GROUND-WATER RESOURCES

OF PARTS OF

WELD, LOGAN, AND MORGAN COUNTIES

COLORADO

By L. J. Bjorklund

WITH A SECTION ON THE CHEMICAL QUALITY OF THE GROUND WATER

By F. H. Rainwater

1957

DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

HYDROLOGIC INVESTIGATIONS ATLAS HA 9

Compiled as a part of the program of the Department of Interior for development of the Missouri River basin

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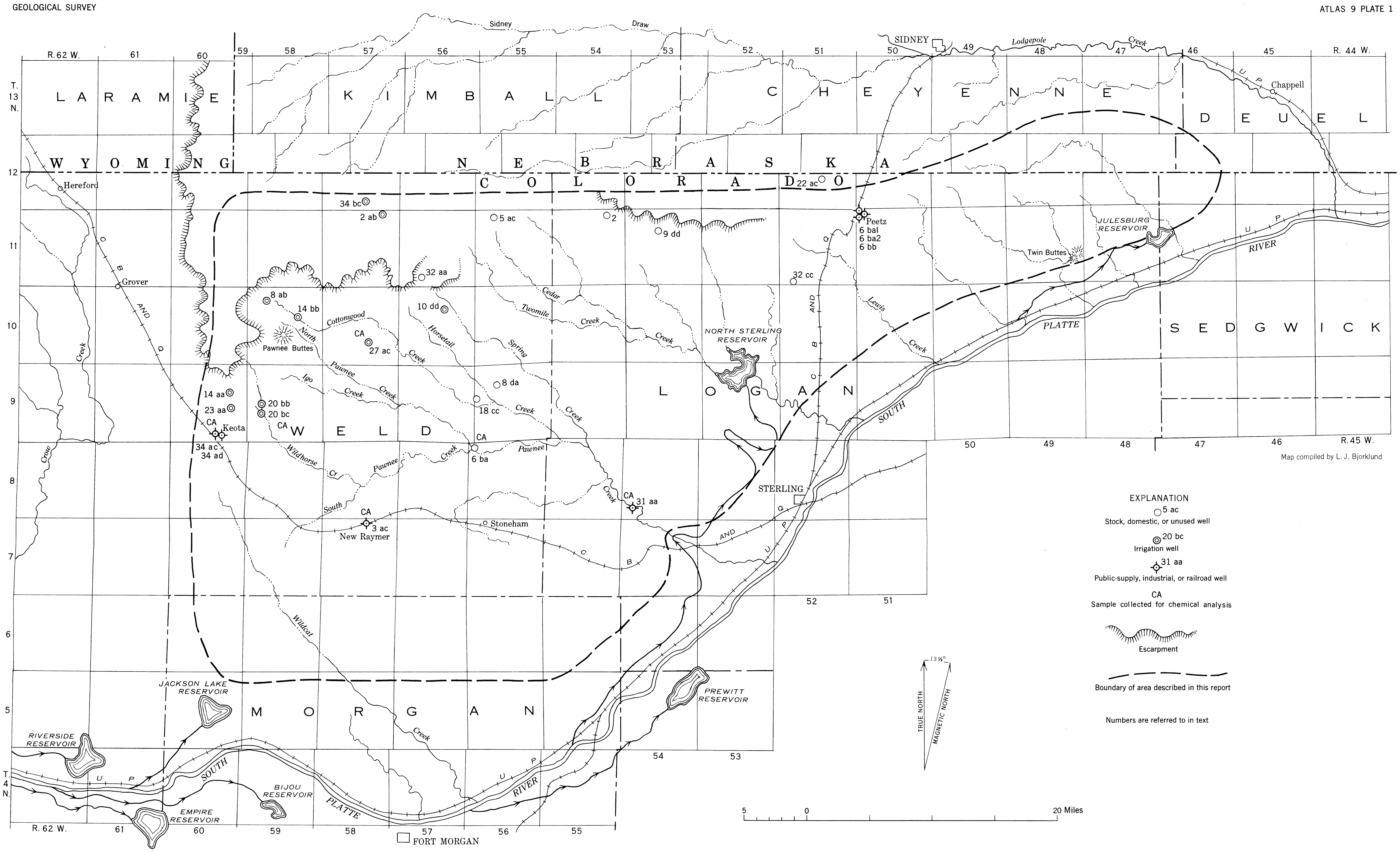

MAP OF PARTS OF WELD, LOGAN, AND MORGAN COUNTIES, COLORADO, SHOWING THE LOCATION OF WELLS FOR WHICH RECORDS ARE GIVEN

INTRODUCTION

Purpose and Scope of the Investigation

The investigation described in this report was one of several made by the United States Geological Survey as part of a program of the Department of the Interior for the development, conservation, and use of water resources in the Missouri River basin. The purposes of this investigation were to collect and analyze information on all wells of moderate to large discharge and some smaller domestic, stock, and unused wells; to delimit the parts of the area where more extensive use of the ground water could be made; and to determine whether detailed ground-water investigations are needed in the area.

The field work was done during July and August 1953. Records were obtained for 26 wells in the area, including all wells yielding more than 100 gallons per minute (gpm), and samples of water for chemical analysis were collected from 6 of the wells. The locations of the 26 wells are shown in plate 1, and data pertaining to the wells are given in table 1.

Location and Extent of the Area

The area described in this report contains about 2,000 square miles, almost wholly in Weld, Logan, and Morgan Counties, Colo. (See pl. 1.) The area is bounded on the north by the lower Lodgepole Creek drainage basin, on the west by the Crow Creek drainage basin, and on the south and east by the valley of the South Platte River.

Topography and Drainage

The area lies mainly in the Colorado Piedmont section of the Great Plains physiographic province, but the northern, higher, part is in the High Plains section of the same province. The altitude of the highest point, in the northwestern part of the area, is about 5,400 feet; and the altitude of the lowest point, at the eastern end of the area, is about 3,700 feet. A prominent escarpment, 200 to 300 feet high, separates the High Plains upland from the Colorado Piedmont lowland. In the report area the Colorado Piedmont is a flat to gently rolling erosional surface dissected by many stream channels. The land surface is more rolling toward the north, where the number of drainage channels is greater and headward stream erosion more active. Several hills and buttes stand above the general land surface. The High Plains section is a flat to gently rolling plain that slopes eastward but has been dissected by southeastward-draining streams.

The area is drained by many creeks that flow in a southeasterly direction toward the South Platte River. The principal creeks are Wildcat, Pawnee, Cedar, and Lewis. For the most part, these creeks are ephemeral; that is, they flow only in direct response to precipitation. However, because they are fed by many springs and seeps, Wildhorse, Cottonwood, and Spring Creeks (tributaries of Pawnee Creek) are perennial in their upper reaches, but within a few miles their channels are dry. All the creeks become perennial where they enter the valley of the South Platte River.

Climate and Agriculture

The nearest station of the United States Weather Bureau is at Kimball, Nebr., just north of the area described in this report. The normal annual precipitation at Kimball is 16.51 inches, most of which occurs during the growing season. Livestock is the chief agricultural product. Some wheat is raised in the southern part and in the extreme northern part, but most of the area is rangeland.

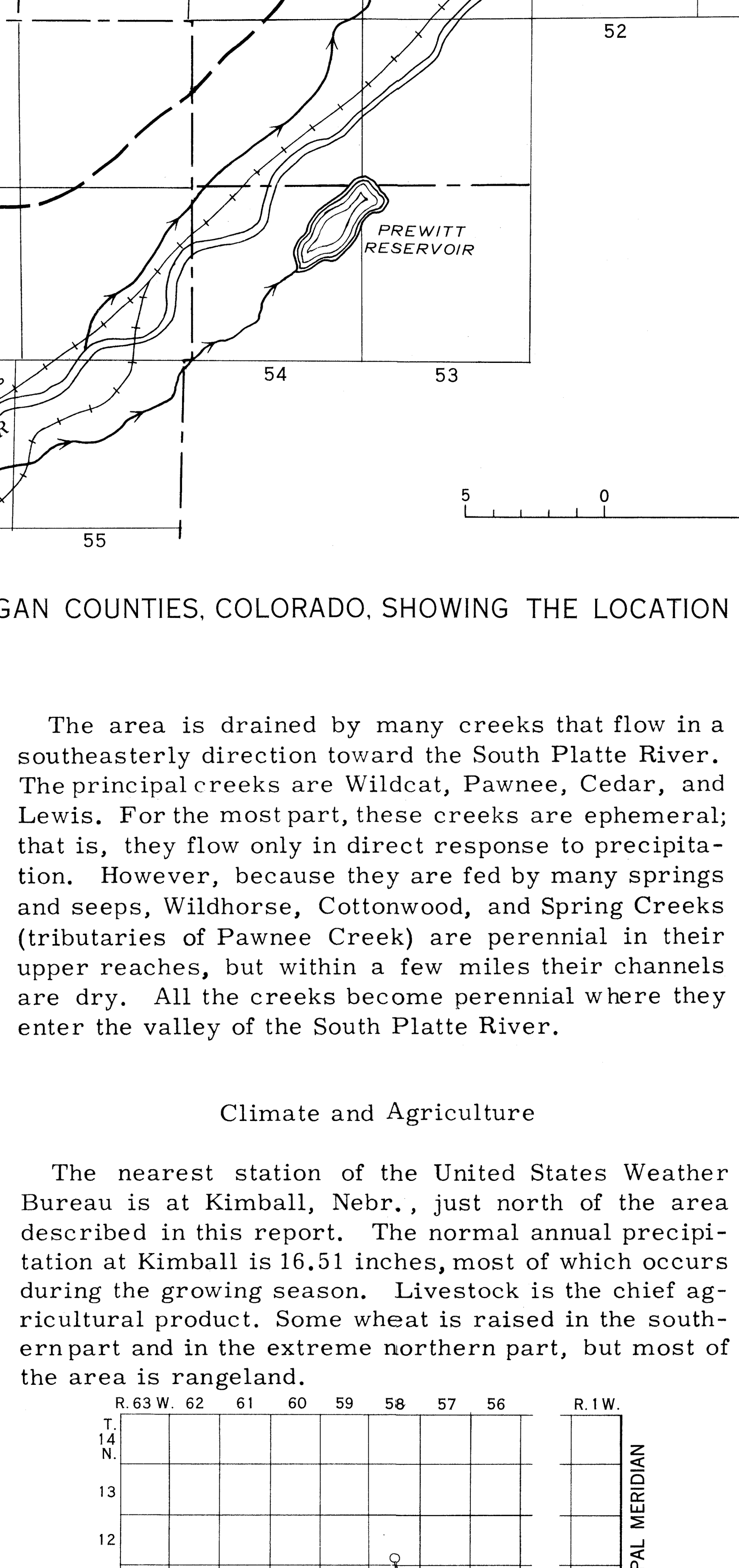

Figure 1. —Well-numbering system.

Well-Numbering System

In this report, wells are numbered according to their location within the system of land subdivision used by the United States Bureau of Land Management. All wells are within the sixth principal meridian and baseline system. The first numeral of a well number indicates the township, the second the range, and the third the section in which the well is situated. The lowercase letters following the section number locate the well within the section. The first letter denotes the quarter section and the second the quarter-quarter section (40-acre tract). Subdivisions of the section are a, b, c, and d in a counterclockwise direction, beginning in the northeast quarter. Where more than one well are in a 40-acre tract, consecutive numbers beginning with 1 are added to the well number. (See fig. 1.)

Locations of the wells are shown in plate 1. The last part of the well number (the part giving the number of the section and the location within the section) is shown beside the well symbol. The part of the well number giving township and range can be determined from the township and range numbers at the margin of the map.

RELATED INVESTIGATIONS

The area described in this report and adjacent areas in which related geologic and ground-water studies have been made are shown in figure 2. Reports on the studies made in the adjacent areas are described below.

1. Babcock, H. M., and Bjorklund, L. J., 1956, Ground-water geology of parts of Laramie and Albany Counties, Wyo., and Weld County, Colo., with a section on the chemical quality of the water by L. R. Kister: U. S. Geol. Survey Water-Supply Paper 1367.

This report describes the occurrence, movement, and chemical character of the ground water; it includes a table showing a generalized section of the geologic formations exposed in the area, and it briefly describes the physical characteristics and water supply of the various formations.

2. Bjorklund, L. J., 1956, Geology and ground-water resources of the lower Lodgepole Creek drainage basin, Nebraska, with a section on the chemical quality of the ground water by E. R. Jochens: U. S. Geol. Survey Water-Supply Paper 1410.

This report contains a description of the occurrence, quality, quantity, movement, availability, and use of ground water and the characteristics, thickness, and extent of the water-bearing formations in the Lodgepole Creek drainage basin in Nebraska; a discussion of the present and potential development of ground water for irrigation, public supply, industry, and domestic and stock use; tables of well records, water-level measurements, logs of wells and test holes, and chemical analyses of the water; and maps showing areal geology, contour of the water table, depth to water, and locations of wells and test holes.

Studies of ground-water conditions in the upper part of the Lodgepole Creek basin in Wyoming have been completed by Bjorklund, and a report is being drafted.

3. Bjorklund, L. J., and Brown, R. F., 1956, Geology and ground-water resources of the South Platte River valley between Hardin, Colo., and Paxton, Nebr., with a section on the chemical quality of the ground water by H. A. Swenson: U. S. Geol. Survey Water-Supply Paper 1378 (in press).

Information on the occurrence, movement, quality, and use of ground water in the valley of the South Platte River is contained in this report, which includes geologic sections across the South Platte River valley and maps showing geology, depth to water, water-table contours, and locations of wells. The report also gives information on the number of irrigation wells in the area and the amount of water pumped.

4. Code, W. E., 1943, Use of ground water for irrigation in the South Platte valley of Colorado: Colo. Agr. Mech. Coll. Agr. Expt. Sta. Bull. 483, 44 p.

The extent, development, and importance of the use of ground water for irrigation in the valleys of the South Platte River and its tributaries in northeastern Colorado are discussed in this report. Fluctuations of the water table are illustrated by hydrographs. Pumpage for the year 1940 and a map showing irrigation districts and the locations of irrigation wells are included.

5. Rapp, J. R., Warner, D. A., and Morgan, A. M., 1953, Geology and ground-water resources of the Egbert-Pine Bluffs-Carpenter area, Laramie County, Wyo.: U. S. Geol. Survey Water-Supply Paper 1140.

This report describes the geology and ground-water resources of the southeastern part of Laramie County, with special reference to the extent of, and possibilities for, ground-water development in the valleys of Lodgepole, Muddy, and Crow Creeks. It discusses the occurrence, source, movement, and chemical character of the ground water. The report contains a geologic map and cross sections, maps showing the contour of the water table and the depth to water, tables of chemical analyses, logs of wells and test holes, and well records.

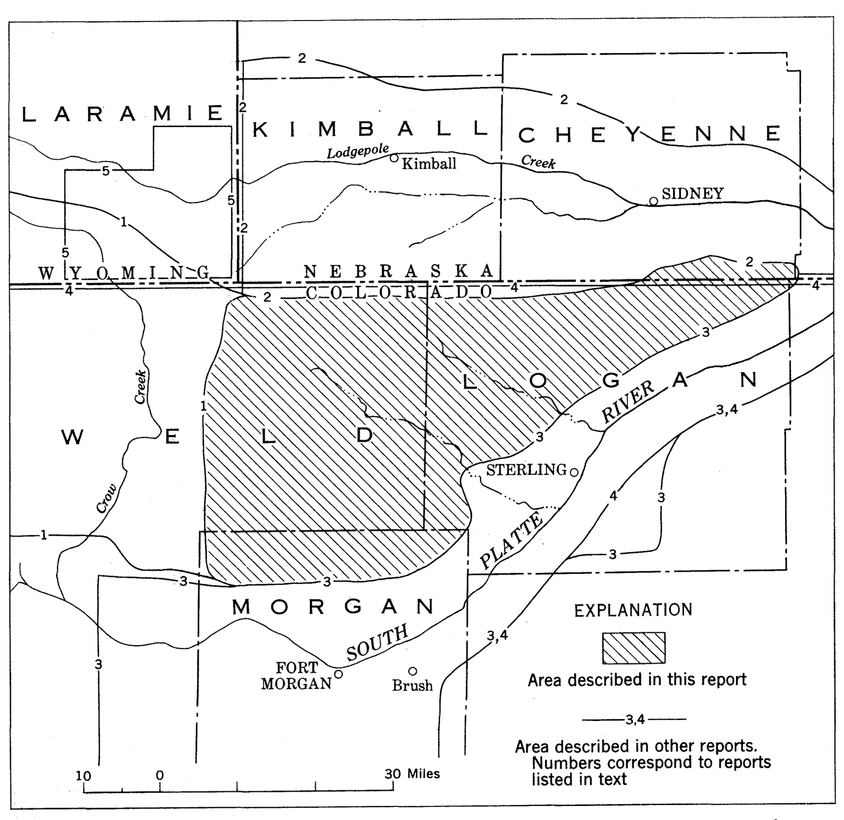

Figure 2.—Index map of parts of Wyoming, Nebraska, and Colorado, showing the area described in this report and other areas in which related ground-water studies have been made.

GEOLOGIC FORMATIONS AND THEIR WATER-BEARING PROPERTIES

Rocks of Late Cretaceous, Tertiary, and Quaternary age are exposed in the report area. The Cretaceous rocks are the Pierre shale, the Fox Hills sandstone, and the Laramie formation; the Tertiary rocks are the Chadron, Brule, and Ogallala formations; and the Quaternary rocks are the deposits of alluvium that lie in the creek valleys. All the formations that crop out in the area probably yield at least small quantities of water to wells in the area; however, only the Brule formation and the alluvium are known to yield large quantities. Detailed descriptions of these formations are not within the scope of this report but are contained in the reports listed above.

Wells penetrating a sandy zone in the Pierre shale about 550 feet below the land surface in T. 11 N., Rs. 54 and 55 W., are reported to yield 15 to 20 gpm. The water is under artesian pressure and rises in wells to a level of about 170 feet below the land surface. Elsewhere in the area the Pierre shale yields water sufficient only for domestic and stock use.

The Fox Hills sandstone and the Laramie formation yield water to many domestic and stock wells south of Keota and Stoneham, Colo. The water from wells tapping the Laramie formation at Stoneham is described as containing sulfur and as being unfit for human or livestock consumption. It may derive its undesirable constituents from seams of coal in the formation.

In the northwestern part of the area, generally north and west of T. 8 N., R. 56 W., the Brule formation yields large quantities of water to wells. The water enters the wells through fissures and permeable zones in the formation. Most of the wells of large discharge deriving water from the Brule are in the upper reaches of the creek valleys but below the escarpment that separates the Colorado Piedmont from the High Plains; however, two wells, 12–58–34bc and 11–58–2ab, are in the upland area north of the escarpment. Elsewhere in the area, the Brule formation yields only small quantities of water to wells.

The uplands in the extreme northern part of the area are mantled by the Ogallala formation. Although that formation generally is quite permeable, it is so well drained that the zone of saturation within it is very thin. Therefore, in the report area the Ogallala formation cannot be expected to yield more than small to moderate quantities of water to wells. The town of Peetz, Colo., obtains water from three wells that tap the Ogallala formation; each well produces a maximum of about 20 gpm.

The alluvium in the creek valleys probably is not more than 10 to 15 feet thick; however, in some of the valleys the alluvium yields moderate quantities of water to large-diameter, or pit, wells. A small pit well in the alluvium of Pawnee Creek (8–54–31aa) yields about 250 gpm with a drawdown of about 3 feet.

OCCURRENCE OF GROUND WATER

Within the report area the aquifers of Cretaceous age transmit water received as underflow from the west. Water that is not withdrawn from these aquifers by pumping wells eventually leaves the area as underflow to the southeast or is discharged where the formations crop out along the southeast border of the area. Because these aquifers consist of only slightly permeable material, the rate of movement through them is very slow. Most of the water reaching the outcrop area either evaporates or is transpired by vegetation, and some probably discharges into the valley fill of the tributaries of the South Platte River. Where a water-bearing stratum is overlain by an impermeable bed, the water is under artesian pressure and rises in wells above the level at which it is first encountered. Within and near the area where such aquifers crop out, water can be obtained at relatively shallow depths; but where the aquifers are buried beneath younger rocks, the overlying shallower aquifers generally are more economical sources of supply.

The aquifers of Tertiary and Quaternary age are recharged by the direct infiltration of precipitation and by influent seepage from streams. No attempt was made during this investigation to determine the amount of water that reaches the water table in the report area, but probably it is only a very small percentage of the total precipitation. As the water-table divide probably conforms closely to the topographic divide that bounds the west and north sides of the report area, it is believed unlikely that these aquifers are recharged significantly by underflow from outside the area. The water moves generally southeastward, and the part that is not intercepted by wells either is discharged where the formations crop out or moves out of the area through the valley fill of the principal streams. As the valley fill is thin, it transmits only a small amount of ground water. No ground water leaves the area as streamflow, for the creeks do not become perennial in their lower stretches until they enter the South Platte River valley, which forms the southeastern boundary of the report area.

Ground water is discharged by evapotranspiration in several places along the upper reaches of the valleys of Wildhorse, Cottonwood, Spring, and other creeks. Some of these places are several miles long, range in width from a few hundred feet to about half a mile, and support a dense growth of meadow grass, bulrushes, and willow and cottonwood trees.

Two types of springs—contact springs and springs discharging from fractures and permeable zones in the Brule formation—are common in the report area. Contact springs issue along the contact of the Brule with the overlying Ogallala formation, especially along the margins of the stream valleys in their upper reaches. Generally the discharge of contact springs is small, and the water is used for watering livestock or for domestic supply. The springs of the other type are larger and generally issue in or near the beds of the creeks in the upper reaches of their valleys. The flow from some of these springs is sufficient for irrigation. If not utilized, the water generally flows for only a short distance before it evaporates or sinks into the ground.

The total amount of ground water discharged by the 10 irrigation wells in the area probably does not exceed 1,000 acre-feet per year. These wells derive water from fractures and porous zones in the Brule formation.

The depth to the water table generally is greatest on the uplands and least in the valleys.

GROUND WATER FOR IRRIGATION

Present Development

About 300 acres of land in the northwestern part of the area is irrigated from 10 wells. (See pl. 1 and table 1.) An undetermined, but rather small, acreage in T. 10 N., Rs. 58 and 59 W., is irrigated from springs.

Potential Development

In favorable localities in the northwestern part of the area, additional wells of moderate to large discharge can be developed in the Brule formation. These localities, however, generally can be determined only by extensive test drilling. In some of the creek valleys also, wells of moderately large discharge probably could be obtained by drilling into the alluvium, but, owing to the thinness of the zone of saturation in the alluvium, the wells either must have large-diameter casing or must be pits similar to well 8–54–31aa. Open excavations 100 to 300 feet long and extending to the bedrock are sources of water supply in the vicinity of Nunn and Carr, Colo. (Babcock and Bjorklund, 1956. See "Related Investigations," above.) Several farmers residing along the creek valleys in the report area have indicated that they plan to develop supplies of water for irrigation by constructing pit wells in the alluvium. In some places in the southern part of the area, irrigation wells of small discharge probably could be developed in the Fox Hills sandstone or the Laramie formation. A few such wells have been drilled in the lower part of the Crow Creek drainage basin west of the report area.

It appears that the part of the area north of T. 9 N. and east of R. 56 W. is the least favorable for the development of irrigation wells. In the lowlands in that part of the area many residents have had to drill to greater depths than 500 feet to obtain supplies sufficient for domestic use and the watering of livestock. The upland plain in that part of the area is underlain by the Ogallala formation, which generally yields sufficient water for domestic and stock use but not enough for irrigation because of the thinness of the zone of saturation. In a recently drilled irrigation well (12–52–22ac) on the upland plain, water was found in the Ogallala formation at 82 feet, and the underlying Brule formation was entered a few feet lower. Although the well was deepened to 500 feet to increase its yield, the well is reported to have "pumped dry" in 12 minutes when pumped at a rate of about 1,000 gpm. The pump was set at about 200 feet below the land surface.

PUBLIC AND INDUSTRIAL SUPPLIES

Only two municipalities in the area have public water supplies. Peetz, Colo., population 250, obtains its supply from 3 drilled wells which derive water mainly from the Ogallala formation and, together, yield about 50 gpm. Keota, Colo., population 21, obtains water from a drilled well in the Fox Hills sandstone or Laramie formation. Residents of New Raymer, population 130, obtain water from privately owned wells, and water for the town of Stoneham, population 100, is hauled from farms a few miles away. The only industrial well in the area is a pit well (8–54–31aa), which derives water from the alluvium. Several wells dug into the Fox Hills sandstone or Laramie formation were used by the Chicago, Burlington & Quincy Railroad on its now abandoned branch line between Sterling, Colo., and Cheyenne, Wyo.

CHEMICAL QUALITY OF THE GROUND WATER

By F. H. Rainwater

Because the reports on adjacent areas contain information on the quality of the ground water under similar geologic, climatic, and hydrologic conditions, only six samples were collected in the report area for chemical analysis. Two of the samples were from wells in the Fox Hills sandstone and (or) Laramie formation, two from wells in the Brule formation, and two from wells in the valley alluvium. The locations of the wells are shown in plate 1, and the results of the chemical analyses are given in table 2.

S. W. Lohman of the Geological Survey stated in a written communication to R. F. Brown (Mar. 17, 1950) that H. A. Aurand, a consulting geologist, used the chemical characteristics of the water to differentiate between the Fox Hills sandstone and the Laramie formation in northeastern Colorado. According to Aurand's classification, water from the Fox Hills sandstone is mainly of the sodium bicarbonate type, whereas water from the Laramie formation is characterized by calcium and sodium sulfates. Kister (*in* Babcock and Bjorklund, 1956. See "Related Investigations," above.) found this relation between formation and water type to be a reasonably reliable basis for classifying water in the Crow Creek-Lone Tree Creek area.

Well 7–58–3ac at New Raymer is believed to tap the Fox Hills sandstone and, possibly, the Laramie formation. The results of analysis of the water show either that the well taps both formations or that the water does not conform to Aurand's classification. The public-supply well of Keota is reported to draw water from the Fox Hills; however, on the basis of Aurand's classification, the water is more representative of the Laramie formation. Possibly the water from this well is a mixture of water from the Fox Hills sandstone and the Brule formation. Sulfate composes 70 percent of the dissolved acidic constituents, and sodium constitutes only 53 percent of the total basic constituents (expressed in equivalents per million). Obviously, more detailed information is needed before water quality can be correlated with geologic source.

Discussion with inhabitants at New Raymer and Stoneham indicates that the problem of obtaining potable water is both common and localized. Water from one well may be very unpleasant to the taste, whereas a well nearby may yield "good" water. The unpleasant taste and odor may result from the presence of hydrogen sulfide, produced from the chemical reduction of sulfate by hydrocarbons from coal in the Laramie formation.

Generally, water from the Fox Hills is suitable for domestic use but is of poor quality for irrigation because of a high percentage of sodium among the cations (commonly termed "percent sodium"). On the other hand, water from the Laramie formation may be better suited for irrigation but is unsuitable for domestic use because of excessive hardness and objectionable amounts of sulfate or sulfide.

The chemical character of water from the Brule formation differs from place to place, probably because the water-yielding properties of the formation are not uniform. Because water from the unfractured, nearly impervious part of the Brule has had ample time to dissolve soluble salts, it is probably more mineralized than water from the part of the formation that is extensively fissured. Data for the two sampled wells tapping the Brule formation are given below:

Well no.	Depth of water in well (ft)	Diameter (in.)	Yield (gpm)	Drawdown (ft)	Specific capacity (gpm per ft of drawdown)	Dissolved solids (ppm)	Sulfate (ppm)
9-59-20bc	27	18	300	6	50	268	24
10-58-27ac	58	16	85	17	5	768	323

Table 2 shows that the bicarbonate concentrations of these two water samples are practically the same and that the higher mineralization is due to a higher concentration of sulfates of sodium and calcium. Unpublished analyses of ground water from the Brule formation in Platte County, Wyo., show a similar relation of sulfate to total mineralization.

The samples collected from wells 8-54-31aa and 8-56-6ba, which tap the alluvium in the report area, had an appreciably greater mineral content than samples from wells which tap the alluvium in areas to the north and west. The total salt content of 848 ppm and 978 ppm, respectively (table 2), was not much less than the average of 1,170 ppm reported by Swenson (*in* Bjorklund and Brown, 1956. See "Related Investigations," above.) for water from the alluvium in the South Platte River valley. Swenson found that the sulfate content of water from the alluvium of the South Platte River valley is directly proportional to the total mineralization of the water. This general relationship appears to be true also of water from the alluvium in both the report area and the adjacent lower Crow Creek valley (Babcock and Bjorklund, 1956. See "Related Investigations," above.). Geochemically, all these samples are similar in that alkaline earths compose about 70 percent of the basic constituents (expressed in equivalents per million).

The logical conclusion concerning the chemical quality of water in the alluvium is that in the upper reaches of the valleys, where the alluvium is recharged primarily by water issuing as springs at the base of the Ogallala formation or from fractures in the Brule formation, the water is relatively more dilute than analyses in table 2 indicate and is of the calcium bicarbonate type. This conclusion is based on the well-known general characteristics of water in the Ogallala and from analyses of water in the Brule formation given in the report on the Egbert-Pine Bluffs-Carpenter area, Laramie County, Wyo. (Rapp, Warner, and Morgan, 1953.) In the lower reaches of the valleys, the water probably becomes more mineralized and modified in type by solution of calcium and sodium sulfates. However, as the generally small volume of alluvium is recharged by runoff from relatively large valley areas, periodic and abrupt changes in total salt content can be brought about easily by the diluent action of infiltration.

CONCLUSIONS

In the southern part of the area, moderate supplies of water probably can be developed from the Fox Hills sandstone and (or) Laramie formation; in the northwestern part of the area, moderate to large supplies of water can be obtained from fractures in the Brule formation; and in places in the creek valleys, moderately large supplies of water can be obtained from the alluvium. Although an areal geologic map would be of great value in planning the development of the ground-water resources, test drilling also would be required to determine favorable sites for wells.

As the present analyses show that the Fox Hills sandstone and (or) Laramie formation yield water of variable salt content and excessive percent sodium, chemical analysis of the water should precede any attempt to develop irrigation supplies from these formations. Water from the Fox Hills is reported to be of the sodium bicarbonate type and capable, therefore, of forming "residual sodium carbonate" when the minerals are concentrated by evapotranspiration.

Water from the Brule formation and alluvium probably is of satisfactory quality for irrigation provided drainage (movement of applied water through and out of the root zone) is adequate. Although the texture of the alluvium in the creek valleys may appear to satisfy drainage requirements, potential irrigation sites should be examined critically to make sure that the depth and configuration of the underlying bedrock are such that free drainage is possible. Without adequate drainage, the concentration and deposition of salts could rapidly produce a saline soil.

Table 1.—*Records of wells*

Well number: See text for description of well-numbering system.
Type of well: Dr, drilled well; Du, dug well.
Depth of well: Measured depths are given in feet and tenths below measuring point; reported depths are given in feet below land-surface datum.
Type of casing: C, concrete or rock masonry; N, none; P, metal pipe.
Character of material: G, gravel; R, rock, undifferentiated; S, sand; Sh, shale; Sls, siltstone.
Geologic source: Kfh, Fox Hills sandstone; Kl, Laramie formation; Kp, Pierre shale; Qa, alluvium; Tb, Brule formation; To, Ogallala formation.
Type of pump: Cy, cylinder; J, jet; S, screw; T, turbine.
Type of power: E, electric motor; G, gasoline engine; T, tractor; W, windmill.
Use of water: D, domestic; I, irrigation; In, industry; N, none; P, public supply; S, stock.
Measuring point: Hpb, hole in pump base; Idp, invert of discharge pipe; Ls, land surface; Tc, top of casing; Tpp, top of pump platform; Twc, top of well cover.
Depth to water: Measured depths are given in feet, tenths, and hundredths below measuring point; reported depths are given in feet below land-surface datum.
Remarks: A, acreage irrigated by well; Ca, sample collected for chemical analysis; Cb, corrosive to boilers; D, reported discharge in gpm; DD, drawdown in feet while discharging at the preceding rate; If, Irrigation well failure; Piw, plans irrigation well at site; Pw, pit well; S, sprinkling system used; T500, well has been tested to yield about 500 gpm; U, reported unfit for human use.

Well no.	Owner or tenant	Year drilled	Type of well	Depth of well (feet)	Diameter of well (inches)	Type of casing	Principal water-bearing bed: Character of material	Principal water-bearing bed: Geologic source	Type of pump	Type of power	Use of water	Measuring point: Description	Measuring point: Height above land surface (feet)	Depth to water level below measuring point (feet)	Date of measurement	Remarks
Logan County, Colo.																
8-54-31aa	Colorado Highway Dept.	......	Du	10	.....	N	S, G	Qa	Cy	G	In	Ls	......	3.50	7-23-53	D250; DD3; Pw; Ca
11-51- 6ba1	Peetz, Colo.	1920	Dr	550	8	P	S	Kp	S	E	P	Ls	......	100	....	D10
6ba2	......do	1952	Dr	125	6	P	S, G	To	J	E	P	Ls	......	100	....	D20
6bb	......do	1942	Dr	125	10	P	S, G	To	J	E	P	Ls	......	100	....	D20
52-32cc	W. B. Baldwin	1950	Dr	350	6	P	Sh	Kp	Cy	W	S	Tc	0.5	83.05	7-24-53	D5; DD120
54- 9dd	Fred Griffith	1910	Dr	160	6	P	Sls, Sh(?)	Tb, Kp(?)	Cy	W	D, S	Ls	......	60	....	D3; DD90
55- 2	Thomas Hatch	......	Dr	590	6	P	S, Sh	Kp	Cy	G	D, S	Ls	......	175	....	D20; DD200+
12-52-22ac	Don Meyers	1953	Dr	500	18	P	Sls	To, Tb	T	G	N	Tc	.5	82.29	7-24-53	If
Weld County, Colo.																
7-58- 3ac	Chicago, Burlington & Quincy RR.	1910	Du	70	180	C	R	Kfh, Kl(?)	Cy	E	In	Twc	1.0	66.62	7-21-53	U; Cb; Ca
8-56- 6ba	H. H. Craig	1920	Du	18	36	N	S, G	Qa	Cy	W	D	Twc	.3	13.60	7-22-53	Piw; Ca
9-56- 8da	Guy Chapel	......	Dr	307	6	P	Sh	Kp	Cy	E	D	Ls	......	100	....	D4; DD200
18cc	Richard Moon	1917	Du	10	10	P	S, G	Qa	Cy	W	S	Tc	3.5	9.05	7-23-53	Piw
59-20bb	James Hickman	......	Dr	65	18	P	Sls	Tb	T	G	I	Idp	.7	38.25	12-10-52	A25; D600
20bc	......do	1941	Dr	65	18	P	Sls	Tb	T	E	I	Ls	......	38	....	A75; D300; DD6; S; Ca
60-14aa	William Rohn	1941	Dr	92	42	P	Sls	Tb	T	T	I	Hpb	1.0	64.11	12-10-52	A60; D1, 050
23aa	William Benner	1941	Dr	75	22	P	Sls	Tb	T	G	I	Tc	.3	44.52	10-17-52	A25; D850
34ac	Keota, Colo.	1919	Dr	100	6	P	R	Kfh	Cy	G	P	Ls	......	40	....	D40; Ca
34dd	Chicago, Burlington & Quincy RR.	1910	Du	......	180	C	R	Kfh	Cy	W	In	Ls	......	30	....	
10-57-10dd	Sprague brothers	1950	Dr	75	12	P	Sls	Tb	Cy	G	S, I	Tc	1.0	22.33	7-23-53	D1,000
58-27ac	Allan brothers	1942	Dr	90	16	N	Sls	Tb	Cy	T	S, I	Tpp	.5	32.54	7-17-53	D85; DD17; Ca
59- 8ab	Elmer Ehmke	1939	Dr	91.5	18	P	Sls	Tb	T	T	I	Tc	1.5	51.95	7-21-53	A10; D300
14bb	Edna Nelson	1941	Dr	65	18	P	Sls	Tb	T	T	I	Tc	.5	23.44	7-17-53	A30; D1,400; DD2
11-56- 5ac	J. T. Moyer	1945	Dr	83	18	N	Sls	Tb	Cy	W	S	Twc	.5	33.45	7-29-53	Piw; T500
57-32aa	J. G. O'Hare	1916	Dr	86	6	P	S, G	Qa	Cy	E	D, S	Ls	......	65	....	Piw
58- 2ab	Gust Kindvall	1940	Dr	100	18	P	Sls	Tb	T	T	I	Tc	0	34.07	7-23-53	A30; D750; DD50; S
12-58-34bc	A. R. Bourlier	1950	Dr	100	18	P	Sls	Tb	T	G	I	Hpb	1.0	66.69	7-23-53	A55; D525; DD30; S

Table 2.—*Mineral constituents and related physical measurements of ground water*

[Chemical constituents are in parts per million. All samples were collected Aug. 21, 1953]

Well no.	Well depth (feet)	Silica (SiO_2)	Total iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids: Residue on evaporation at 180°C	Dissolved solids: Sum	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Percent sodium	Specific conductance (micromhos at 25°C)	pH
Alluvium																				
8-54-31aa	10	26	......	119	35	82	15	204	428	12	0.4	1.2	0.18	848	......	440	273	28	1,160	7.2
56- 6ba	18	36	0.10	125	39	124	13	313	450	17	.5	2.3	.23	978	......	472	215	36	1,360	7.2
Brule formation																				
9-59-20bc	65	55	0.05	38	8.5	28	4.4	174	24	9.5	0.5	13	0.22	268	......	130	0	31	383	7.5
10-58-27ac	90	56	.01	94	16	107	14	193	323	32	.2	8.3	.01	768	......	300	142	42	1,080	7.4
Fox Hills sandstone-Laramie(?) formation																				
7-58- 3ac	70	13	0.02	54	27	376	23	540	545	46	0.7	2.4	0.31	......	1,350	244	0	75	2,030	7.4
Fox Hills sandstone																				
9-60-34ac	100	17	......	94	17	163	9.4	218	448	12	0.1	0.1	0.18	886	......	306	127	53	1,280	7.2

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