Three principal anticlines occur in conjunction with the synclines in the eastern part of the area (pl. 1). The Tow Creek anticline plunges toward the southwest and is the largest of the four anticlines; it has 3,000 ft of vertical relief. The Tow Creek anticline has been stripped to its core in the Mancos Shale, which underlies the Mesaverde Group, hydraulically isolating its eastern and western flanks. The Sage Creek and Fish Creek anticlines are subparallel anticlines southeast of Hayden; both plunge northward. Of the two, the Sage Creek anticline is larger, tighter, and has more vertical relief. The eastern flanks of all three anticlines are much steeper than the western flanks. Outcrops on the eastern flanks commonly dip 30 to 60˚; those on the western flanks commonly dip 10 to 20˚. The steep-ended flanks resulted from compressive stresses produced by the north–south trending Park Range as it formed east of the study area.

Faults are more common east of Dry Creek. Although Bass and others (1955) mapped several surficial fault traces on the western flank of the Tow Creek anticline and to the northeast and south of Twentymile Park, many more faults are known to exist in the subsurface. Difficulty in identifying fault offset and orientation from lithologic or geophysical logs precluded most additional mapping. Numerous northwest-trending faults located south of Twentymile Park exhibit vertical offset of less than 100 ft, as measured in the dip slope south of Foidel Creek. Some of these offsets may result from strike-slip movement on the dip slope as indicated by slickenslides observed in coal mines in this area (Richard Tifft, Twentymile Coal Co., oral commun., 1985). Vertical offset ranges from 0 to 400 ft along the fault, or fault zone, located within the study area to the northeast of Twentymile Park. In addition to offset, faulting in this area has created an extensively fractured zone of rock within or between several fault planes that parallel the fault trace shown on plate 1.

Structural warping and faulting in the eastern part of the study area is indicated by the configuration and lateral extent of the bedrock formations. The top of the Trout Creek Sandstone Member has 3,200 ft of structural relief, between the trough of the Twentymile Park syncline and the southern outcrops of the formation (fig. 15). The basin underlying Twentymile Park contains two structural lows, one on the Twentymile syncline, the other at the southern end of the Tow Creek anticline. The combination of structure and topography produces an irregular, contorted outcrop line that delineates the limit of the water-yielding units considered in this study. The deformed and faulted structure of the Trout Creek Sandstone Member in the Iles Formation is expressed in the structure map of the base of the Twentymile Sandstone Member in the Williams Fork Formation (fig. 16). Structural relief on this surface exceeds 1,700 ft. The two structural low areas in the Trout Creek Sandstone Member also are evident in the structure of the base of the Lewis Shale (fig. 17). Maximum structural relief on the Lewis Shale is about 1,000 ft.

CLIMATIC CONDITIONS

All surface water and ground water in the study area is the result of precipitation. Changes in climatic conditions such as precipitation, temperature, wind, and evaporation can cause large and rapid changes in streamflow and more gradual changes in ground-water flow. The changes

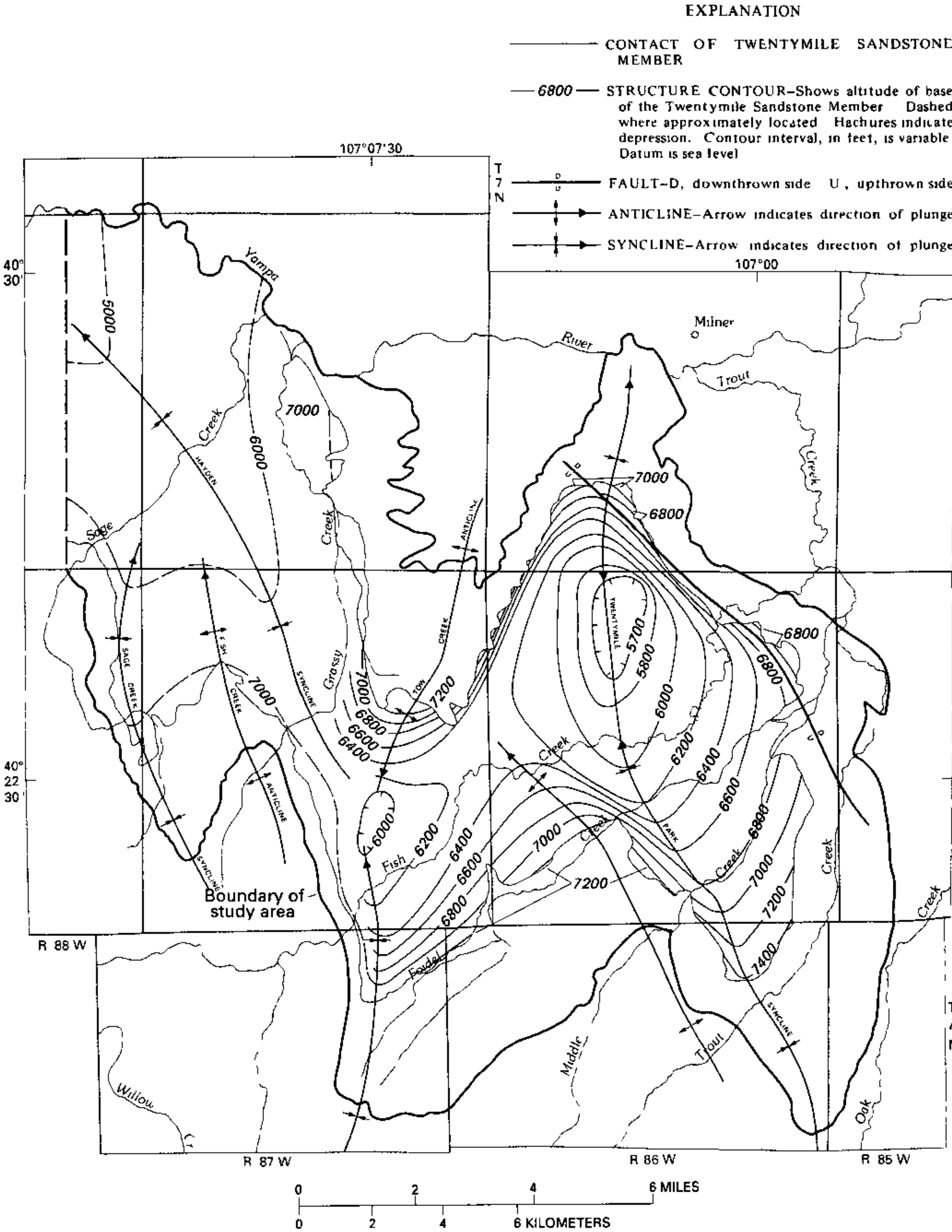

Figure 16.--Structural altitude of the base of the Twentymile Sandstone Member of the Williams Fork Formation in the eastern part of the study area.

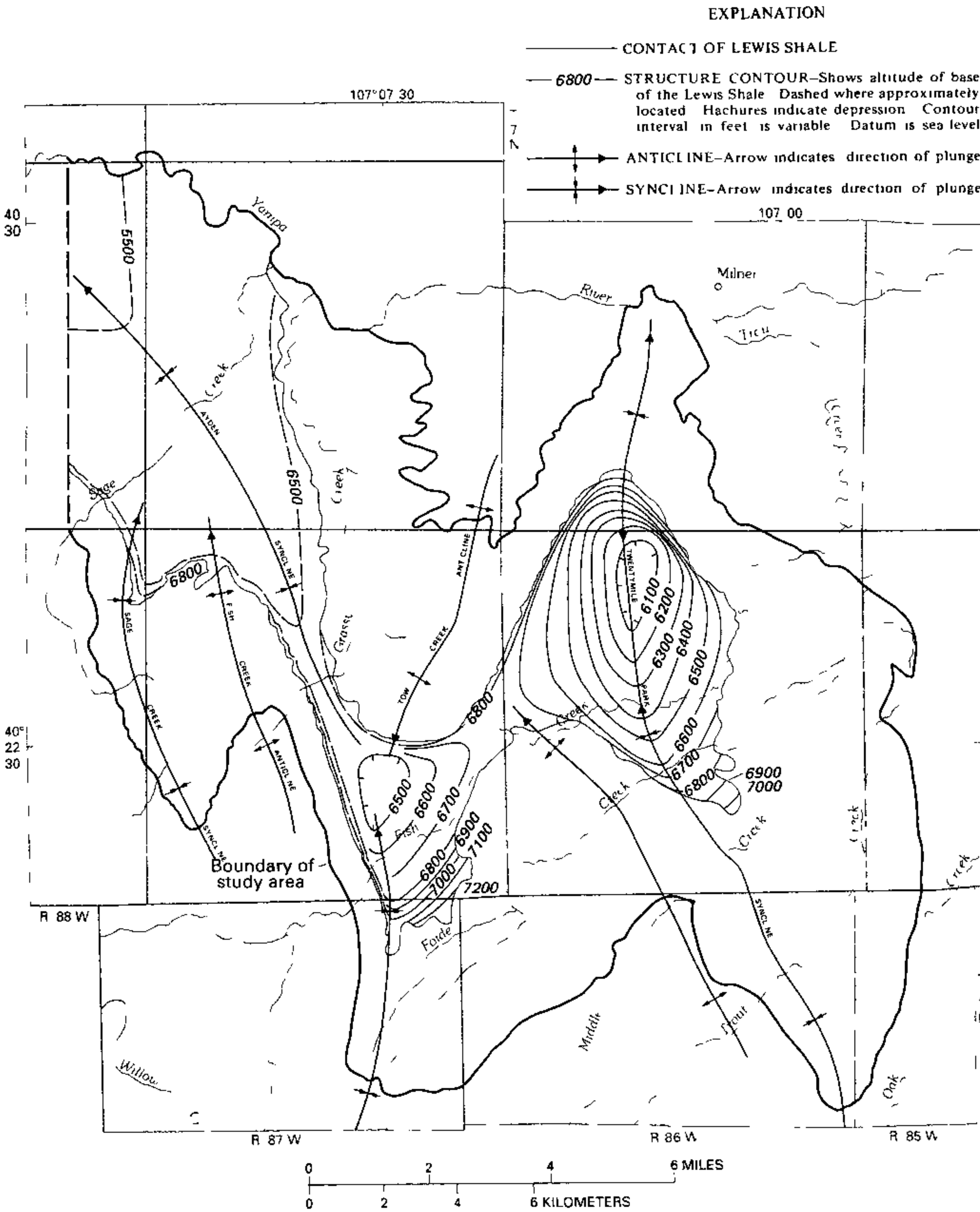

Figure 17.--Structural altitude of the base of the Lewis Shale in the eastern part of the study area.

in ground-water flow primarily occur through changes in ground-water recharge. Climatic conditions affect ground-water recharge by means of changes in precipitation, evapotranspiration, vegetation, weathering, and landform and soil development. Principal climatic factors include precipitation, temperature, wind, and evaporation.

Precipitation

Precipitation on the western slope of the Rocky Mountains primarily is controlled by a diabatic cooling of eastward-tracking Pacific storm systems. As the systems gain altitude in crossing the mountains, the air cools and loses part of its moisture as rain and snow on the western slope and Continental Divide. Precipitation in the study area thus is correlated with altitude. Mean annual precipitation ranges from 13.8 in. at Craig (altitude 6,190 ft) to more than 46 in. near the crest of Quarry Mountain (altitude 8,200 ft) southwest of Steamboat Springs. The relations between precipitation and altitude (fig. 18) are based on data from 9 U.S. Weather Bureau (National Oceanic and Atmospheric Administration, 1890–1987) gages and 20 U.S. Geological Survey or privately operated gages (fig. 19; table 1). Periods of record ranged from 2 years to more than 90 years at Craig and Steamboat Springs. Monthly precipitation data were used to regress the shorter record stations in the eastern part of the study area against the longer record stations to better estimate the 90-year mean annual precipitation (table 1) in this area. Regressions of the 78-year mean annual precipitation at Hayden, Yampa, and Pyramid were not done because the mean for the 78-year period was not significantly different from the mean for the 90-year period. Stations located in the Williams Fork and Willow Creek drainage areas are outside the study area and did not correlate well with the distant longer record stations. As a result, the 18- to 50-year periods of record for the Williams Fork and Willow Creek stations were only used to estimate mean annual precipitation to the southwest of the study area.

The relations between precipitation and altitude for the drainage areas of the Williams Fork, Willow Creek, Grassy Creek, Trout Creek, Fish Creek, and Foidel Creek generally are similar, indicating that precipitation increases moderately with altitude in the southern and eastern parts of the study area. A much more rapid increase in precipitation with altitude occurs along the valley of the Yampa River west of Steamboat Springs. However, along the upper valley of the Yampa River southwest of Steamboat Springs, mean annual precipitation decreases with altitude. These marked differences in the precipitation patterns result from the complex interaction of storm movement and topography. Precipitation increases when topographic features such as the Williams Fork Mountains and the Yampa River valley enhance up-valley movement of storms. Cross-valley movement of storms may produce a rain shadow effect on the leeward slopes such as Twentymile Park, the upper reaches of the Yampa River, and Oak Creek. The resulting relations between precipitation and altitude range in slopes from 0.016 to -0.014 inches of precipitation per foot of altitude depending on the configuration and orientation of topography with respect to principal storm tracks.

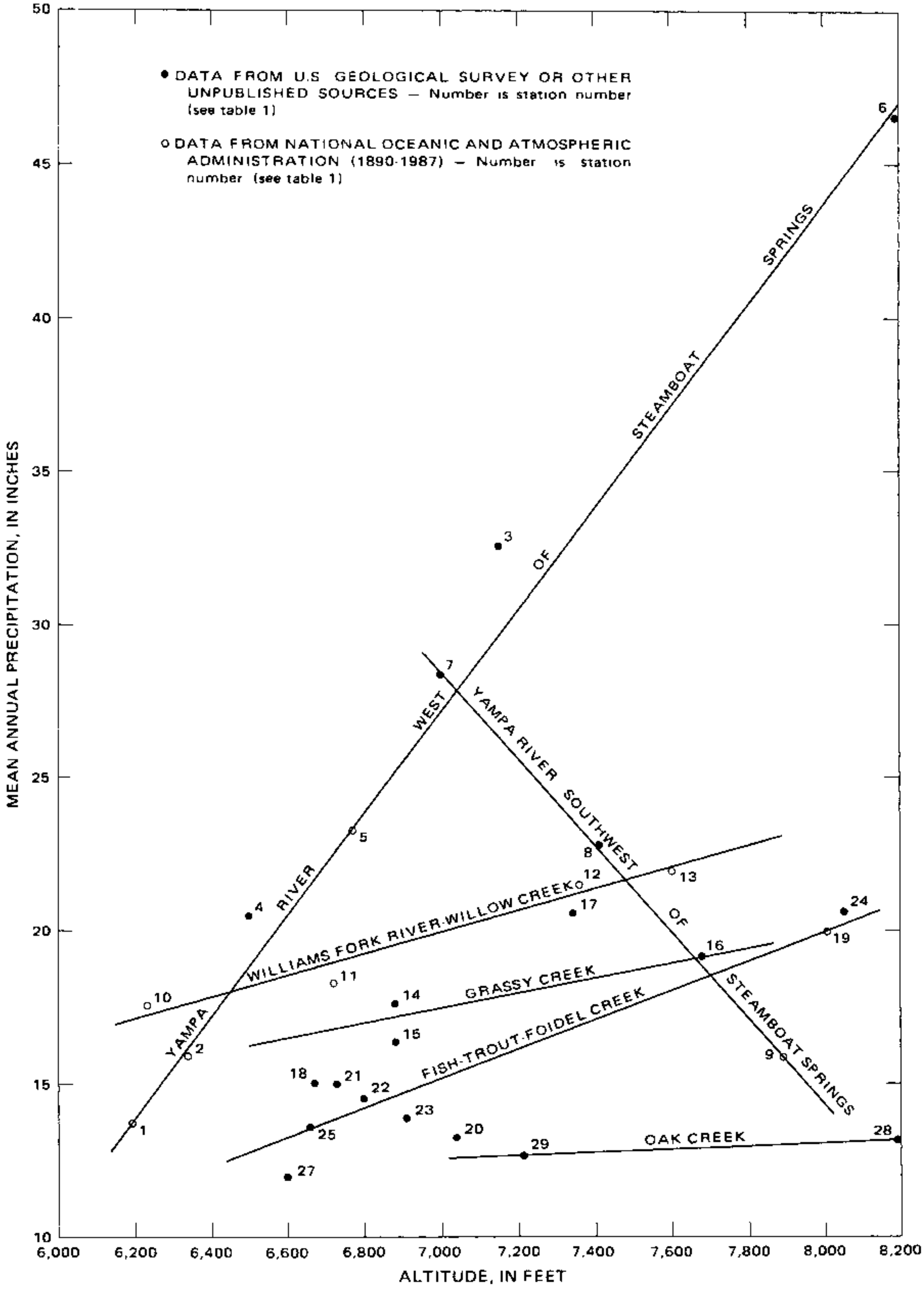

Figure 18.--Relation between mean annual precipitation and altitude.

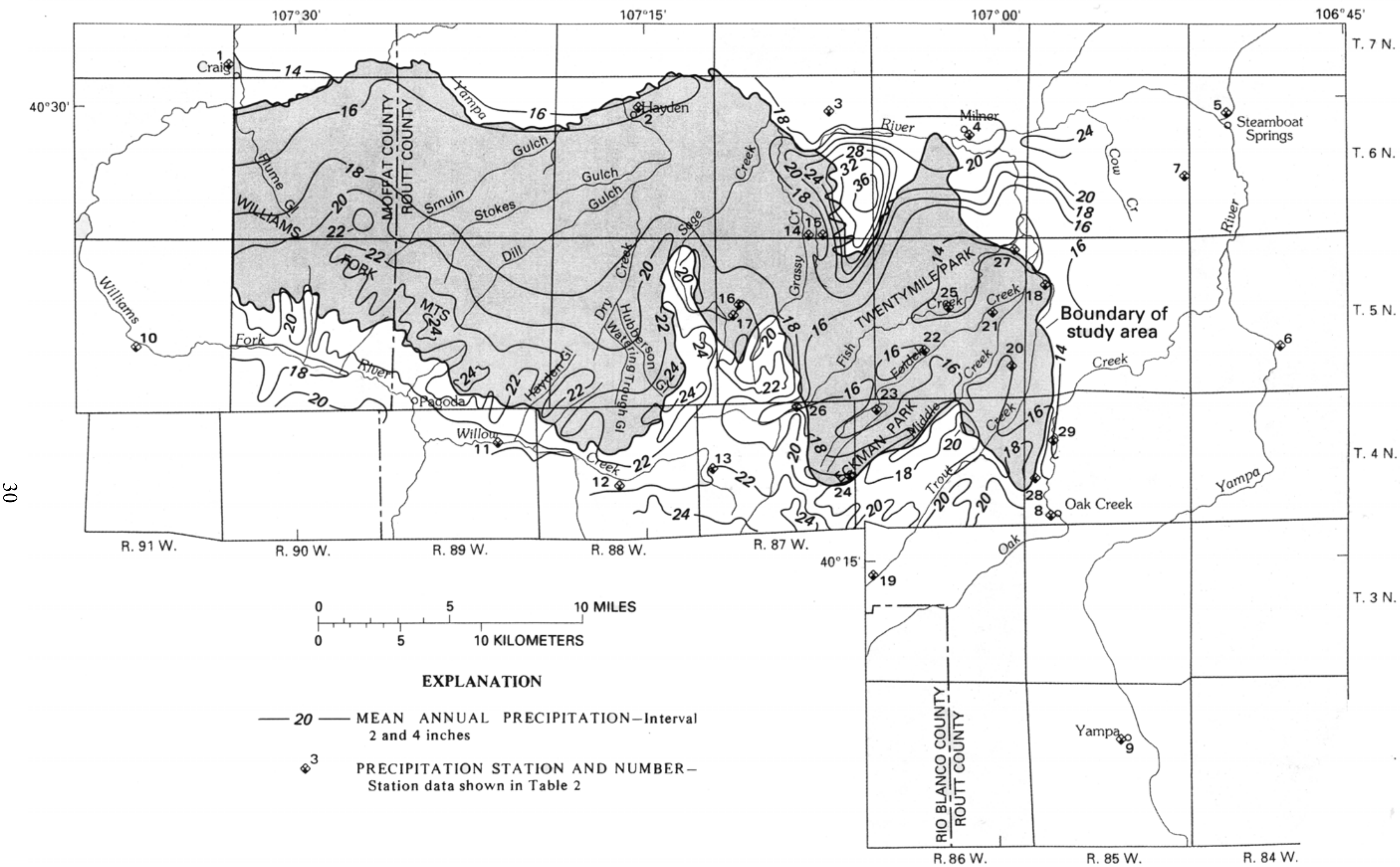

Figure 19.-- Isohyetal map of the study area.

Table 1.--*Precipitation station index* [NR, no regression]

Station number (figs. 18, 19)	Station name	Drainage area	Period of record	Regression station[1]	Regression correlation, R	Mean annual precipi- tation,
1	Craig	Yampa River	1894–1986	NR	NR	13.8
2	Hayden	(west	1909–1986	NR	NR	15.9
3	Mt. Harris	Steamboat	1964–1966	5	([2])	32.6
4	Milner	Springs)	1964–1966	5	([2])	20.5
5	Steamboat Springs	|	1891–1986	NR	NR	23.3
6	Emerald	|	1964–1966	5	([2])	46.6
7	Catamount Lake	Yampa River (southwest	1983–1985	5	0.84	28.4
8	Oak Creek	of Steamboat	1964–1966	5	([2])	22.8
9	Yampa	Springs)	1909–1986	NR	NR	15.9
10	Hamilton	Williams Fork River	1936–1986	NR	NR	17.6
11	Pagoda	|	1890–1912	NR	NR	18.3
12	Willow Creek	Willow	1930–1948	NR	NR	21.5
13	Dunckley	Creek	1905–1909	11	0.66	22.0
14	Seneca M	Grassy Creek	1981–1985	2	0.84	17.6
15	Seneca L	|	1978–1983	2	0.89	16.4
16	Y-6	|	1980–1983	2	0.80	19.2
17	Y-l	Sage Creek	1980–1983	2	0.83	20.6
18	A	Trout Creek	1983–1985	2, 5, 9	0.84	15.0
19	Pyramid	|	1910–1986	NR	NR	20.0
20	Green	|	1980–1983	2, 5, 9	0.85	13.2
21	Lower Foidel	Foidel	1975–1981	2, 5, 9	0.84	15.0
22	2005	Creek	1982–1985	2, 5, 9	0.78	14.5
23	2001	|	1982–1985	2, 5, 9	0.71	13.9
24	Upper Foidel	|	1975–1981	2, 5, 9	0.78	20.6
25	1002	Fish Creek	1982–1983	2, 5, 9	0.78	13.6
26	[3]1001	|	1982–1983	2, 5, 9	0.80	12.6
27	Fish	|	1980–1981	2, 5, 9	0.90	12.0
28	Skyline	Oak Creek	1980–1985	2, 5, 9	0.91	13.2
29	Oak	|	1980–1982	2, 5, 9	0.83	12.6

[1]Mean of three monthly values was used for regression of three stations.
[2]Snow-course data, monthly correlation unavailable.
[3]Data not usable for figure 18.

The isohyetal map (fig. 19) for the area shows the distribution of mean annual precipitation. The map was developed using mean annual precipitation data and relations between precipitation and altitude shown in figure 18. Mean annual precipitation ranges from more than 36 in/yr on the crest of Mount Harris to less than 14 in/yr in Twentymile Park and in the Yampa Valley near Craig. Precipitation along the crest of the Williams Fork Mountains is estimated to range from 20 to 24 in/yr.

The mean monthly precipitation pattern varies from east to west across the study area. The mean monthly pattern for Steamboat Springs is characteristic of conditions in much of the western United States—greater precipitation in the winter, lesser precipitation in the summer. Precipitation patterns at Craig and Hayden are more characteristic of conditions in the study area; precipitation averages about 1 in/mo throughout the year (fig. 20), Orographic effects are pronounced at Steamboat Springs, producing greater winter snowfall than at Craig or Hayden.

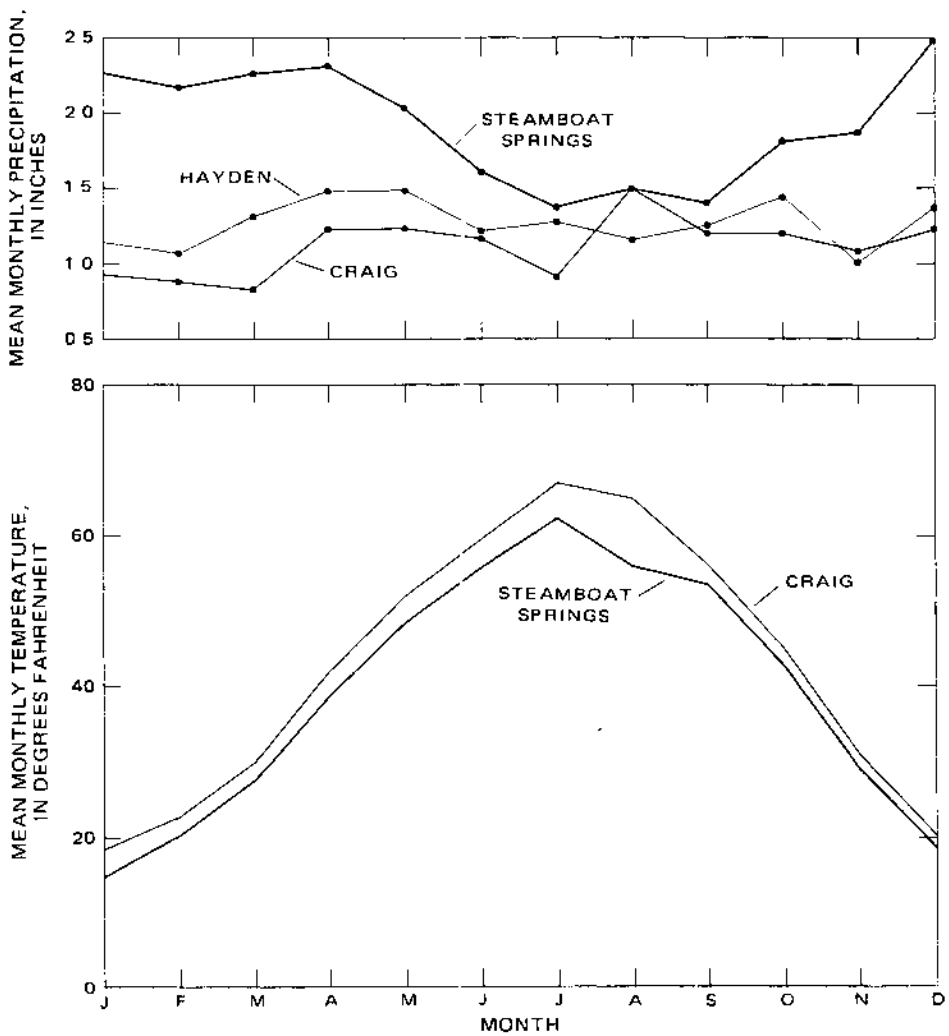

Figure 20.--Mean monthly precipitation and temperature distributions near the study area.

Temperature

Mean temperatures at Steamboat Springs and Craig have a strong seasonal correlation (fig. 20). Both curves have the same general shape but differ by 4 to 6 ˚F. This correlation indicates that factors that control temperature are more uniform in the area than factors that control precipitation.

The normally dry, cloudless conditions that occur at this altitude produce extreme seasonal and diurnal temperature fluctuations. Mean maximum daily temperatures in July range from 80 ˚F in Steamboat Springs to 85 ˚F in Craig. Mean minimum daily temperatures in January throughout the area are approximately -2 ˚F. Diurnal temperatures may fluctuate throughout a rangeof 40 ˚F or more at any time of the year.

Evaporation

Evaporation data for the study area are more limited than temperature or precipitation data. Only seven evaporation sites are maintained in the Colorado River watershed of western Colorado (table 2). Evaporation primarily is a function of available heat, solar insolation, humidity, and wind. At Hayden, the low humidity, intermittent winds, and small number of cloudy days result in a pan evaporation rate from May to October of about 42 in. (table 2). Using a pan coefficient of 0.7 (Kohler and others, 1959), lake evaporation is estimated to be about 29 in., well in excess of mean annual precipitation inmost of the study area. Because information at Hayden is available only for May to October, annual evaporation actually is larger. This results in a precipitation–evaporation deficit, which greatly decreases the volume of water available to recharge the aquifers. No wind and humidity data are available for the study area. In general, the relative humidity is low, increasing only during thundershowers and snowstorms. Actual wind effects are unknown.

SURFACE-WATER HYDROLOGY

Surface-water hydrology data are important to ground-water studies because knowledge of streamflow distribution and timing provides information about when and where recharge or discharge to streams may occur. Surface-water-chemistry data also provide information about ongoing surficial geochemical processes and about the chemical composition of discharging ground water.

Drainage Systems and Streamflow

Drainage systems and streamflow are affected by origin and geographic location of the stream. The Yampa River and the Williams Fork are the two major streams that drain the study area. These streams are perennial throughout the area and have a mean annual flow of 1,100 ft^3/s (Yampa River at Hayden) and 44 ft^3/s (Williams Fork at Pagoda). The steams are located near the northern and southern periphery of the area and flow nearly due west across existing structural trends: both streams probably are antecedant and superposed (Hunt, 1969). Most of