Formation and the Williams Fork Formation, and (3) the Lewis Shale. Data from sites 1, 2, and 3 (table 4) represent runoff from geologic materials older than the Trout Creek Sandstone Member. These rocks generally are located at higher altitudes and outside of the study area. Water in streams that drain these geologic materials is a calcium bicarbonate type that generally has dissolved-solids concentrations ranging from 100 to 400 mg/L. This surface water is of better chemical quality than any other in the study area.

Data from sites 4 through 13 primarily represent runoff from the Trout Creek Sandstone Member and from the Williams Fork Formation. Rocks in this interval were deposited under a combination of marine, deltaic, and continental conditions. As a result, runoff is of a dissimilar chemical composition; generally, the water is either calcium magnesium bicarbonate or calcium magnesium sulfate. Three of the 10 sites in this group (sites 11, 12, and 13) are located downstream from large strip mines, and water quality may be affected by mine drainage. Dissolved-solids concentrations commonly range from 300 to 800 mg/L in streams unaffected by mining activities. At sites 11, 12, and 13, dissolved-solids concentration commonly range from 300 to 3,000 mg/L.

Streams that primarily drain the Lewis Shale or the shale units in the upper member of the Williams Fork Formation were sampled at sites 14 through 18. The marine sediments in these rock units markedly affect the surface-water chemistry. The streams in this group generally have a magnesium sodium sulfate water composition and dissolved-solids concentrations that commonly range from about 1,000 to about 8,000 mg/L.

GROUND-WATER HYDROLOGY

Lohman (1972) defines an aquifer as "...a formation...that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs." "...Significant quantities of water..." in one region for one application may be insignificant in other regions or for other applications. The water-yielding units that are classified as aquifers in this study generally produce such small sustained yields (about 0–10 gal/min) that they would not be considered aquifers for many water-supply applications. However, these water-yielding units are the principal source of water in the local bedrock formations; they cause inflow to mines, and they supply usable volumes of water to the few stock or domestic wells in the area. Therefore, in this report, these water-yielding units are classified as aquifers.

Depositional Environments

Coal and associated deposits of the Iles and Williams Fork Formations developed in marine and deltaic plain environments located close to the shoreline (Weimer, 1976). Marine deposits of mudstone and shale generally are thick and homogeneous. These deposits have low permeability and are classified as regional confining beds. Near-shore marine deposits grade upward into massive transitional sandstones. These extensive sandstones

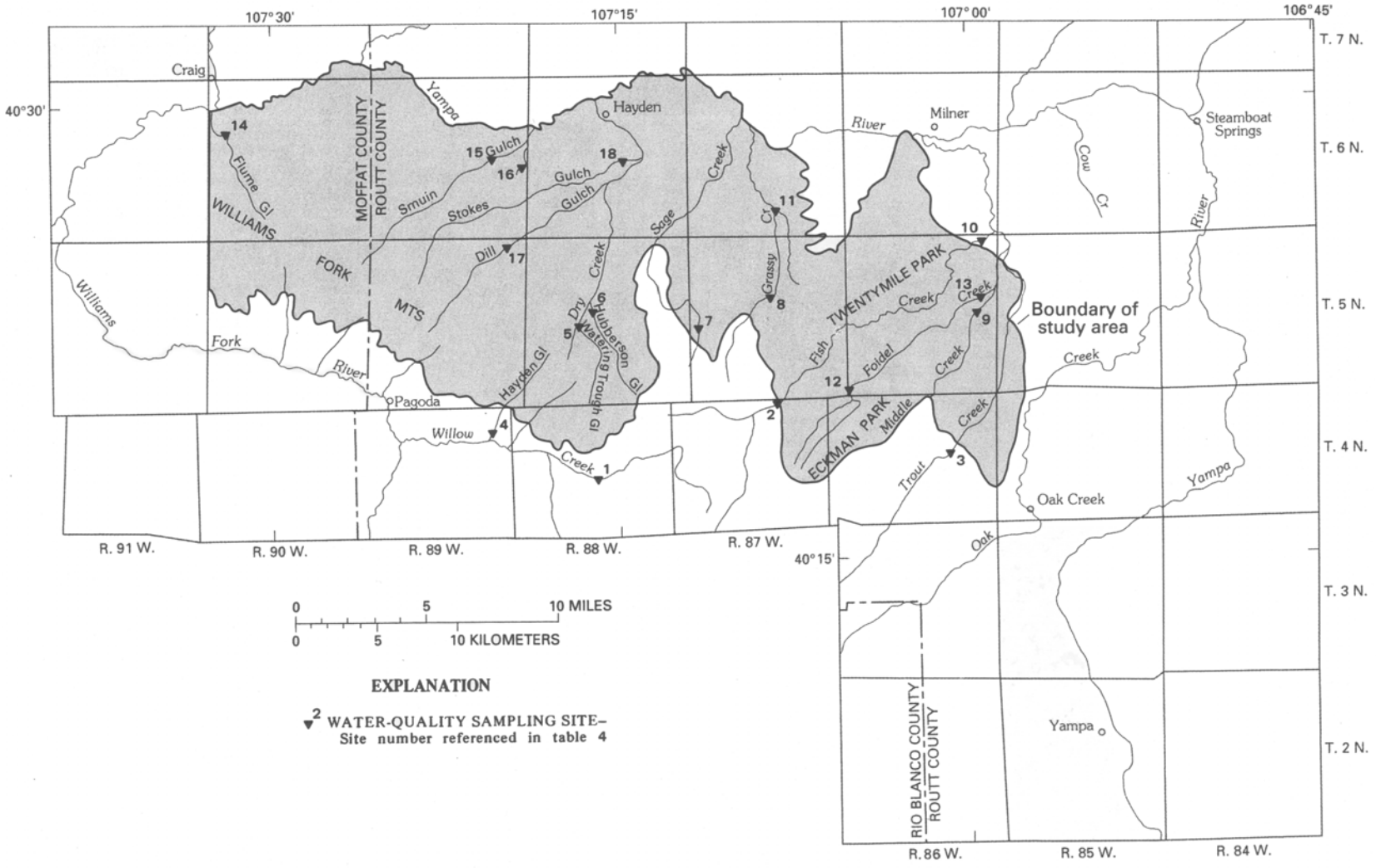

Figure 23.-- Location of water-quality sampling sites at streams.

Table 4.--*Summary of surface-*

[µS/cm, microsiemens per centimeter; $\bar{x}$, mean; S, standard deviation

Site number (fig. 24)	Stream	Station number	Number of analyses	Specific conductance (µS/cm)		pH (units)		Calcium	
				$\bar{x}$	S	$\bar{x}$	S	$\bar{x}$	S
1	Willow Creek near Dunckley	401747107161600	8	462	77	8.1	0.2	58	6
2	Fish Creek near Milner	09244100	8	513	153	8.2	0.2	55	15
3	Trout Creek near Oak Creek	401816107011000	7	184	61	8.0	0.2	23	8
4	Hayden Gulch near Pagoda	401913107204100	8	1,380	162	8.1	0.3	126	14
5	Watering Trough Gluch near Hayden	09244460	26	1,010	105	7.8	0.2	105	12
6	Hubberson Gulch near Hayden	09244464	28	1,010	429	7.9	0.3	116	34
7	Sage Creek near Hayden	09244415	13	616	227	8.1	0.3	78	22
8	Grassy Creek at Grassy Gap	402330107082000	7	864	760	7.9	0.3	65	26
9	Middle Creek near Oak Creek	09243700	50	620	155	8.0	0.4	68	13
10	Fish Creek at mouth near Milner	402530106585700	7	671	171	8.2	0.3	61	11
11	Grassy Creek near Mt. Harris	09244300	9	1,880	574	8.0	0.2	168	53
12	Foidel Creek near Oak Creek	09243800	33	862	294	7.7	0.4	97	27
13	Foidel Creek at mouth near Oak Creek	09243500	36	1,200	540	7.9	0.4	142	74
14	Flume Gulch near Craig	402911107323500	7	4,410	488	8.0	0.1	291	46
15	Smuin Gulch near Hayden	402829107193700	4	3,320	914	8.2	0.1	180	45
16	Smuin Tributary near Hayden	402845107185100	6	3,980	1,490	8.0	0.1	167	20
17	Dill Gulch near Hayden	402605107181500	3	5,540	1,830	8.2	0.1	203	15
18	Stokes Gulch near Hayden	09244470	9	4,120	2,930	8.0	0.5	170	88

water-chemistry data
values in milligrams per liter except where noted]

Magnesium		Sodium		Total alkalinity		Sulfate		Chloride		Dissolved solids	
$\bar{x}$	S	$\bar{x}$	S	$\bar{x}$	S	$\bar{x}$	S	$\bar{x}$	S	$\bar{x}$	S
22	6	15	4	214	47	51	23	3.6	1.1	293	49
33	15	16	6	213	68	86	37	3	2.4	338	113
8	2.6	3.5	0.6	87	31	6.1	3	0.71	0.46	106	33
95	13	59	9	317	19	471	67	13	2	972	112
57	7	39	7	344	29	228	34	11	2	664	77
76	22	58	23	347	44	389	147	13	9	837	282
40	14	16	6	228	57	158	75	5.9	2.3	449	146
35	14	27	9	204	85	154	59	5.7	1.8	424	162
29	7	30	11	220	55	117	37	4.4	1.4	395	97
37	10	41	21	193	48	190	89	4.9	2.3	463	137
116	43	124	59	278	114	816	274	29	13	1,450	459
48	17	37	19	291	77	236	106	9.5	9.6	599	207
69	40	66	33	228	70	507	385	11	5	937	562
341	36	426	72	373	113	2,390	353	86	42	3,770	515
258	86	360	178	365	31	1,720	741	66	36	2,820	1,090
253	138	533	268	465	67	1,830	972	120	53	3,200	1,420
513	123	777	280	497	68	3,330	1,040	140	30	5,270	1,530
438	277	806	462	221	92	3,280	1,960	100	73	5,060	3,030

are fine grained, well sorted, and permeable; thus, they form the regional aquifers in the area. The remaining rocks in the area primarily result from two nonmarine depositional environments—deltas and swamps. These various types of rocks may form either local aquifers or local confining layers. Distributary sandstones were deposited in deltaic distributary channels and are linear and vary in thickness and lateral continuity. Coals were formed in poorly drained bank deposits associated with distributary sands in a deltaic setting. The coals usually are variable in thickness and extent. Local aquifers are present in most of these units. Local confining layers, consisting of freshwater shales and mudstones, were formed in the low-energy environments of deltas and swamps. Thickness and lateral continuity of these deposits also are variable.

Regional Aquifers

Two lithologic units within the stratigraphic boundaries of the study area are classified as regional aquifers—the Trout Creek Sandstone Member of the upper Iles Formation and the Twentymile Sandstone Member of the Williams Fork Formation.

Trout Creek Aquifer

The Trout Creek aquifer is the lower of the two regional aquifers, generally occurring from 1,000 to 1,100 ft below the top of the Twentymile Sandstone Member (fig. 9). Thickness averages about 100 ft, with a range from 70 to 150 ft. The aquifer extends from the formational outcrops in the study area, into the subsurface to the west of the study area, and to the north of the Buck Peak anticline. The Yampa River forms a hydrologic boundary along the northern edge of the study *area.* The aquifer overlies about 300 ft of a marine shale that hydraulically isolates it from underlying formations. The upper aquifer boundary is poorly defined by nonmarine mudstones, thin, poorly developed coals, and silty sandstones, all of which can be classified as confining beds. The confining beds vary in thickness and lateral continuity and thus form a leaky confining layer.

Twentymile Aquifer

Physical characteristics of the Twentymile Sandstone Member are nearly identical to those of the Trout Creek Sandstone Member because of their similar depositional histories and environments. However, the Twentymile aquifer is less well defined by the boundaries of the geologic unit than is the Trout Creek aquifer. In the western part of the area, the Williams Fork Formation is much sandier than in the east, and the limits of the Twentymile aquifer are difficult to discern. In the eastern and western parts of the area, the Twentymile Sandstone Member is overlain by interbedded sandstone, coal, and shale of the upper member of the Williams Fork Formation. Because closely overlying and underlying sandstone and coal likely are in hydraulic connection with the Twentymile Sandstone Member, they are here considered to be part of the Twentymile aquifer. The aquifer thus extends from the base of the Lewis Shale to the top of the middle member in the eastern part of the area. In the central and western parts of the area the aquifer limits are

poorly defined but include overlying and underlying hydraulically connected sandstone units. The middle member forms an underlying regional confining layer to the Twenty-mile aquifer. The Lewis Shale forms an overlying confining layer. Both units consist of as much as 600 ft of uniform marine shale in Twentymile Park. The Twentymile aquifer extends laterally from formational outcrops in the area to, and beyond, the hydrologic boundary of the Yampa River and beyond the western limit of the study area.

Local Aquifers

Local aquifers do not underlie the entire area but may have an important effect on the hydrology of some parts of the area. The aquifers are composed of discontinuous beds of coal or sandstone.

Coal Aquifers

Coal beds may form the most important aquifers in the area. Fracturing produces secondary permeability in the coal and can make a coal seam the most permeable bed in a specific area. More important, some coal aquifers are disrupted by mining, allowing aquifer water to come into direct contact with surface water or leachate from spoils.

The metamorphosed nature of coal makes it hydrologically similar to fractured crystalline materials. Limited data are available on fracturing in the local coal beds. In one area on the Fish Creek anticline, core samples indicated extensively fractured Wadge coal. These cleats primarily are conchoidal and oblique to subparallel lineations in the coal. No estimation of fracture density was made (Nancy Driver, U.S. Geological Survey, oral commun., 1980). Because of the limited data, no conclusions were reached on preferential fracture directions, nor was any attempt made to define the fracture pattern. The most likely patterns would be fractures parallel and perpendicular to the original bedding.

In the area east of Hayden Gulch, three coal seams in the lower member of the Williams Fork Formation and one coal seam in the upper member may be significant aquifers. The coal seams are, in ascending order, the Wolf Creek, Wadge, and Lennox coal of the lower member, and the Fish Creek coal of the upper member of the Williams Fork Formation. The Fish Creek coal seam is the only significant coal aquifer in the upper member of the Williams Fork Formation. Erosion has markedly decreased the areal extent of this coal; it occurs only beneath the Lewis Shale in the Twentymile Park area.

Much less information is available for the area west of Hayden Gulch. In general, the number and thickness of coal seams increases toward the west (Bass and others, 1955). A few isolated beds occur in the middle member of the Williams Fork Formation; however, these beds are difficult to correlate from drill hole to drill hole and probably are not laterally continuous. The lower member contains numerous thick seams, several of which correlate for a number of miles. The most widespread and most easily correlated seam west of Hayden Gulch is located 370 ft above the

Trout Creek Sandstone Member. The bed is 10 ft thick and occurs in all drill holes and sections in that interval. The seam appears continuous through much of the central western area, but it eventually splits and cannot be correlated as it approaches the western boundary. A coal seam about 20 to 40 ft below the continuous coal seam also extends through part of the western area; it is about 5 to 10 ft thick and is not as continuous as the overlying seam. This particular seam is typical of the coal seams in the western area and correlates well for about 5 mi.

The upper member of the Williams Fork Formation contains coals that thicken appreciably toward the west. These seams are poorly correlated, indicating limited lateral continuity of coal beds. Most of these seams occur west of Hayden Gulch.

Thin Sandstone Aquifers

These local aquifers are not as important as regional aquifers or the coal aquifers; however, they can yield small quantities of water to wells. This type of aquifer consists of lenticular sandstone beds with a 40- to 60-ft maximum thickness. The aquifers generally are restricted to certain geographic localities and stratigraphic intervals (fig. 9).

Thin sandstone aquifers are most common in the west-central part of the study area. Here, two lenticular sandstone beds are located within the middle member of the Williams Fork Formation. These units are lithologically similar to the regional aquifers and consist of white to gray to light brown, moderately well-sorted, fine-grained quartz arenites that contain chert. The first local sandstone aquifer, 520 ft above the Trout Creek Sandstone Member, extends for about 12 mi and reaches a maximum thickness of 40 ft. The second sandstone aquifer was not entirely defined by drilling. This bed, about 700 ft above the Trout Creek Sandstone Member, seems to thicken to about 60 ft and extends a minimum of 9 mi (fig. 9). Local aquifers in the west central area are lenticular, reach a maximum thickness of about 50 ft, and extend for 10 to 20 mi. Fine-grained siltstone beds that overlie and underlie the sandstones form confining layers for these aquifers.

The thin sandstone and coal aquifers that are in the lower member of the Williams Fork Formation in the eastern part of the area seem to function as a single hydrologic unit and in this report are collectively referred to as the basal Williams Fork aquifer. This local aquifer consists of the three principal coal seams (Wolf Creek, Wadge, and Lennox) interbedded with shale and lenticular sandstone. The basal Williams Fork aquifer extends throughout the eastern part of the area, averages about 300 ft in thickness, and contains about 50 percent shale. The middle marine member of the Williams Fork Formation forms the overlying confining layer. Shale beds within and below the aquifer form a leaky confining layer between the basal Williams Fork aquifer and the underlying Trout Creek aquifer.