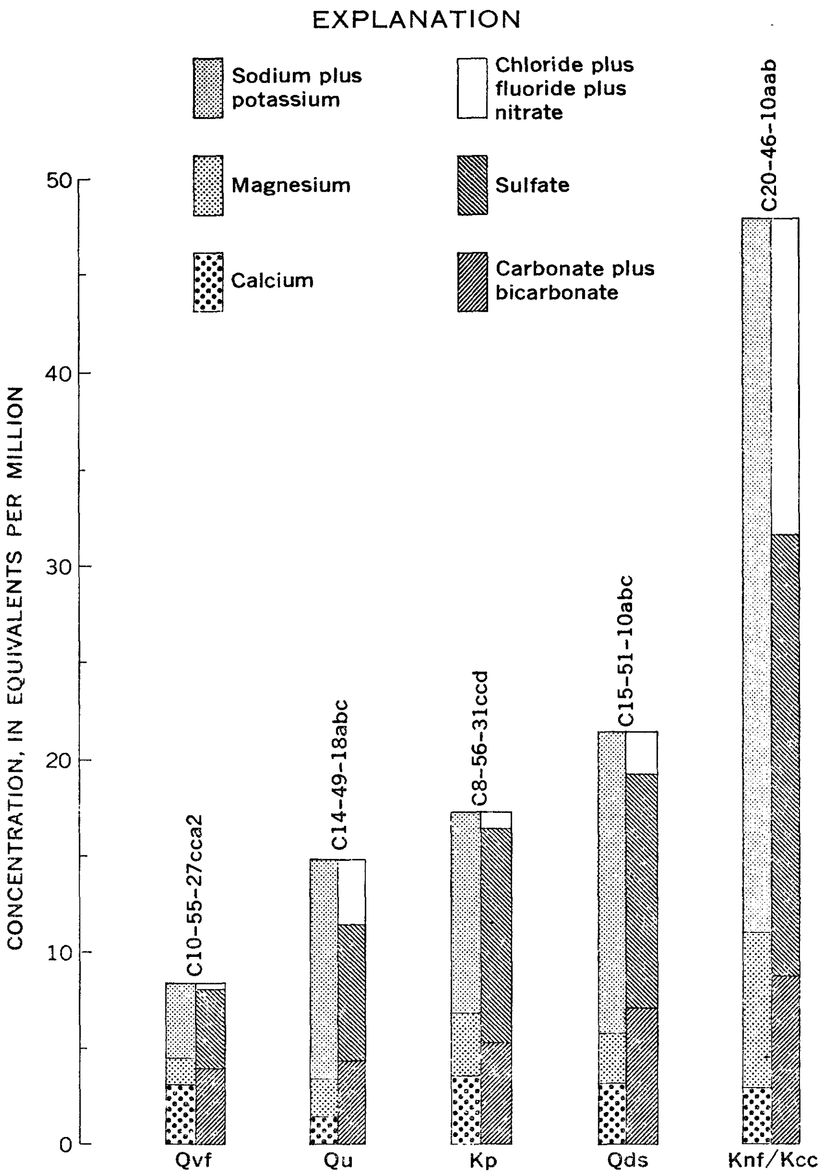

FIGURE 10.—Chemical quality of the water from valley-fill deposits and bedrock sources. See plate 1 for explanation of geologic symbols.

Recommended maximum limits for public water supply

Constituent	*Concentration (ppm)*	*Constituent*	*Concentration (ppm)*
Iron (Fe)	0.3	Fluoride (F^{-1})	[1] 1.2
Manganese (Mn)	.05	Nitrate (NO_3^{-1})	45
Chloride (Cl^{-1})	250	Dissolved solids	500
Sulfate (SO_4^{-2})	250		

[1] U.S. Public Health Service (1962) gives lower, optimum, and upper control limits based on the annual average of maximum daily air temperatures. For Big Sandy Creek valley, the limits are 0.7 ppm (lower), 0.9 ppm (optimum), 1.2 ppm (upper). Concentrations of twice the optimum limit (1.8 ppm) are grounds for rejection of the supply.

Water with concentrations of these chemical constituents that exceed the recommended limits are undesirable for domestic use. High sulfate concentrations have laxative effects. Excess chloride gives water a characteristic salty taste. Fluoride in water at concentrations ranging from 0.7 to 1.2 ppm have been shown (U.S. Public Health Service, 1962) to prevent dental caries; however, higher concentrations produce fluorosis of bone and teeth. Nitrate in excess of 45 ppm (U.S. Public Health Service, 1962) is particularly hazardous for infant feeding and causes methemoglobinemia or cyanosis. Excessive nitrate is sometimes an indication of contamination by decaying plant or sewage.

Hardness of water is a property that results in the formation of soap scum. Hardness is caused principally by calcium and magnesium, although other constituents such as barium, strontium, aluminum, and free acid contribute to hardness. The hardness-of-water classification established by the U.S. Geological Survey (Durfor and Becker, 1964, p. 27) is shown in the following table:

Hardness range (parts per million of calcium carbonate)	*Hardness description*
<60	Soft.
61–120	Moderately hard.
121–180	Hard.
>181	Very hard.

Chemical analyses of water, in parts per million, from six wells used for domestic or public supply are summarized in the following table:

Well	Chloride	Sulfate	Fluoride	Dissolved solids	Hardness as $CaCO_3$
C11–53–32bbc	31	330	1.0	818	216
54–6aaa	17	230	1.0	667	198
C13–50–10aad	14	246	1.0	574	344
C15–48–4cca	46	605	1.0	1,160	420
C17–46–18cdd	47	553	1.5	1,120	356
C18–45–18dac	102	1,560	.9	2,570	1,020
Recommended limit	250	250	1.8	500	--------

The dissolved-solids content of samples of water from the six wells and the sulfate content in four of the six exceed the recommended limits, which are shown in the table. Concentrations of chloride and fluoride are below the limits. Analyses for iron and manganese were not made, and it is not known if these ions exceed recommended limits. Water from well C17–45–31aba, tapping valley-fill deposits, contains 0.11 ppm of selenium, which is 11 times greater than the recommended limit. The water is very hard, and softening may be desirable.

STOCK USE

Few data are available to rate water for stock use. Although animals can tolerate water with higher dissolved-solids content than can be tolerated by human beings, water that meets the standards for domestic use should be used for maximum effectiveness. Prolonged periods of ingestion of highly mineralized water may result in wasting gastrointestinal disturbances, disease, reduction in lactation and rate of reproduction, and eventual death.

The Western Australia Department of Agriculture (1950) lists the following threshold salinity (dissolved solids) concentrations in parts per million for:

Poultry	2,860	Cattle, dairy	7,150
Swine	4,290	Sheep, adult dry	12,900
Horses	6,435		

The State of Colorado (California State Water Quality Control Board, 1963, p. 113) recommends that water containing as much as 2,500 ppm of dissolved solids be rated as acceptable for stock. Montana (California State Water Quality Control Board, 1963, p. 113) rates water containing less than 2,500 ppm dissolved solids as good, 2,500 to 3,500 ppm as fair, 3,500 to 4,500 ppm as poor, and greater than 4,500 ppm as unfit. Apart from total salt concentrations, certain constituents such as nitrate, fluoride, selenium, and molybdenum are specifically toxic to animals even in low concentrations. According to Colorado's criteria and on the basis of dissolved-solids content, water used for stock from the following wells in the study area would be rated as unacceptable.

Well	*Dissolved solids (ppm)*	*Well*	*Dissolved solids (ppm)*
C14–50–17cbc	2,910	C18–45–18dac	2,570
50–23ccd	2,960	C20–45–16bca	2,920
C16–48–13dda	3,460	46–10aab	2,940
50–15add	3,460	46–24bca	3,210

It should be recognized that the critical factor in the animals' metabolism is the total quantity of salts ingested. This will depend on the daily water consumption, which, in turn, depends on the water content of feed, the humidity and temperature, and the degree of exertion of the animal.

IRRIGATION USE

The economy of the Big Sandy Creek valley is based on dryland farming and stock raising. Irrigated farming has not been developed extensively because of unsuitable soil and relatively small well yields. However, a small expansion of irrigation may be possible with water from the valley fill along Big Sandy and Rush Creeks.

One of the factors that determines the success or failure of an irrigation project is the quality of water applied. Whereas interpretation of water quality in relation to irrigation has been based largely on field observations and studies of plant tolerances in arid regions, recent investigations (Eaton, 1950, 1954; U.S. Salinity Laboratory Staff, 1954) are providing a better understanding of the subject. It should be stressed, however, that the standards quoted are for arid areas, and in an area that has 12 to 15 inches of rainfall per year, mostly in the growing season, somewhat different standards may apply.

With respect to quality, the suitability of water for irrigation is determined by the total salt concentration, the concentration of certain elements such as boron, the concentration ratios of certain salts, and the chemical reactions and increase in salt concentration in the soil after water application. Application of water that is rated as good may, with poor irrigation practices such as inadequate provision for drainage, cause deterioration and eventual destruction of the productive capacity of the soil.

Conversely, application of water of poor quality in sufficient quantities on well-drained soil, so that salts are leached beyond the root zone, and use of soil amendments may result in good productivity for long periods of time. The ratio of calcium to sodium in irrigation water is an important consideration because of exchange reactions that take place in the soil. Irrigation water that is high in sodium in relation to calcium will result in a tight soil with poor tilth. The reverse is true with water of high calcium content. Hence, soil structure and permeability will be maintained with irrigation water having a favorable calcium to sodium ratio if the soil has good internal drainage and if good irrigation practices are followed.

The U.S. Salinity Laboratory Staff (1954, p. 79–81) diagram for rating irrigation water with respect to salinity and sodium (alkali) hazards is interpreted as follows:

Salinity hazard

* * * * * * *

Low-salinity water (C1) can be used for irrigation with most crops on most soils with little likelihood that soil salinity will develop. Some leaching is required, but this occurs under normal irrigation practices except in soils of extremely low permeability.

Medium-salinity water (C2) can be used if a moderate amount of leaching occurs. Plants with moderate salt tolerance can be grown in most cases without special practices for salinity control.

High-salinity water (C3) cannot be used on soils with restricted drainage. Even with adequate drainage, special management for salinity control may be required and plants with good salt tolerance should be selected.

Very high salinity water (C4) is not suitable for irrigation under ordinary conditions, but may be used occasionally under very special circumstances. The soils must be permeable, drainage must be adequate, irrigation water must be applied in excess to provide considerable leaching, and very salt-tolerant crops should be selected.

Sodium [hazard]

The classification of irrigation waters with respect to SAR is based primarily on the effect of exchangeable sodium on the physical condition of the soil. Sodium-sensitive plants may, however, suffer injury as a result of sodium accumulation in plant tissues when exchangeable sodium values are lower than those effective in causing deterioration of the physical condition of the soil.

Low-sodium water (S1) can be used for irrigation on almost all soils with little danger of the development of harmful levels of exchangeable sodium. However, sodium-sensitive crops such as stonefruit trees and avocados may accumulate injurious concentrations of sodium.

Medium-sodium water (S2) will present an appreciable sodium hazard in fine-textured soils having high cation-exchange-capacity, especially under low-leaching conditions, unless gypsum is present in the soil. This water may be used on coarse-textured or organic soils with good permeability.

High-sodium water (S3) may produce harmful levels of exchangeable sodium in most soils and will require special soil management—good drainage, high leaching, and organic matter additions. Gypsiferous soils may not develop harmful levels of exchangeable sodium from such waters. Chemical amendments may be required for replacement of exchangeable sodium, except that amendments may not be feasible with water of very high salinity.

Very high sodium water (S4) is generally unsatisfactory for irrigation purposes except at low and perhaps medium salinity, where the solution of calcium from the soil or use of gypsum or other amendments may make the use of these waters feasible.

* * * * * * *

The U.S. Salinity Laboratory Staff (1954, p. 75–76) further explains that:

In the classification of irrigation waters, it is assumed that the water will be used under average conditions with respect to soil texture, infiltration rate, drainage, quantity of water used, climate, and salt tolerance of crop. Large deviations from the average for one or more of these variables may make it unsafe to use what, under average conditions, would be a good water; or may make it safe to use what, under average conditions, would be a water of doubtful quality.

Although only three of the wells that were sampled—C15–53–4acc, C18–46–8cbc, and C19–46–23acc—are irrigation wells, all the ground water sampled in the Big Sandy Creek valley has been rated for potential irrigation use (table 4) by use of the above criteria. The ground water is rated high (C3) or very high (C4) with respect to salinity hazard. The sodium (alkali) hazard of the water covers the entire range from low (S1) to very high (S4). Water from two wells (C14–48–16ddd and C19–46–23acc) was not rated because the specific conductance was greater than 5,000 micromhos.

TABLE 4.—*Suitability of ground water for irrigation*

Well	Specific conductance (micromhos per cm at 25° C)	Percent sodium (Na)	Sodium-adsorption-ratio (SAR)	Classification [1]	Residual sodium carbonate (RSC) (epm)
C10–55–27cca2	796	52	3.1	C3–S1	0.00
53–32bbc	1,220	67	6.2	C3–S2	1.15
54–6aaa	1,000	60	4.6	C3–S1	.91
54–16aaa	1,390	59	5.2	C3–S2	.00
C12–53–17bda	1,550	61	5.8	C3–S2	.00
C13–47–35aad	1,290	46	3.4	C3–S1	.00
48–33aaa	1,320	31	2.0	C3–S1	.00
50–8ccc	2,040	25	2.1	C3–S1	.00
50–10add	872	30	1.6	C3–S1	.00
52–34bbd	2,620	54	6.3	C4–S2	.00
53–1ddc	2,080	52	5.4	C3–S2	.00
C14–47–30ddd	2,090	44	4.2	C3–S2	.00
48–16ddd	9,470	73	22	(2)	.00
48–30cdd	2,070	62	6.8	C3–S2	.00
49–18abc	1,440	76	8.5	C3–S2	.86
49–22acb	2,420	53	5.9	C4–S2	.00
50–17cbc	3,770	72	13	C4–S4	.00
50–23ccd	3,600	54	7.7	C4–S3	.00
51–6ddd	1,720	60	6.0	C3–S2	.00
C15–47–27bbb	1,030	50	3.4	C3–S1	.00
48–4cca	1,640	31	4.3	C3–S1	.00
49–2cbc	2,190	57	6.2	C3–S2	.00
49–6abc	981	50	3.3	C3–S1	.00
51–10abc	1,970	74	9.7	C3–S3	1.59
53–4acc	2,810	61	8.0	C4–S2	.00
C16–46–30ccb	1,710	65	6.8	C3–S2	.00
48–15dda	4,400	35	4.6	C4–S2	.00
5C–15add	4,160	55	8.6	C4–S3	.00
C17–45–31aba	4,370	58	9.3	C4–S3	.00
46–15bbd	1,980	59	6.3	C3–S2	.00
46–33abc	1,110	96	25	C3–S4	8.98
47–11bdd	3,000	42	4.8	C4–S2	.00
C18–45–18dac	3,170	47	5.7	C4–S2	.00
46–8cbc	2,660	43	4.6	C4–S2	.00
C19–46–1aab	3,470	32	3.8	C4–S2	.00
46–23bdd	5,990	45	7.8	(2)	.00
46–35cac	3,360	27	3.0	C4–S1	.00
C20–45–16bca	4,800	91	31	C4–S4	12.45
46–10aab	4,350	77	16	C4–S4	.00
46–14ada	3,030	59	6.6	C4–S2	.00
46–24bca	3,960	57	8.6	C4–S3	.00

[1] Classification according to U.S. Salinity Laboratory Staff (1954).
[2] Not classified because of high specific conductance.

Eaton (1950, p. 124), in his study of the significance of carbonate in irrigation water, defined the term "residual sodium carbonate" (RSC) as the excess of carbonate plus bicarbonate over calcium plus magnesium, all expressed in equivalents per million. He points out that in water having RSC the percent sodium is effectively increased, thus raising the potential hazard of irrigating with such water. Results of his experiments showed that water containing more than 2.5 epm RSC is not suitable for irrigation, water containing from 1.25 to 2.5 epm RSC is marginal, and water containing less than 1.25 epm RSC is safe. Accordingly, water from wells C17–46–33abc and C20–45–16bca would be rated as unfit, water from well C15–51–10abc would be marginal, and water from the remainder would be safe for irrigation.

Evapotranspiration, amount of water retained in the root zone, and harvesting practices result in a soil solution that may contain many times more dissolved solids than the applied irrigation water. To keep irrigation agriculture productive, accumulation of salts in the soil must be prevented by the application of sufficient quantities of water to leach the root zone. However, application of water in excess of plant and leaching requirements results in waste and in leaching of required plant nutrients and may result in drainage problems.

Eaton (1954) proposed a method for the characterization and interpretation of analyses of irrigation water on the basis of (1) the percentage of irrigation water that should be applied in excess of plant requirements to leach salts (leaching percent) to attain reasonable yields (70 to 80 percent of yields on nonsaline land) and (2) the amount of calcium, as gypsum, that should be added to the soil per acre-foot of irrigation water to keep the sodium concentration of the soil solution leaving the root zone at not more than 70 percent.

Estimates of the leaching percentage and required calcium have been made using Eaton's formulas (Eaton, 1954) for ground water in the project area. These estimates, shown in table 5, provide the water user with a knowledge of the limitations and requirements for the successful use of water, and enable him to judge the feasibility of developing a water supply and land for irrigation.

Chemical analyses and data shown in tables 4 and 5 indicate that ground water in the Big Sandy Creek valley may be used for irrigation of very salt-tolerant crops provided that sufficient excess water, an average of 28 percent, is used to prevent harmful accumulation of salts in the root zone and provided that soil amendments (gypsum, about 600 lb per acre-foot) be used to maintain soil permeability and tilth. However, actual measurements of soil salinity are required before leaching rates and gypsum requirements can be determined accurately.

In summary, the chemical quality of ground water in Big Sandy Creek valley is fair to poor for most uses. For domestic and public supply the dissolved-solids content exceeds the 500-ppm limit; and

TABLE 5.—*Leaching and gypsum requirements for ground water in part of the Big Sandy Creek valley*

[Calculated from Eaton's (1954) formulas. Asterisk(*) indicates calcium content of water is in excess of that needed for maintenance of satisfactory soil, permeability, and tilth]

Well	Reasonable crop yield		Well	Reasonable crop yield	
	Leaching requirement (D percent)	Gypsum requirement (lb per acre-ft)		Leaching requirement (D percent)	Gypsum requirement (lb per acre-ft)
C10-55-27cca2	4	467	C15-48-4cca	10	(*)
C11-53-32bbc	9	1,180	49-2cbc	17	(*)
54-6aaa	6	884	49-6abc	6	323
54-16aaa	9	685	51-10abc	18	1,860
C12-53-17cdd	11	820	53-4acc	23	385
C13-47-35aad	8	(*)	C16-46-30ccb	13	(*)
48-33aaa	10	(*)	48-15dda	71	(*)
50-8ccc	16	(*)	50-15add	57	1,830
50-10add	4	(*)	C17-45-31aba	51	(*)
52-34bbd	24	1,510	46-15bbd	14	360
53-1ddc	14	(*)	46-33abc	14	3,290
C14-47-30ddd	16	(*)	47-11bdd	28	(*)
48-16ddd	100	(*)	C18-45-18dac	31	(*)
48-30cdd	14	(*)	46-8cbc	22	(*)
49-18abc	13	1,210	C19-46-1aab	42	(*)
49-22acb	19	(*)	46-23acc	100	678
50-17cbc	40	1,130	46-35cac	36	(*)
50-23ccd	37	(*)	C20-45-16bca	103	5,290
51-6ddd	12	505	46-10aab	65	2,160
C15-47-27bbb	6	166	46-14ada	27	(*)
			46-24bca	42	(*)

in water from 37 of the 41 wells tested, sulfate content was greater than the 250-ppm limit recommended by the U.S. Public Health Service (1962). Other constituents are below the maximum recommended concentration limits. However, because 0.11 ppm of selenium was found in the water from well C17-45-31aba (U.S. Public Health Service recommends a limit of 0.01 ppm), it would be desirable to test water from other wells for selenium content. Ground water for stock use, with some exceptions, particularly in the southern part of the project area, is acceptable under Colorado standards. Tentative estimates of the amount of excess water needed to leach salts from the root zone and of the gypsum needed to maintain soil permeability indicate that an average of 28 percent excess water and 600 pounds of gypsum per acre-foot of water are required for reasonable yields of very salt-tolerant crops.

SUMMARY AND CONCLUSIONS

In many places the soil and topography make the land unsuitable for irrigation; the soil is thin, and leveling or other preparation may destroy crop-producing ability. Also, the sandy soil and the relatively small yield of wells make it difficult to develop large areas for irrigation. Flood irrigation requires that large amounts of water be applied because the sandy soil allows much downward percolation. These facts indicate that irrigation in the immediate future will be confined to small areas, and crops irrigated will be those that provide a constant land cover, such as alfalfa or forage grasses. Sprinkler irrigation may become predominant, because excessive erosion can be avoided and better distribution and more efficient use of water can be obtained. Application of small quantities of water that wet only the root zone may result in the accumulation of salts in the soil and may thus reduce the productivity of the land.

The location of adequate water supplies is important to landowners throughout the area. Although stock and domestic water supplies can be developed almost anywhere in the valley-fill deposits of Big Sandy and Rush Creeks, test drilling commonly is necessary in other places and is everywhere necessary in locating irrigation supplies. For aid in planning test-drilling programs refer to plate 1.

Obtaining water of suitable quality is a problem in many areas. To help solve this problem, stock and domestic supplies should be developed from the valley fill where possible. Leaching requirements for irrigation water are shown in table 5, which will enable landowners to estimate the leaching requirement of the water for proposed irrigation developments and thus allow rough calculations to be made of the amount of water that should be applied. An increased use or reuse of ground water for irrigation will result in increased mineralization of the water, but a sampling program would enable detection of the increase before it became serious. Periodic conductivity measurements should be made to show changes in dissolved-solids content; these measurements would be useful in determining collecting sites of water for chemical analyses.

Future extensive exploitation of ground water may cause problems such as (1) depletion of storage, (2) decreasing yields, and (3) worsening of water quality. Depletion of storage can be detected by regular measurement of water levels in observation wells installed during this study. Local areas of depletion may be detected by continued measurement of the water levels in irrigation wells. Decreased yields are generally caused by (1) lowering of water level, (2) plugging or encrustation of the casing or well screen, and (3) failure or wear of the pump or motor. A continuing record of periodic water-level measurements, both static and pumping, would be useful in detecting problems before they become severe. Generally, this type of record will show whether a decline in yield is caused by the pump or the well. Optimum well construction and thorough well development by surging and bailing are among the most economical and satisfactory methods for preventing excessive well encrustation. Optimum well spacing will prevent excessive lowering of the water table owing to interfering wells.

Another problem that may become more important is the increase in phreatophytes. Cottonwood trees grow throughout the Big Sandy Creek valley, and saltcedars are becoming more numerous in the lower end. If these plants follow a growth pattern similar to that in other regions in Colorado, they will continue to spread and to use increasing amounts of water. At the present time (1963) these trees furnish cover for wildlife and domestic stock and thus provide some benefit. Periodic surveys of their extent should be made, however, to determine when their water use outweighs their benefit.

Management policies involving the Big Sandy Creek and Rush Creek valleys should recognize the relation between surface water and ground water, as explained on page 34. Surface water generally is available only as floodflows, and expensive dams and reservoirs must be constructed to impound the water for irrigation. On the other hand, ground water may be developed for irrigation with relatively small expense. The percolation of floodflows to the ground-water reservoir may be increased by lowering the water level near the streambed and perhaps by water spreading in streambeds. The conservation of surface water in these ways is less expensive and more efficient than it is in surface reservoirs.

The maximum benefit of ground-water resources can be obtained only through planned management and operation of ground-water reservoirs; data regarding the hydrologic system, therefore, must be continually collected and evaluated. Such data include records of streamflow, precipitation, ground-water pumpage, water levels, and chemical quality of water.

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