SECTION 4.0
ENVIRONMENTAL ASSESSMENT

4.1 BASELINE DESCRIPTION

4.1.1 Climatology and Air Quality

The Crow Reservation is located in the south-central part of Montana, just southeast of the town of Billings. The reservation covers a large area—1,554,254 acres—and is characterized by rolling plains and complex terrain with elevations ranging from 2,900 feet at Hardin to above 7,000 feet in the Bighorn Mountains. Since climate is dependent on terrain and elevation, the climate within the reservation correspondingly demonstrates some variability depending on location and elevation.

For the purposes of this evaluation, climatic data collected at Billings, Colstrip, Sarpy Creek, Decker, Hardin, Crow Agency, Busby, Wyola, Montana, and Sheridan, Wyoming, and other locations were used to identify the climatic conditions that exist on the reservation. The individual sites were not characterized according to climate because no site-specific data were available and because all the sites are in close proximity to each other with relatively the same elevations, 3,000 to 3,700 feet. The climatic factors necessary for environmental and engineering feasibility analysis are expected to be defined for all sites using the existing information.

4.1.1.1 Regional Climate

The Crow Reservation is located in the transition zone between the Northern Great Plains and the Rocky Mountains. It has a climate which takes on some of the characteristics of both regions. The climate of the reservation area has been classified as a continental semiarid steppe with the associated characteristics of large range of temperatures, clear skies, and low relative humidities. Since the area is in the path of a major storm track, frequent passages of storm systems occur in the winter. The other climatic controls which influence the climate on the reservation are (1) location with respect to mountain ranges, (2) location with respect to large bodies of water, and (3) elevation. Since the reservation is located downwind from the Rocky Mountains to the west, moisture available to the reservation is reduced in the winter, thereby causing arid conditions. Also, the mountain ranges to the west tend to shield some weather systems from the reservation; therefore, moderating the climate to some degree on the reservation. The great distance to water bodies and the relatively moderate elevation of the area tend to foster variations in temperature and precipitation which can occur not only from day to day, but also from year to year.

For the candidate plant sites, the annual precipitation is roughly 12 to 15 in., with most of the average annual precipitation occurring in the spring and early summer months. The period of least precipitation is during the winter from November through February, although heavy snows of 6 to 12 in. can occur during these winter months. The snowfall rate at Hardin averages about 33 in./yr. Thunderstorms, which occur about 30 days of the year, are restricted mainly to the warm growing season, May through September, and occasionally are accompanied by strong gusty winds and occasional hail. Fog and ice storms seldom occur and are usually of short duration.

The climate in the winter is influenced by the storms generated by the Aleutian Low and the subsequent cold artic air outbreaks from western Canada that usually follow such storms. Cold front passages with high winds and snow followed by cold subzero air masses can result. Winter is usually cold, with the average temperature in January of about 22°F. The winter cold periods are usually initiated by moderately strong north-to-northeast winds and snow, with the coldest period coming the first or second night after the snow ends and the sky clears. Blizzard conditions with intense temperatures may drop to -50°F during these cold waves. The storm systems and cold air usually move through the region rapidly and can be replaced by a week to several weeks of relatively mild weather. During the winter and spring months, cold periods sometimes are followed by strong westerly winds (Chinook) which are relatively warm. Chinook conditions are associated with the formation of a high pressure area west of the mountains. Occasionally when many of the severe cold waves pass f. r to the east, a mild winter is experienced.

Spring and summer climatic conditions on the reservation are primarily influenced by the Bermuda High in the Atlantic Ocean which forces warm, humid air from the Gulf of Mexico into the Great Plains. More than half of the annual precipitation occurs during these months. The spring brings a period of frequent, intense variability in the weather. Precipitation in the spring can occur either as rain or snow, although snow usually will not accumulate to any great degree. Summer temperatures up to 105°F have been recorded in the area; however, prolonged periods of hot temperatures normally do not last. The average temperature in July is around 72°F. Summer evening and morning temperatures are usually comfortable due to the general nighttime cooling caused by relatively low humidities and clear skies.

The fall months are also characterized by climate variability with the potential for both warm, pleasant weather and cold winter weather. The change to severe winter weather does not, on the average, occur before the middle of November, but there have been years when the more severe type of winter weather has occurred as early as September or has been as late as December. The snows which occur during the early fall months seldom accumulate and stay on the ground for any appreciable period.

4.1.1.2 Meteorology

Temperature

Temperature data have been collected at a number of different locations on and near the reservation. For this analysis, long-term temperature information collected at Billings, Colstrip, Montana, and Sheridan, Wyoming, are used. In addition, short-term data for Sarpy Creek, Hardin, Crow Agency, Wyola, Busby, Youngs Creek, and Lovell, Wyoming, were used to supplement the longer-term records.

The long-term temperature records for the U.S. Weather Service operated stations in Billings, Colstrip, and Sheridan are shown in Tables 4.1.1-1, 4.1.1-2, and 4.1.1-3. The general temperature characteristics of these three sites are the same with mean

TABLE 4.1.1-1

CLIMATOLOGICAL TEMPERATURE SUMMARY FOR COLSTRIP, MONTANA, 1941-1970

	Temperatures, °F					Number of Days			
Month	Daily Max	Daily Min	Monthly Mean	Record High	Record Low	T Max 90°	T Max 32°	T Min 32°	T Min 0°
Jan	34.2	7.7	21.0	67	-40	0	11	30	10
Feb	39.8	13.9	26.9	70	-31	0	7	27	6
Mar	45.8	18.9	32.3	80	-28	0	5	22	3
Apr	59.3	30.1	44.7	87	3	0	0	19	0
May	69.2	39.4	54.3	96	13	1	0	5	0
Jun	77.6	46.7	62.7	102	28	3	0	0	0
Jul	89.2	53.8	71.5	107	34	17	0	0	0
Aug	88.1	52.1	70.1	111	33	15	0	0	0
Sep	75.9	42.0	59.0	102	18	4	0	4	0
Oct	64.8	32.4	48.6	94	7	0	0	15	0
Nov	47.5	21.1	34.3	79	-32	0	3	26	2
Dec	38.2	12.8	25.5	71	-35	0	9	30	6
Year	60.8	31.0	45.9	111	-40	40	35	184	27

Source: Bureau of Indian Affairs, 1979.

TABLE 4.1.1-2

CLIMATOLOGICAL TEMPERATURE SUMMARY FOR SHERIDAN, WYOMING, 1940-1979

	Temperature, °F									Mean Number of Days			
Month	Daily Max.	Daily Min	Monthly	Record Highest	Year	Record Lowest	Year	Heating	Cooling	T Max 92°	T Max 32°	T Min 32°	T Min 0°
Jan	33.5	8.5	21.0	70	1974	-35	1963	1364	0	0	16	30	12
Feb	38.0	13.8	25.9	73	1951	-31	1949	1095	0	0	9	28	4
Mar	43.1	18.9	31.0	77	1978	-23	1965	1054	0	0	6	28	2
Apr	56.3	30.9	43.6	87	1946	-2	1975	642	0	0	1	20	*
May	66.0	40.2	53.1	95	1960	13	1954	375	7	0	0	6	0
Jun	74.3	47.8	61.1	100	1974	27	1951	168	51	2	0	*	0
Jul	86.1	54.6	70.4	106	1954	35	1971	28	195	8	0	0	0
Aug	85.3	53.0	69.2	105	1949	34	1966	31	161	10	0	0	0
Sep	72.9	42.9	57.9	100	1940	15	1965	245	32	2	0	4	0
Oct	62.5	33.1	47.8	91	1963	1	1971	533	0	0	1	17	0
Nov	46.0	20.8	33.4	78	1975	-25	1959	948	0	0	5	29	2
Dec	37.6	13.4	25.5	71	1941	-30	1972	1225	0	0	12	30	7
Year	58.5	31.5	45.0	106	Jul 1954	-35	Jan 1963	7708	446	22	49	192	27

Source: U.S. Department of Commerce, 1979b.

TABLE 4.1.1-3

CLIMATOLOGICAL TEMPERATURE SUMMARY FOR SHERIDAN, WYOMING, 1934-1979

	Temperature, °F									Mean Number of Days			
Month	Daily Max.	Daily Min	Monthly	Record Highest	Year	Record Lowest	Year	Heating	Cooling	T Max 92°	T Max 32°	T Min 32°	T Min 0°
Jan	31.2	12.5	21.9	68	1953	-30	1937	1336	0	0	16	28	10
Feb	37.1	17.7	27.4	72	1961	-38	1936	1053	0	0	8	25	3
Mar	42.1	23.1	32.6	79	1978	-19	1951	1004	0	0	6	24	2
Apr	55.8	33.4	44.6	87	1962	-5	1936	612	0	0	1	14	0
May	65.7	43.3	54.5	96	1935	14	1954	333	8	*	0	2	0
Jun	73.7	51.5	62.6	102	1966	21	1969	131	59	3	0	*	0
Jul	85.6	58.0	71.8	106	1937	41	1972	10	220	12	0	0	0
Aug	83.8	56.3	70.1	105	1961	40	1939	15	173	11	0	0	0
Sep	71.3	46.5	58.9	100	1950	25	1972	221	38	2	0	1	0
Oct	61.0	37.5	49.3	90	1963	3	1971	487	0	*	1	8	0
Nov	45.0	26.4	35.7	73	1975	-22	1959	879	0	0	6	23	1
Dec	35.8	17.7	26.8	69	1957	-26	1964	1184	0	0	12	28	4
Year	57.3	35.3	46.3	106	Jul 1937	-38	Feb 1936	7265	498	28	49	151	191

Source: U.S. Department of Commerce, 1979a.

January temperatures around 21 to 22°F and the mean July temperatures of 70 to 72°F. Record high temperatures have exceeded 105°F at all sites. However, the number of days where maximum and minimum temperatures occur can differ from site to site. The mean number of days where the temperature has exceeded 90°F is higher at Colstrip than at the other station sites. Similarly, Colstrip has the least number of days recorded when the maximum daily temperature was below 32°F. About one-half of the days of the year recorded a temperature at or below 32°F in the area. The general temperature characteristics of these three station sites would be expected to be exhibited on the Crow Reservation at comparable elevations (i.e., 3,000 to 4,000 feet). (References 5, 63, 64).

The monthly mean temperature information for locations on or near the reservation are shown in Table 4.1.1-4. As indicated from the data presented in Table 4.1.1-4, the local monthly temperatures do not vary substantially from location to location. Although the Billings temperature data show a slightly higher mean monthly temperature than Hardin, Crow Agency, or Wyola, the Billings temperature data seem to be generally representative of the reservation. (Reference 65).

Freeze Data. Temperature data indicate the number of days available to grow vegetation without encountering a freeze. The mean number of days between the mean date of the last spring occurrence of a temperature below or equal to 32°F and the mean date of the first fall occurrence of a temperature below or equal to 32°F is called a "growing season." The growing season data for a number of locations, either on or near the Crow Reservation, are shown in Table 4.1.1-5. The data indicate that the "growing season" on the reservation for altitudes of 3,000 to 4,000 feet ranges from 105 to 125 days. Table 4.1.1-6 illustrates more detailed information for Billings on freeze threshold data at temperatures lower than 32°F. (References 16, 65).

Degree Days. Table 4.1.1-7 illustrates, by month, the average heating and cooling degree-days (based on the 65°F standard) for Billings. January has the largest heating degree-days and July the largest cooling degree-days. The Billings area requires over 7,200 heating degree-days annually. (Reference 63).

TABLE 4.1.1-4

MEAN MONTHLY TEMPERATURES FOR STATIONS ON OR NEAR THE CROW RESERVATION

	Billings Airport	Busby	Crow Agency	Hardin	Huntley	Wyola	Youngs Creek
Jan	21.9	17.6	19.2	18.9	19.0	22.1	16.0
Feb	27.4	23.8	26.2	25.9	26.0	27.3	-
Mar	32.6	30.6	33.0	32.5	32.4	32.1	-
Apr	44.6	43.6	45.8	45.3	44.7	44.7	-
May	54.5	53.3	55.7	55.8	55.0	53.8	-
Jun	63.5	61.1	63.1	63.3	62.4	61.1	-
Jul	71.8	69.9	71.5	-	70.6	69.6	72.0
Aug	70.0	68.3	69.8	-	68.9	68.2	-
Sep	58.9	57.0	58.7	-	58.1	57.6	-
Oct	49.3	46.7	48.5	-	48.1	48.3	-
Nov	35.7	31.7	34.2	-	34.0	34.4	-
Dec	25.0	22.8	24.6	-	24.4	26.3	-
Annual	46.4	43.9	45.9	-	45.4	45.5	44.0

- Indicates data missing or not available.

Source: U.S. Department of Commerce, 1980.

TABLE 4.1.1-5
MEAN FREEZE DATA FOR VARIOUS LOCATIONS ON OR NEAR THE CROW RESERVATION

Station	Last Spring Frost	First Fall Frost	Growing Season (days)	Years of Record
Busby	May 29	September 14	209	29
Crow Agency	May 17	September 19	125	28
Wyola	June 26	September 15	105	16
Billings Water Plant	May 15	September 24	132	30
Huntley	May 11	September 25	137	—
Lovell, Wyoming	May 16	September 18	125	—
Sheridan, Wyoming	May 15	September 22	130	—
Youngs Creek	—	—	105	—

-- Indicates data missing or not available.

Source: U.S. Department of Commerce, 1980.

TABLE 4.1.1-6
BILLINGS FREEZE DATA

Freeze Temperature	Mean Date of Last Occurrence	Mean Date of Last Occurrence	Mean Number Between Dates
32	5/15	09/24	132
28	4/29	10/09	163
24	4/17	10/18	185
20	4/09	11/01	206
16	3/29	11/12	228

Source: Cordell, 1971.

TABLE 4.1.1-7
MEAN AVERAGE DEGREE-DAYS
BILLINGS, MONTANA

Month	Normal Degree-Days (Base 65°F) Heating	Cooling
Jan	1336	0
Feb	1053	0
Mar	1006	0
Apr	612	0
May	333	8
Jun	131	59
Jul	20	220
Aug	15	173
Sep	221	38
Oct	487	0
Nov	879	0
Dec	1184	0
Year	7265	498

Source: U.S. Department of Commerce, 1979

Precipitation and Humidity Characteristics

Total Precipitation. The average annual precipitation on the Crow Reservation and the ceded area has been developed from information collected at the various monitoring sites and is shown in Figure 4.1.1-1. For the proposed plant sites, the annual precipitation is roughly 12 to 15 inches. (Reference 52).

The amount of precipitation varies with the time of the year. The average monthly precipitation values are shown in Table 4.1.1-8. Also, Figure 4.1.1-2 illustrates the same monthly precipitation information selected from the data in Table 4.1.1-8. A very similar pattern for all the monitoring sites is noted, leading one to conclude that the locations of the proposed synfuels plant will have precipitation characteristics very similar to those of Hardin or Billings. The data in Tables 4.1.1-6, 4.1.1-7, and 4.1.1-8 illustrate the fact that approximately 75 percent of the precipitation occurs during the growing season. Most of the precipitation falls as rain. The driest months of the year are typically November through February.

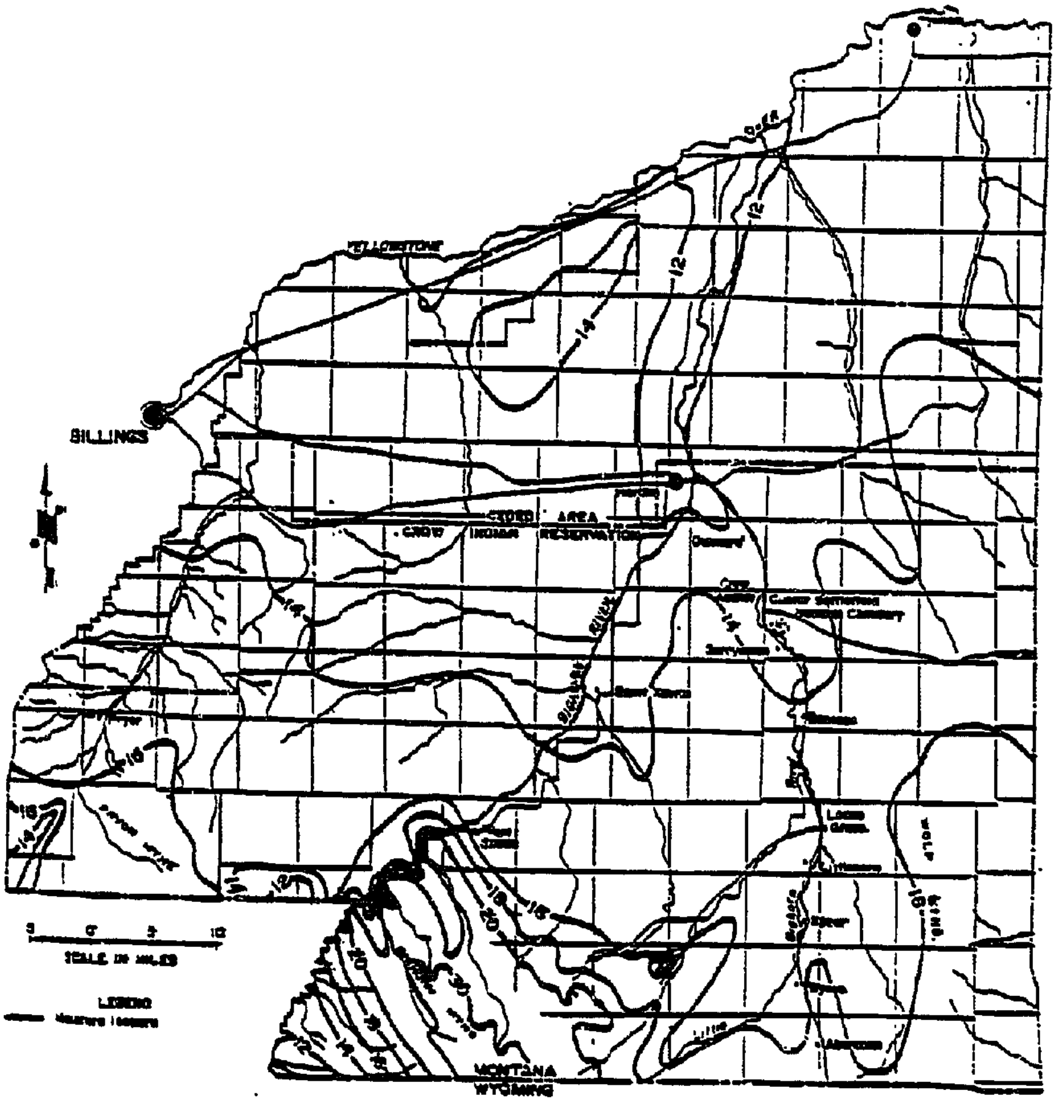
Available records indicate that annual precipitation can vary substantially from year to year. For example, using a 39-year record, Billings' lowest record of precipitation was 7.90 in. in 1948 and was 26.80 in. in 1978. Table 4.1.1-9 illustrates the values of other monitoring sites.

Snowfall. Snowfall amounts vary within the Crow Reservation. Table 4.1.1-10 indicates the average mean snowfall at different monitoring sites. The data indicate that Hardin receives the least snowfall of all the areas monitored. Data from Billings indicate that the amount of snowfall is evenly distributed over the months of November through April. At Billings, the annual snowfall has ranged, over the past 10 years, from 26.2 in. in 1943 to 93.8 in. in 1954. Measurable snowfall has been recorded in Billings as early as September and as late as June.

FIGURE 4.1.1-1

AVERAGE ANNUAL PRECIPITATION ON

THE CROW RESERVATION AND CEDED AREA



Source: Rocky Mountain Research, 1977

TABLE 4.1.1-8

RAINFALL, INCHES, CROW RESERVATION

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Busby	0.58	0.45	0.65	1.38	2.21	2.04	1.15	1.33	1.36	0.05	0.60	0.61	13.97
Crow Agency	0.64	0.58	0.93	1.09	2.05	2.97	0.71	1.01	1.55	1.07	0.78	0.69	14.87
Wyola	0.77	0.67	1.04	2.11	2.45	2.75	0.92	0.93	1.52	1.09	0.50	0.73	15.88
Lovell, Wyoming	0.42	0.34	0.62	1.12	0.82	0.87	0.59	0.48	0.69	0.51	0.33	0.28	6.52
Sheridan, Wyoming	0.69	0.77	1.21	2.45	2.99	1.07	0.95	1.28	1.02	0.92	0.69	0.51	16.16
Billings	0.48	0.43	0.60	1.39	1.70	2.90	0.90	1.03	1.41	0.77	0.59	0.51	14.15
Hardin	0.48	0.43	0.60	1.39	1.70	2.90	0.90	1.03	1.41	0.77	0.59	0.51	12.71

Source: Rocky Mountain Research, 1977.

<u>FIGURE 4.1.1-2</u>

<u>AVERAGE MONTHLY PRECIPITATION</u>

<u>FOR SELECTED SITES</u>

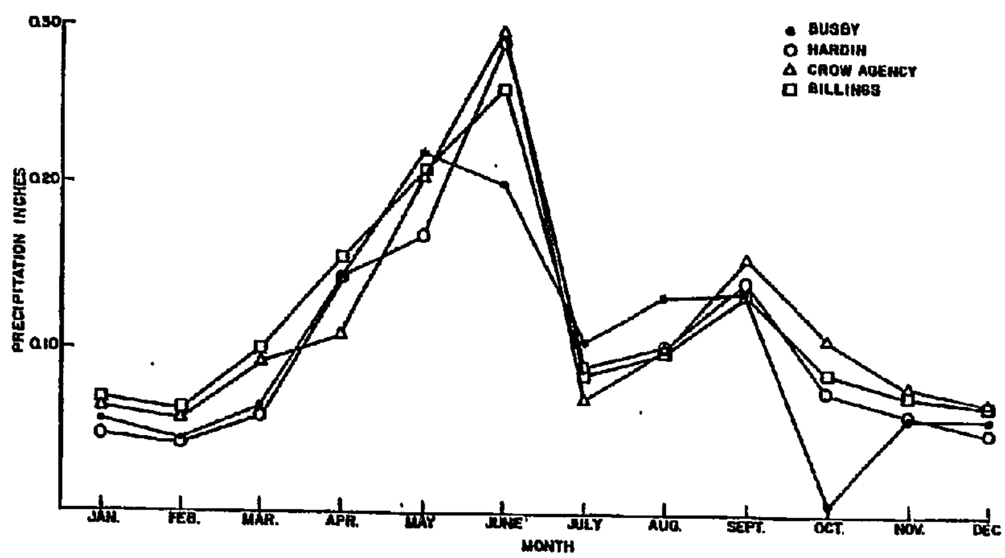


TABLE 4.1.1-9

PRECIPITATION DATA FROM SELECTED SITES

	Wyola	Sheridan[a]	Busby	Crow Agency	Hardin	Billings[b]
Annual Average Precipitation, Inches	15.9	16.2	14.0	14.9	12.7	14.2
Annual Precipitation Range, Inches	8.4-17.2	8.2-24.6	6.9-16.4	8.4-21.2	7.3-17.2	7.9-26.8
Approximate elevation, feet above mean sea level	3700	3900	3300	3100	2900	3570

TABLE 4.1.1-10

SNOWFALL DATA FROM SELECTED SITES

	Wyola	Sheridan[a]	Busby	Colstrip	Hardin	Billings[b]
Annual Mean Snowfall, Inches	60.2	66.9	44.5	45.8	33.3	56.5

SOURCES: BIA-PSG, 1975.
[a]Sheridan data source (1941-1979): U.S. Department of Commerce, 1979a.
[b]Billings data source (1939-1979): U.S. Department of Commerce, 1979b.

Evaporation. Evaporation data have been collected at a number of different locations on and near the reservation. Although some of the data vary, the generally accepted evaporation rate for the area, identified in all the previous work, is 40 in./year during the months of May through October.

Fog. Fog data are only available from the major Weather Service Stations of Billings and Sheridan. However, that data should be representative of the reservation. Heavy fog, which is defined as fog which reduces visibility to 1/4 mile or less, occurred in Billings on the average of 18 days/year and in Sheridan 6 days/year. Therefore, heavy fog would be expected to occur infrequently on the reservation.

Humidity. Similar to other arid continental climates which are removed from large bodies of water, the data collected in the area indicate that the relative humidity in the area is generally low. Long-term, relative humidity data are available from Billings, Sheridan, and Colstrip; and a short-term record has been developed for Sarpy Creek. The data for Billings are representative of all that was reviewed, shown in Table 4.1.1-11. Humidities reach as low as 5 to 10 percent frequently during the year. The annual average relative humidity expected on the proposed sites would be 50 to 60 percent. (Reference 63).

Precipitation Frequency. On the average, most of the precipitation occurs with thunderstorms or major snow storms. About three-fourths of the annual precipitation falls during the April to September growing season. Tables 4.1.1-12 and 4.1.1-13 illustrate the precipitation frequency for Billings and Sheridan. The snowfall data are probably not representative of what is occurring on the reservation. The maximum rainfall in a 24-hour period for Billings was 3.9 in. in April 1978 and the maximum 24-hour snowfall was 23.7 in. in 1955. Thunderstorms would be expected to occur approximately 30 days/year although the frequency and magnitude of the storm can vary substantially from location to location and from one year to the next.

TABLE 4.1.1-11

MEAN RELATIVE HUMIDITY (%)

BILLINGS, MONTANA[a]

	Local Time			
	0500	1100	1700	2300
Jan	64	61	58	64
Feb	65	58	53	64
Mar	67	53	46	61
Apr	68	50	42	60
May	69	48	43	60
Jun	71	47	41	59
Jul	63	39	31	49
Aug	60	40	30	46
Sep	66	48	38	54
Oct	63	49	41	55
Nov	66	58	54	62
Dec	64	60	57	63
Year	66	51	44	58

[a]Based on records from 30 years prior to and including 1979.
Source: U.S. Department of Commerce, 1979a.

TABLE 4.1.1-12

AVERAGE AND EXTREME PRECIPITATION EVENTS, BILLINGS, MONTANA

Month	Normal Inches	Max. Monthly, Inches	Year	Min. Monthly, Inches	Year	Max. in 24 Hrs., Inches	Year	Max. Monthly, Inches	Year	Snow, Max. in 24 Hrs., Inches	Year	Number of Days: Precipi-tation (0.1 in. or more)	Number of Days: Snow, Ice Pellets (01. in. or more)	Number of Days: Thunder-Storm
Jan	0.70	2.35	1972	0.04	1941	1.41	1972	27.7	1963	16.6	1972	8	4	*
Feb	0.64	1.77	1978	0.05	1977	0.61	1952	22.4	1978	9.0	1944	7	3	*
Mar	1.01	2.70	1954	0.13	1936	1.01	1973	27.6	1935	10.5	1964	9	3	*
Apr	1.56	4.42	1955	0.36	1962	3.19	1978	42.3	1955	23.7	1955	10	2	1
May	2.08	6.97	1978	0.53	1937	2.83	1952	7.7	1967	5.7	1967	11	*	4
Jun	2.61	7.64	1944	0.24	1961	2.78	1937	2.0	1950	2.0	1950	11	*	8
Jul	0.87	3.12	1958	0.[illegible]	1976	1.87	1958	0.0		0.0		7	0	8
Aug	1.00	3.50	1965	0.05	1955	2.47	1965	0.0		0.0		6	0	6
Sep	1.39	4.99	1941	0.06	1965	2.19	1966	6.3	1962	6.3	1962	7	*	2
Oct	0.88	3.80	1971	0.02	1948	1.98	1974	23.1	1949	10.0	1949	6	1	*
Nov	0.73	2.34	1978	T[a]	1954	1.37	1959	25.2	1978	15.3	1959	6	2	0
Dec	0.68	2.00	1973	0.05	1957	0.96	1978	28.8	1955	13.7	1978	7	3	*
Year	14.15	7.64	1944	T[a]	1954	3.19	1978	42.3	Apr 1955	23.7	1955	95	19	29

aT = trace. Source: U.S. Department of Commerce, 1978a.

TABLE 4.1.1-13

AVERAGE AND EXTREME PRECIPITATION EVENTS, SHERIDAN, WYOMING

Month	Normal, Inches	Max. Monthly, Inches	Year	Min. Monthly, Inches	Year	Max. in 24 Hrs., Inches	Year	Max. Monthly, Inches	Year	Snow Max. in 24 Hrs., Inches	Year	Number of Days: Precipitation (0.1 in. or more)	Number of Days: Snow, Ice Pellets (01. in. or more)	Number of Days: Thunder-Storm
Jan	0.69	1.79	1972	0.12	1961	1.01	1972	26.3	1977	13.5	1972	9	4	0
Feb	0.77	2.68	1955	0.08	1977	1.10	1955	35.0	1955	11.0	1955	9	4	*
Mar	1.21	3.26	1946	0.14	1978	2.25	1946	36.8	1954	13.3	1946	11	4	0
Apr	2.12	4.80	1963	0.60	1960	3.84	1948	39.6	1955	26.7	1955	11	3	1
May	2.45	6.80	1978	0.30	1958	2.04	1956	12.5	1979	10.9	1979	12	1	5
Jun	2.99	9.54	1944	0.28	1971	3.44	1944	4.0	1969	4.0	1969	11	*	10
Jul	1.07	3.78	1958	0.87	1959	2.28	1948	0.0		0.0		7	0	10
Aug	0.95	3.02	1968		1979	1.71	1943	0.0		0.0		7	0	7
Sep	1.28	3.08	1951	0.06	1964	1.33	1947	9.5	1970	5.5	1970	7	*	3
Oct	1.02	3.16	1971	0.02	1965	1.91	1974	14.8	1971	8.4	1977	7	1	*
Nov	0.92	2.23	1942	0.15	1951	0.87	1978	25.8	1964	12.0	1942	8	2	*
Dec	0.69	2.03	1955	0.23	1979	0.54	1946	27.6	1955	8.6	1960	9	4	0
Year	16.16	9.54	1944	T[a]	1970	3.84	1948	39.6	Apr 1955	26.7	1955	108	35	36

aT = trace. Source: U.S. Department of Commerce, 1979b.

Data collected at Colstrip indicate the same general precipitation frequency characteristics. Table 4.1.1-14 illustrates the mean number of days with precipitation greater or equal to 0.10 in. and 0.[illegible] in. at Colstrip. The greatest potential for intense precipitation occurs in the spring and early summer months. Snowfall data in Colstrip are available and indicate that deep snow occurs infrequently in the region with no more than 10 in. recorded in any day between 1946 and 1963 (Bureau of Indian Affairs, 1976). Snow accumulation is not usually great in the area due to minimal snowfall rates and occasional thawing periods. (Reference 6).

The estimated (statistical) return period for maximum precipitation events has been calculated for the Sarpy Creek area and the results are shown in Table 4.1.1-15. For a 100-yr return period (i.e., for the second time the event occurs in 100 years), the maximum rate for 24 hours is 3.8 in. (Reference 6).

Wind

Wind Direction. Surface wind data have been collected at Sarpy Creek, the Youngs Creek area, Colstrip, Billings, Montana, and Sheridan, Wyoming. The records at Billings and Sheridan are more long term and complete than those collected at other sites. Wind roses (i.e., diagrams which show the prevailing wind directions and the frequency of occurrence) for four representative sites are indicated in Figure 4.1.1-3. The four sites are characterized by differing wind direction patterns. Most of the data demonstrate a strong prevailing westerly sector wind characteristic from the northwest (Colstrip) to the west (Youngs Creek) to the southwest (Billings). Sarpy Creek wind is more uniform with a preference for the southern and western directions. (References 63, 64, 66).

The variations in the wind patterns for these sites are due primarily to the dominating effect of local conditions (i.e., terrain). Surface wind characteristics are particularly sensitive to local river drainage patterns. The Billings data illustrate the effect of the Yellowstone River drainage pattern in the wind direction. It is difficult to ascertain the prevailing surface wind situation for the proposed sites on

TABLE 4.1.1-14

MEAN NUMBER OF DAYS WITH PRECIPITATION

0.10 AND 0.50 INCH, COLSTRIP, MONTANA

	J	F	M	A	M	J	J	A	S	O	N	D	Yr
0.10 Inch	1	2	2	5	6	6	2	4	2	2	3	3	37
Years of record	7	7	7	7	7	7	7	7	7	7	7	7	7
0.50 Inch	0	0	*	1	1	2	1	1	*	*	*	*	6
Years of record	10	10	10	10	10	10	10	10	10	10	10	10	10

*Less than one-half day.

Source: Bureau of Indian Affairs, 1976.

FIGURE 4.1.1-3

SELECTED WIND ROSES FOR THE CROW RESERVATION

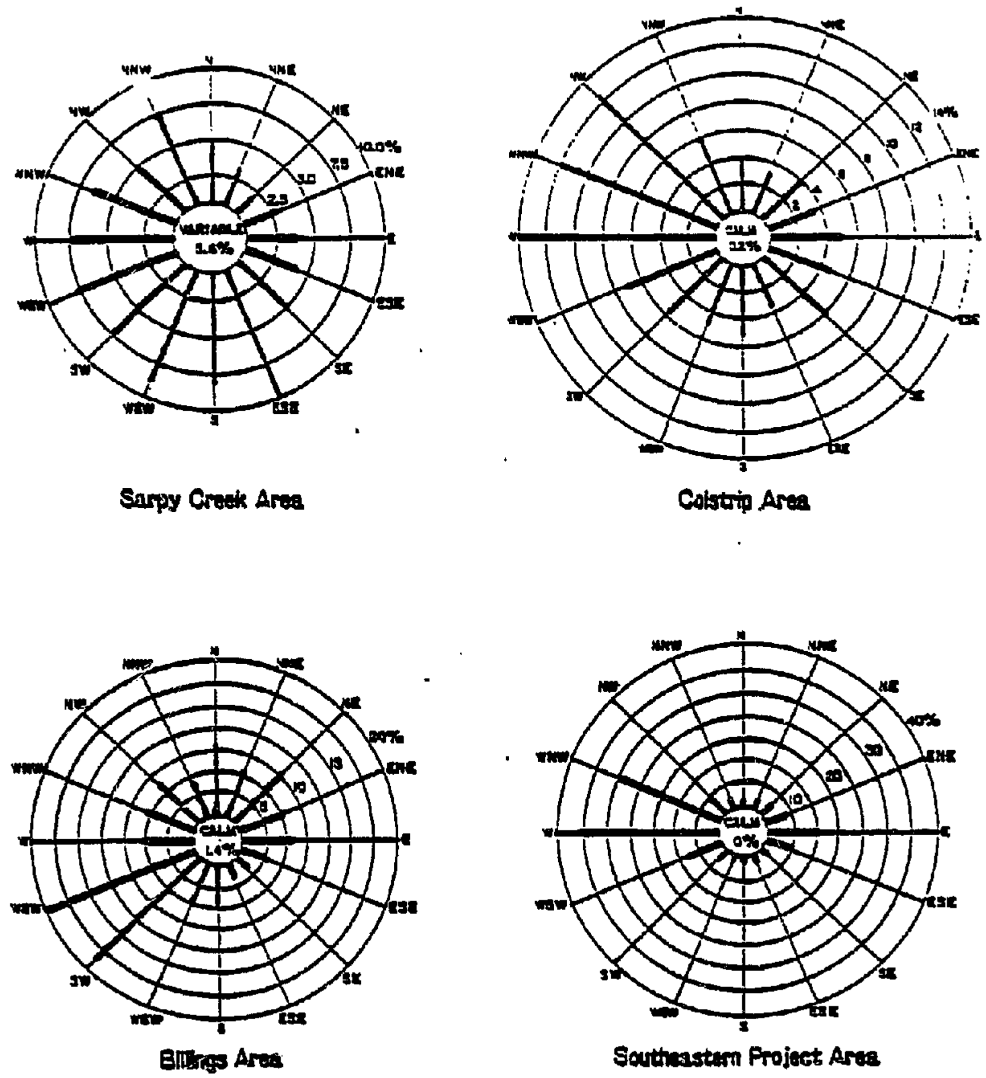


TABLE 4.1.1-15

ESTIMATED RETURN FOR SPECIFIED PRECIPITATION EVENTS FOR SARPY CREEK AREA

6-hour precipitation (inches)	24-hour precipitation (inches)	Return period (years)
1.0	1.4	2
1.3	2.0	5
1.6	2.4	10
2.0	3.0	25
2.2	3.4	50
2.4	3.8	100

Source: Bureau of Indian Affairs, 1976.

the reservation without onsite wind information, but it generally would be dominated by local conditions with some influence anticipated from the mountains to the west. As a general statement, the annual wind information available indicates that west to northwest winds probably dominate in the area, with a secondary frequency of winds coming from the southern quadrant.

Variability in the wind patterns from season to season is expected. The data from Sarpy Creek indicate that the prevailing winds are from the western and northern quadrants during the winter months. During the spring and fall months, the winds are more from the southern and northern quadrants. The summer months do not demonstrate any definitive wind pattern or prevailing wind direction. It is expected that the same general season variability of wind patterns would apply throughout the Crow Reservation.

Wind Speed. Available surface wind information on or near the Crow Reservation indicates a substantial variance in wind speed from one site to the next. This variance is probably due to a number of factors including local terrain considerations, duration of record, and height of instruments above ground. The most complete wind histories available in the area are for Billings, Montana, and Sheridan, Wyoming. Tables 4.1.1-16 and 4.1.1-17 illustrate the monthly wind parameters for Billings and Sheridan. The wind speed patterns for Billings indicate the existence of a relatively high annual mean wind speed of 11.4 mph. The monthly distribution of mean wind demonstrates a very distinct winter maximum and a summer maximum. Sheridan wind speed characteristics are different than those for Billings. Table 4.1.1-17 shows a much lower annual wind speed at Sheridan with a slight spring maximum and a late summer/fall minimum. (References 63, 64).

A small amount of surface wind speed information is available at the other sites. However, due to local topographic considerations, the varying height above the ground of the sensors, and the short record periods of these data may not be representative of the area. Also, it would be difficult to compare these data with data shown for Billings. Generally, the data from the Youngs Creek area indicate an annual wind speed of 5 mph, with a spring maximum and a November minimum.

Also, the short-term records at Sarpy Creek indicate an annual wind speed of 6.3 mph with a spring maximum and a November minimum.

Dispersion Meteorology

Information on dispersion meteorology is necessary for the determination of ambient air quality impact. Many of the same climatological parameters discussed previously are elements in the dispersion meterology. The major components of the dispersion meteorology are:

- wind speed and direction (as a function of height),
- temperature and humidity (as a function of height),
- solar radiation, and
- atmospheric stability (including information on inversions, mixing heights).

Some of these parameters are related and can be determined from common measurements. In order to accurately specify the dispersion meteorology, site-specific information is preferred. For the study areas on the Crow Reservation, site-specific meteorological information is lacking. However, some meteorological information has been collected at Sarpy Creek, Youngs Creek, Billings, and Colstrip. This information is used to infer the dispersion meteorology at the proposed sites.

Wind Speed and Direction. In addition to the surface wind data shown in Figure 4.1.1-3, information obtained from upper air meteorological studies at Colstrip and Billings are available. At Colstrip, data from a 103-foot tower and a 306-foot tower have been collected for the period 1975 to 1977. Upper air data at the Vocational, Technical, and Career Placement Center (Vo-Tech) west of Billings were collected from July 1978 through March 1980.

Figures 4.1.1-4 and 4.1.1-5, illustrate the wind roses for the Colstrip tower data at 103 feet and 305 feet. The predominant west to northwest wind is noted over 40

TABLE 4.1.1-16

NORMALS, MEANS, AND EXTREMES, FOR WINDS AT BILLINGS, MONTANA

Month	Mean Speed (mph)	Prevailing Direction	Fastest Mile Speed (mph)	Fastest Mile Direction	Fastest Mile Year
Jan	13.1	SW	66	W	1953
Feb	12.5	SW	72	W	1963
Mar	11.7	SW	61	NW	1956
Apr	11.7	SW	72		1939
May	11.0	NE	68	NW	1968
Jun	10.4	SW	79	NW	1960
Jul	9.7	SW	73	N	1947
Aug	9.7	SW	66	N	1947
Sep	10.4	SW	61	NW	1949
Oct	11.1	SW	68	NW	1949
Nov	12.3	SW	63	NW	1948
Dec	13.2	WSW	66	NW	1953
Year	11.4	SW	79	NW	June 1968

Source: U.S. Department of Commerce, 1979a.

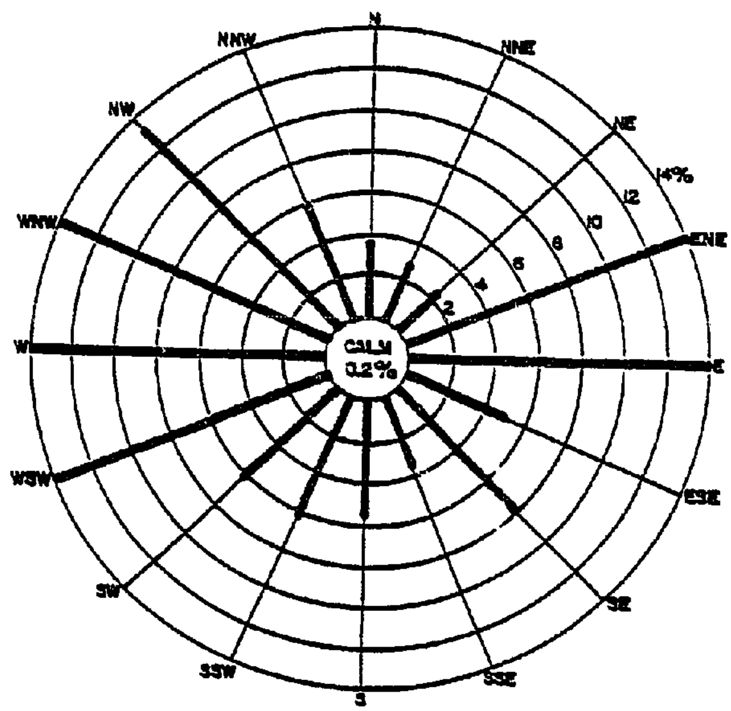
TABLE 4.1.1-17

NORMAL, MEANS, AND EXTREMES, FOR WINDS AT SHERIDAN, WYOMING

Month	Mean Speed (mph)	Prevailing Direction	Fastest Mile		
			Speed (mph)	Direction	Year
Jan	7.8	NW	73	NW	1946
Feb	8.0	NW	70	W	1957
Mar	9.1	NW	66	SW	1963
Apr	9.9	NW	66	NW	1947
May	9.1	NW	71	NW	1946
Jun	8.1	NW	66	SW	1952
Jul	7.2	NW	73	W	1947
Aug	7.3	NW	72	NW	1945
Sep	7.5	NW	66	NW	1945
Oct	7.5	NW	66	NW	1958
Nov	7.8	NW	84	SW	1949
Dec	7.7	NW	63	NW	1958
Year	8.1	NW	84	SW	Nov 1949

Source: U.S. Department of Commerce, 1979b.

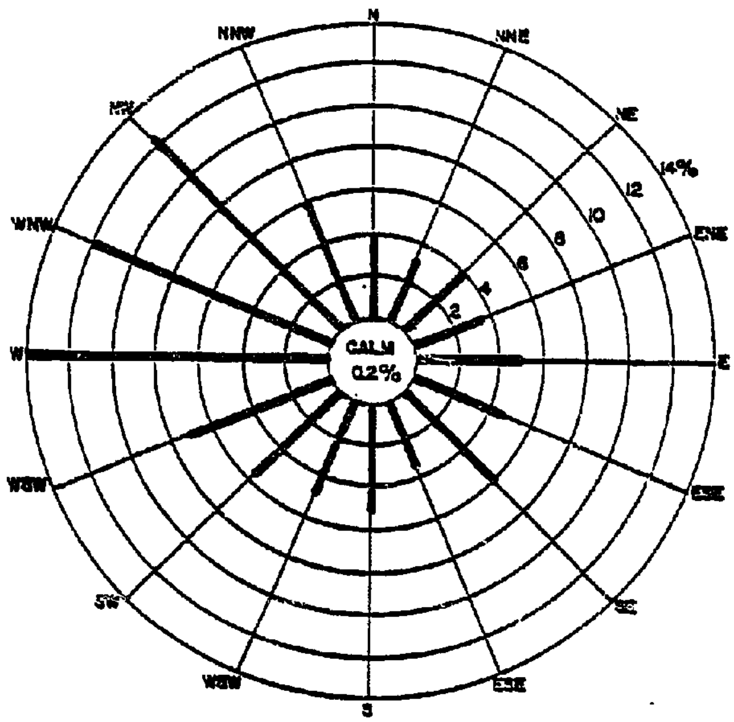
FIGURE 4.1.1-4
COLSTRIP UPPER AIR METEOROLOGICAL WIND ROSES
1975-1977, 103-FOOT LEVEL



TOWER LOCATION:
1 MILE NORTH OF UNITS 1 AND 2
1-1/2 MILE NORTHEAST OF COLSTRIP
103-FT LEVEL

Source: U.S. Department of Interior, 1979.

FIGURE 4.1.1-5
COLSTRIP UPPER AIR METEOROLOGICAL WIND ROSES
1975-1977, 306-FOOT LEVEL



TOWER LOCATION:
1 MILE NORTH OF UNITS 1 AND 2
1-1/2 MILE NORTHEASE OF COLSTRIP
306-FOOT LEVEL

Source: U.S. Department of Interior, 1979.

percent of the time at the 103-foot level. The wind patterns are generally the same at the 306-foot level, except west-northwest and northwest wind frequencies have slightly diminished. The average wind speed at 103 feet above the surface was 11.6 mph. The average wind/speed at 306 feet was 14.1 mph. (Reference 68).

The upper air wind direction frequency distributions for the Billings data are shown in Figures 4.1.1-6 and 4.1.1-7 for 100 m (328 feet) and 200 m (656 feet). The wind frequency distribution indicates a very strong wind direction preference from the southwest or west-southwest (more than 50 percent of the time). The wind frequency direction does experience some slight change from 100 m to 200 m in that the southwest wind becomes less predominant. The average wind speed measured at Billings at 100 m (328 feet) is 5.3 m/sec. (11.9 mph). At 200 m, the average wind speed is 7.1 m/sec. (14.8 mph). The upper air frequency distribution at the sites on the Crow Reservation probably would have characteristics similar to those exhibited by the Colstrip and Billings data. A predominant westerly sector wind frequency is expected on the Crow Reservation with the wind speed increasing from the surface to the troposphere.

<u>Atmospheric Temperature Profile and Stability</u>. Critical to the determination of dispersion meterology are the atmosphere temperature profile and atmospheric stability. They are related but require a different set of measurements to determine. The information necessary to identify both atmospheric temperature profiles and stability characteristics vary but usually include some of the following parameter determinations:

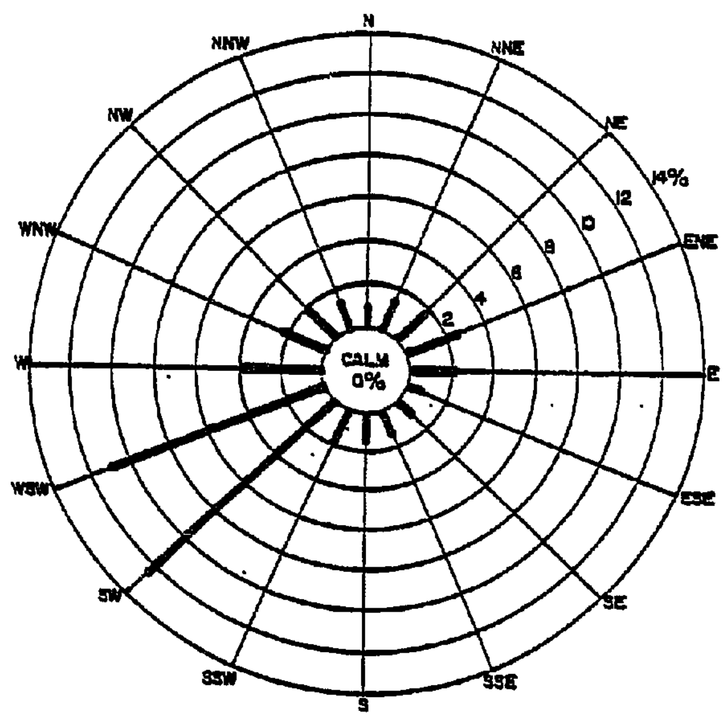
- temperature as a function of height,
- solar radiation,
- cloud cover,
- horizontal and vertical wind fluctuations, and
- inversion (mixing) height.

FIGURE 4.1.1-6

BILLINGS UPPER AIR METEOROLOGICAL WIND ROSE

JULY 1978-MARCH 1980, 100 METERS

PILOT BALLOON STUDIES



BILLINGS WIND ROSE
JULY 1978-MARCH 1980
100 METERS (328 FEET)
PILOT BALLOON STUDIES

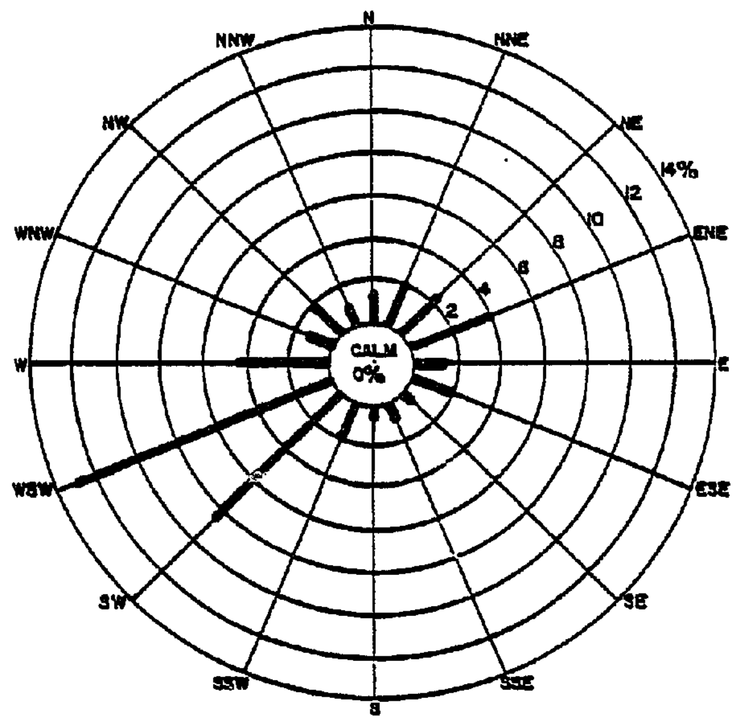
Source: Montana Air Quality Bureau, 1981a.

FIGURE 4.1.1-7

BILLINGS UPPER AIR METEOROLOGICAL WIND ROSE

JULY 1978-MARCH 1980, 200 METERS

PILOT BALLOON STUDIES



BILLINGS WIND ROSE
JULY 1978-MARCH 1980
200 METERS (656 FEET)
PILOT BALLOON STUDIES

Source: Montana Air Quality Bureau, 1981a.

These data can be obtained by using a number of methods ranging from aircraft, tower, pilot balloon, or acoustic radar determinations. Atmospheric stability can be directly measured from surface or tower wind information or indirectly inferred from surface solar radiation, wind speed, and cloud data in conjunction with atmospheric temperature profiles. (Reference 39).

Temperature Profile, Inversion and Mixing Heights. Vertical temperature profile information which relates to inversions and mixing height has been collected at Billings and Colstrip. In addition, inversions and mixing height characteristics have been investigated for eastern Montana in the literature.

Low-level, surface-based inversions are common in Montana and occur approximately 45 to 50 percent of the time in the fall and winter and approximately 30 to 35 percent of the time in the spring and summer in southeastern Montana (Hosler, 1961). The mixing heights or the heights of the inversion in southeastern Montana have been generalized by Holzworth (1972) and the results are shown in Table 4.1.1-18. The data indicates that the mixing heights are the lowest in the winter months and the highest during the spring and summer months. Therefore, the winter months would expect to have the least potential for dispersion of pollutants emitted into the mixing layer. (References 29, 30).

This general conclusion has been verified by temperature profile data collected at Colstrip and in Billings. Colstrip temperature profiles were taken by aircraft for a 1-yr period in 1972. During this period, 215 inversion periods existed, with 14 of these inversion periods lasting longer than 24 hours (Environmental Systems, 1973). (Reference 20).

Temperature sonde measurements and acoustic radar soundings were conducted for Billings at the Vo-Tech site, in conjunction with the pilot balloon studies previously discussed. The Montana Air Quality Bureau reported the following:

TABLE 4.1.1-18

ESTIMATED AVERAGE MIXING HEIGHTS AND WIND SPEEDS IN MIXING LAYERS IN SOUTHEASTERN MONTANA

	Winter		Spring		Summer		Autumn		Annual	
	AM	PM	AM	PM	AM	PM	AM	PM	AM	PM
Mixing Heights (meters)	300	900	400	2000	300	2800	300	1600	325	1325
Wind Speeds	11	15	13	18	10	15	10	16	11	16

Source: Holzworth, 1972.

Inversions were present for almost all mornings sampled with most of these inversions being surface type inversions 100 to 250 meters thick. Very few surface inversions were more than 500 meters thick. In addition to the surface inversions, most mornings also had one or more elevated inversions present. These elevated inversions were most often less than 100 meters thick. Elevated inversions also were weaker than surface inversions.

The afternoons sampled had fewer inversions than the mornings. The afternoons also had a pronounced seasonal variation with the least surface inversions occurring during the summer and the most occurring during the winter. The seasonal variation of elevated inversions showed the same general trend. (Reference 39).

Also, for this study the average wind speed through the mixing layer was calculated. Table 4.1.1-19 illustrates the results and indicates that the highest wind speeds occur in the winter months.

Atmospheric Stability. Atmospheric stability is a measure of the atmosphere's capability to horizontally and vertically disperse pollutants. A standard measure of stability has been the Pasquill stability classification. The Pasquill stability classes are defined as follows:

A - Extremely unstable
B - Moderately unstable
C - Slightly unstable
D - Neutral
E - Slightly stable
F - Moderately stable

This coding system defines each category as follows: 1) unstable conditions (Classes A, B, and C) occur when layers of air close to the ground undergo warming with associated low wind speeds; 2) stable conditions (Classes E and F) occur when the layers of air close to the ground undergo cooling with associated low wind speeds; 3)

TABLE 4.1.1-19

BILLINGS VO-TECH MIXED-LAYER WIND: AVERAGE WIND SPEED

	1978											1979												
	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
Average Wind Speed Thru Mixed Layer (m/sec)	5.4	4.0	7.2	3.4	-	-	-	4.2	3.4	5.6	4.6	9.0	5.5	7.8	5.8	7.6	-	-	-	4.3	5.4	9.6	10.3	10.7

Source: Montana Air Quality Bureau, 1981a.

drainage winds occur under E and F stability conditions; and 4 neutral conditions (Class D) occur with cloudy skies and/or high wind speeds. Figure 4.1.1-8 illustrates smoke plume patterns from an elevated source for some of the various conditions. As a general rule, stable conditions or fumigation are the conditions which produce the highest ground-level concentrations of air pollutants. (Reference 36)

Atmospheric stability information has been collected for Billings, Colstrip, and Youngs Creek using a number of different methods. Billings surface data collected at the airport (sky conditions, wind speed, time of day, and solar radiation) were used to determine stability. The results along with average wind speed for January 1967 to December 1971 are shown in Table 4.1.1-20. The highest occurrence frequency was 64 percent of the time. Also, the associated average speed of 12 mph with stability class D is noted. These data are contrasted with that shown in the next section for the Logans Airport at Billings using the same method but for a longer time frame (1968 to 1978). Classes E and F frequencies of occurrence are significantly different at the Billings airport. (Reference 6).

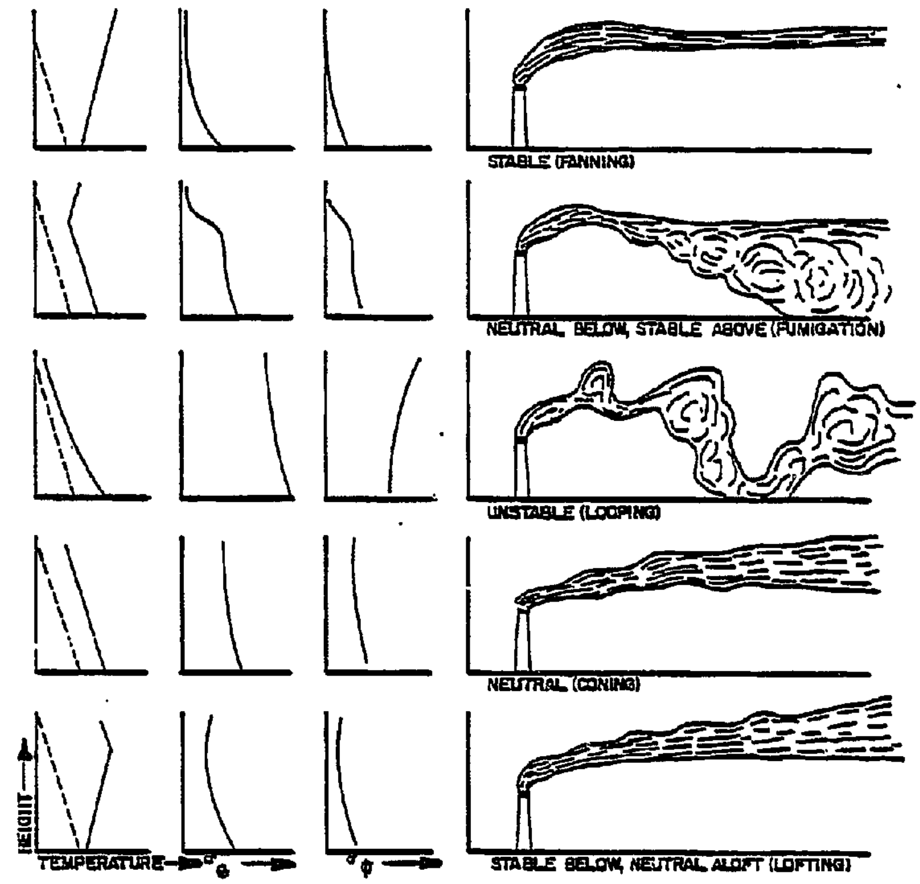
Stability information was also collected in Billings at the Vo-Tech site from September 1978 through April 1980, using a combination of surface data and acoustic radar information. The frequency of occurrence for each stability class is summarized in Table 4.1.1-21. This analysis was performed for a 2-hr averaging time throughout the day. A substantial frequency occurrence for Class E stability is noted. The frequency of occurrence for stability classes C through F in this data set does not match frequencies in Table 4.1.1-20. (Reference 39).

Colstrip stability information was collected at the 306-foot tower by using the horizontal wind fluctuations as the measure of stability. The data results are shown in Table 4.1.1-22. (stability class F was not calculated in this analysis). Table 4.1.1-22 indicates a greater frequency of unstable atmospheric conditions (classes A and B) than the data for Billings. (Reference 68).

FIGURE 4.1.1-8

VARIOUS TYPES OF SMOKE-PLUME PATTERNS

OBSERVED IN THE ATMOSPHERE



Note: The dashed curves in the left-hand column of diagrams show the adiabatic lapse rate, and the solid lines are the observed profiles. The abscissas of the columns for the horizontal and vertical wind direction standard deviations (and) represent a range of about 0° to 25°.

Source: Mariatt and Associates, 1978.

TABLE 4.1.1-20

FREQUENCY OCCURRENCE AND MEAN ANNUAL WIND SPEED BY STABILITY CLASS FOR BILLINGS, MONTANA[a]

Stability Class	Occurrence Frequency (%)	Mean Wind Speed (mph)
A (unstable)	1	4.8
B	4	6.6
C	10	8.7
D (neutral)	64	12.0
E	14	8.2
F (stable)	7	5.6

[a]Covers period 1/67 to 12/71.
Source: Bureau of Indian Affairs, 1976.

TABLE 4.1.1-21

ATMOSPHERIC STABILITY FREQUENCY OF OCCURRENCE FOR BILLINGS, MONTANA AT THE VO-TECH SITE, 9/78-4/80

Stability Class	Frequency of Occurrence (%)
A	0
B	1
C	18
D	32
E	45
F	4

Source: Montana Air Quality Bureau, 1981a.

TABLE 4.1.1-22

ATMOSPHERIC STABILITY FREQUENCY OF OCCURRENCE FOR COLSTRIP, MONTANA, 1975-1977

Stability Class	Frequency of Occurrence[a] (%)
A	19
B	17
C	13
D	28
E	22
F	—

[a]Using the horizontal wind fluctuations.
+F stability was not calculated but included in E.
Source: U.S. Department of Interior, 1979.

The stability class frequency was calculated for one year at Youngs Creek from October 1975 to October 1976. The results are shown in Table 4.1.1-23 with the average wind speed for the stability class. Neutral and unstable conditions exist most of the time from the data outlined in Table 4.1.1-23. (Reference 13).

The stability data collected in the vicinity of the proposed sites using various methods do not offer a consistent determination of expected atmospheric stability on the reservation. Variations in methodology, time, and location make it difficult to determine atmospheric stability without site-specific surface and upper wind data.

Sky Cover and Sunshine. The amount of solar radiation (insolation) received at the surface can be indirectly measured with sky cover or sunshine observations. The 40-yr record of observations at Billings for percentage of possible sunshine and for mean sky cover is shown in Table 4.1.1-24. The annual percentage of sunshine is 62 percent with a characteristic winter minimum and a summer maximum. Limited insolation measurements made at Sarpy Creek and at Youngs Creek indicate that the Billings observations are representative of the region, including the reservation. (Reference 63).

Visibility. Visibility or visual range-related measurements are lacking for the Crow Reservation. Visual range data, however, have been collected at Billings by an observer. Visual range is the largest distance that one can presumably discern objects or targets. Figure 4.1.1-9 illustrates the average visual range data on a national basis. For this information the visual range on the Crow Reservation would be good, about 45 to 70 miles on the average.

Using this general information and the familiar Koschmieder relationship of

$$V = \frac{3.912}{B_{scat}}$$

TABLE 4.1.1-23

MEAN ANNUAL WIND SPEED BY STABILITY CLASS

SOUTHEAST PROJECT AREA, (10/75-10/76)

Stability Class	Occurrence Frequency (%)	Wind Speed (mph)
A	12	3.8
B Unstable	14	4.1
C	23	5.7
D Neutral	36	8.1
E	15	7.4
F Stable	2	4.3

Source: CIRL, 1976.

FIGURE 4.1.1-9
VISUAL RANGE (MILES) ISOPLETHS FOR SUBURBAN/NONURBAN AREAS, 1974-76

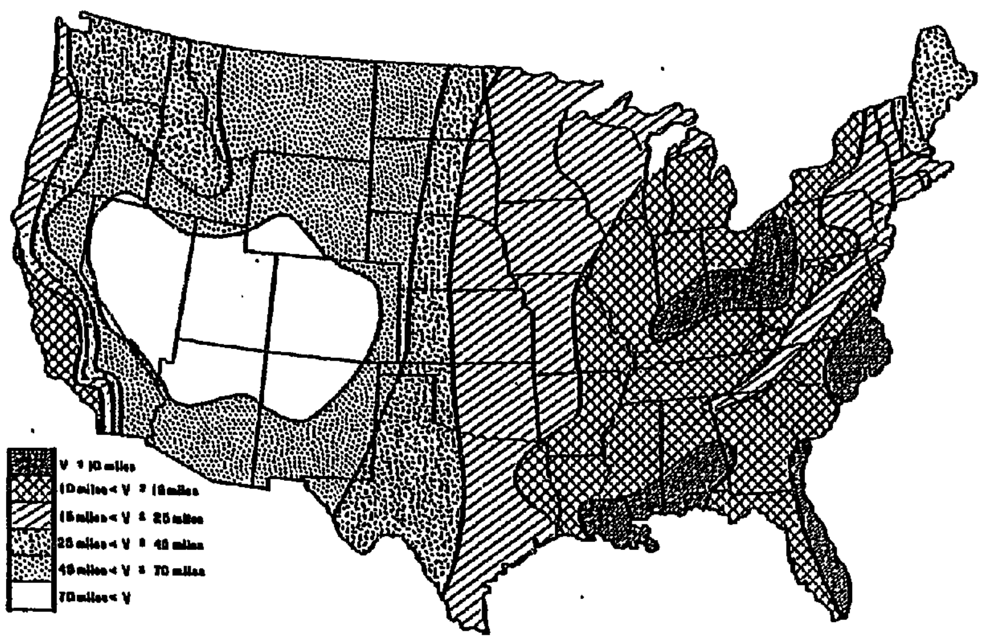


TABLE 4.1.1-24

SKY COVER DATA, BILLINGS, MONTANA[a]

	Possible Sunshine (%)	Mean Sky Cover, Sunrise to Sunset[b]	Sunrise to Sunset: Clear Days	Partly Cloudy Days	Cloudy Days
Jan	47	7.2	5	8	18
Feb	54	7.1	4	8	16
Mar	62	7.1	4	9	18
Apr	59	7.1	4	9	17
May	61	6.6	6	10	15
Jun	64	5.9	7	12	11
Jul	77	4.0	14	12	5
Aug	76	4.2	14	11	6
Sep	68	5.1	10	10	10
Oct	62	5.7	9	10	12
Nov	46	6.8	6	8	16
Dec	45	6.8	6	9	16
Year	62	6.1	89	116	160

[a] Based on records from 40 years prior to and including 1979.
[b] Sky cover is expressed in a range of 0 for no clouds or obscuring phenomena to 10 for complete sky cover.
Source: U.S. Department of Commerce, 1979a.

Where V = visual range and B_{scat} is the scattering extinction coefficient given in inverse distance units, for discussion purposes, an initial comparison of background conditions with the state visiblity standard can be made. At an average of 45 to 70 miles visual range, the standard is exceeded. This standard only applies to mandatory PSD Class I areas and is incremental in nature, so the question of noncompliance is moot on the Crow Reservation (see Table 4.1.1-27 for details).

Severe Weather

Extreme weather events in addition to those described for precipitation are identified in this section. Included in the discussion of severe weather are extreme winds, thunderstorms, blizzards, tornadoes, hail and ice storms, floods, and dusty hours.

Severe Wind Events. Data taken from major airport stations, presented in Table 4.1.1-16, indicate the maximum surface wind velocities recorded by month in Billings. Winds in excess of 60 mph have been recorded in at least each month, with the maximum recorded wind speed of 79 mph. The wind direction for the maximum winds are either from the north, northwest, or west. High winds greater than 40 mph are not uncommon in the area. These winds are associated with frontal thunderstorms or chinook events. Table 4.1.1-25 illustrates the mean recurrence intervals for extreme winds in southeastern Montana. The 50-yr mean recurrence wind speed is 80 to 90 mph. (Reference 58).

Other Extreme Events. Table 4.1.1-26 summarizes the other extreme climatic events which were measured or calculated for Billings. The general frequency of all these events are relatively low when compared to other areas of the country. However, tornadoes have been reported in Treasure County and in Big Horn County during the period 1963 to 1972. Also, hail storms related to thunderstorm activity have been estimated to cause crop and property damage amounting to about $5 million annually in Montana (Cordell, 1971). (References 2, 16, 18, 48, 50, 56, 63).

TABLE 4.1.1-25

MEAN RECURRENCE INTERVALS FOR EXTREME WINDS, SOUTHEASTERN MONTANA[a]

Wind Speed (mph)	Mean Recurrence Interval (years)
60	2
70	10
80	25
90	100

[a] Figure 4.1.1-10 indicates the same results.
Source: Thom, 1968.

TABLE 4.1.1-26
EXTREME CLIMATIC EVENTS,
BILLINGS, MONTANA, AREA

Extreme Event	Number of times occurred or maximum quality
Maximum snowfall per storm	20-30 in.[a]
Average thunderstorms per year	29[b]
Total hail reports, 3/4-in. (1955-1967)	25-75[c]
Annual percent frequency of dusty days	0.005-0.01%[d]
Number of times ice of 1/4 in. thickness was observed during the 9-yr period	0[e]
Fastest wind	79 mph[b]
Tornado strike probability per 1-yr period	8.5/100,000[f]
Estimated maximum ppt for 24 hours at a 50-yr return interval	3.0 inches

[a]Daniels, 1971
[b]U.S. Department of Commerce, 1979a.
[c]Pautz, 1974
[d]Orgill and Sehmel, 1976
[e]Bennet, 1954
[f]Stevenson, 1976

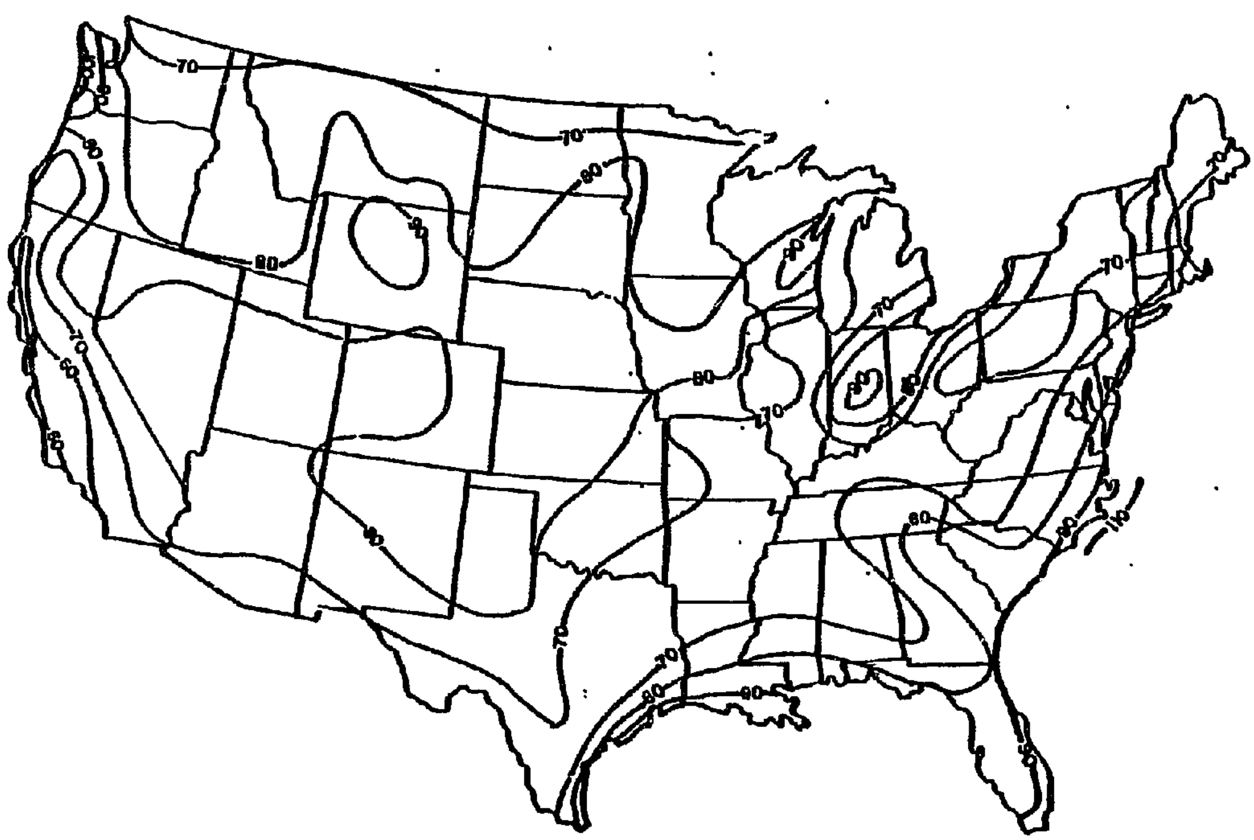
TABLE 4.1.1-27

NATIONAL AND STATE OF MONTANA AMBIENT AIR QUALITY STANDARDS[a]

Pollutant	Averaging Time	National Primary	National Secondary	Montana
Carbon monoxide	1 - hour 8 - hour	9 ppm 35 ppm	same as primary same as primary	9 ppm 23 ppm
Lead	90 - day	1.5 ug/m^3	same as primary	1.5 ug/m^3
Nitrogen oxide	1 - hour Annual	- 0.05 ppm (100 ug/m^3)	- same as primary	0.30 ppm (60 ug/m^3) 0.05 ppm (100 ug/m^3)
Ozone	1 - hour	0.12 ppm (240 ug/m^3)	0.08 ppm (160 ug/m^3)	0.10 ppm (200 ug/m^3)
Sulfur dioxide	1 - hour 3 - hour 24 - hour Annual	- - 0.14 ppm (365 ug/m^3) 0.03 ppm (80 ug/m^3)	- 0.5 ppm (1,300 ug/m^3) - -	0.50[b] ppm (1,300 ug/m^3) - 0.10 ppm (260 ug/m^3) 0.02 ppm (52 ug/m^3)
Total suspended particulates	24 - hour Annual	260 ug/m^3 75[c] ug/m^3	150 ug/m^3 60[c] ug/m^3	250 ug/m^3 75 ug/m^3
Fluoride[d]	Monthly	-	-	20 ug/g
Hydrogen sulfide	1 - hour	-	-	0.05 ppm
Settled particulate Matter	30 - day	-	-	10 g/m^2
Visibility[c]	Annual	-	-	-

[a]All long-term standards (i.e., greather than 30-days) are not to be exceeded. Unless otherwise noted, all short-term standards (i.e., 1-, 8-, and 24-hour) are not to be exceeded more than once per year. Unless otherwise noted, all averages are computed on an arithmetic basis.
[b]Not to be exceeded more than 18 times in an 12 consecutive months.
[c]Geometric average, the secondary value is a guideline.
[d]Computed as fluoride in or on forage.

FIGURE 4.1.1-10
MAXIMUM EXPECTED WINDS FOR A 50-YR RECURRENCE INTERVAL



Floods are most likely to occur in spring and early summer as a result of melting snow or heavy rain. Information from Sarpy Creek indicated that floods in the streambeds are more likely to be the result of locally heavy thunderstorms in late spring and summer.

Blizzards, with a resulting high wind, cold temperatures, and snow, are relatively common in Montana. Blizzard conditions seldom last longer than 2 to 4 days. However, strong surface winds may create ground blizzards with blowing snow for an extended period of time, even after the blizzard has ended. Due to radiative cooling under clear skies, nighttime surface temperatures may drop to -30° to -50°F following the passage of such storms.

Ice storms may occur when rain falls from a warm layer of air through a shallow layer of cold air and freezes upon contact with objects on the ground. For Montana such events occur rather infrequently, about 3 to 6/yr. The thickness of accumulated ice on any surface can be expected not to exceed 1/4 in. (Environmental Systems, 1973). (Reference 73).

4.1.1.3 Air Quality

Air quality information collected near or on the Crow Reservation indicates that the general air quality at the candidate sites is excellent. Data on air quality have been collected by a number of different public and private organizations pursuant to the proposed developments at Colstrip, Westmoreland mine (Sarpy Creek), and Shell (Youngs Creek) mine. Also, the state of Montana has been measuring air quality in Billings at a number of locations.

In addition to data collected by air quality instrumentation, air quality can be inferred from information on air pollution emission sources in the vicinity of the reservation. Air emission data on sources in Billings and Colstrip are available.

Classification of Air Quality and the Location of Air Quality Designated Areas

The Crow Reservation is designated as a PSD Class II area, with no violations of human health-related ambient air quality standards noted on the reservation (A discussion of PSD classifications and ambient air quality standards is included in Section 4.3). The Class II designation is the same classification that applies to most of the geographic area of the United States and implies that a moderate level of industrial growth would be permitted on the reservation.

Most of the area adjacent to the reservation is also designated as Class II air quality, with two very important exceptions. The Northern Cheyenne Reservation located directly to the east of the Crow Reservation has been designated as a Class I area. The designation is reserved for clean, pristine areas and would permit little or no industrial development. Since there are industrial sources located on the Crow Reservation, the Class I status of the Northern Cheyenne Reservation was a significant factor in the feasibility study that has been performed.

The other air quality designated area which may have an impact on any development on the Crow Reservation is the town of Billings. Billings is currently classified as "nonattainment" for Total Suspended Particulates (TSP) meaning that violations of the health standard for TSP have been measured in Billings and that little or no growth will be permitted in or adjacent to Billings until the standard is reached. Also, Billings is an "unclassified" area for sulfur dioxide meaning that whether or not the sulfur dioxide ambient air quality standards are being met in Billings is questionable. The state of Montana is involved in a sulfur dioxide monitoring program to determine the status of the area. If violations of the sulfur dioxide health standard are found, the area will be designated as "nonattainment" for sulfur dioxide. If no violations are found, the Billings area will retain a Class II designation for sulfur dioxide.

The Northern Cheyenne Reservation's Class I designation and the Billings "nonattainment" classification are potential constraints to industrial development on the Crow Reservation.

Ambient Air Quality Data

Ambient air quality data have been collected in conjunction with the Colstrip, Westmoreland, and Shell projects. Further, the state of Montana has monitored air quality in Billings. Data on total suspended particulates, settled particulate matter (dust fall), particulate trace chemistry, and gaseous pollutants are available for these sites. However, some of the data have been collected on a short-term, noncontinuous basis and sometimes use different measurement techniques. The somewhat inconsistent monitoring record that results makes a complete determination of ambient air quality difficult.

Using the best available data for the monitoring sites identified close to the reservation, a general baseline ambient air quality will be postulated for the reservation. Site-specific data should be collected to more completely identify baseline air quality resources.

Total Suspended Particulates. Substantial information on Total Suspended Particulates (TSP) has been collected in the area. Table 4.1.1-28 summarizes the available data from 1973. The data for Colstrip and Billings indicate that the ambient air quality standards, measured in the more urban environments, were exceeded. The maximum TSP concentrations for the nonurban areas surrounding the reservation do not show any violations. Some of the stations—McRae, Sarpy Creek, Youngs Creek, Hardin, and Lame Deer—indicate very low, annual TSP levels.

Settled Particulate Matter (dust fall). Historically, one of the first methods to determine air quality was to measure the amount of dust that has been settled out of the atmosphere. Although there is not a federal standard for settled particulate matter, the state of Montana follows the standard of 10 g/m^2 for a 30-day period. Settled particulate matter data has been collected at a number of different sites. However, the data that have been collected sometimes use different methods and different averaging times; thus, a direct comparison of the data is not recommended. The results are shown in Table 4.1.1-29. All values except those reported for Sarpy Creek are equal to or less than the present Montana standard.

TABLE 4.1.1-28

SUMMARY OF TOTAL SUSPENDED PARTICULATE DATA COLLECTED IN THE VICINITY OF THE CROW RESERVATION

Site	Maximum Annual Geo. (Mean (ug/m^3)	Maximum 24-Hr (ug/m^3)	Violations Noted[a] Federal Primary	Violations Noted[a] Federal Secondary	Violations Noted[a] Montana
Colstrip[b]			x	x	x
Colstrip Town[c]	115	612			
McRae	17	102			
Sarpy Creek[d]	22	205			
Youngs Creek[3]	15	164			
Billings[f]			x	x	x
Central Park	68	266			
KGHL	41	130			
Harding[g]	20	135			
Lame Deer[h]	11	143			
Decker[i]	38	134			

[a]Violations are indicated for the 24-hour standard after the first occurrence above the standard. Therefore, the maximum 24-hour standard may be above the standard, but no violation is noted because the standard was not exceeded a second time.
[b]Data collected in 1974 to 1977 pursuant to the Colstrip power plant activities. The maximum and minimum stations are reported
[c]Refers to station titled "MGP-3." The high values are attributed to traffic, fugitive dust, and construction activities within the town of Colstrip.
[d]Data collected from February 1975 through March 1976.
[e]Data collected in 1973 to 1979.
[f]Data collected in 1979. The maximum and minimum violation stations are reported.
[g]Data collected in 1978 and 1979.
[h]Data collected in 1979 for Fisher Butte.
[i]Data collected in 1979.

TABLE 4.1.1-29

SUMMARY OF SETTLED PARTICULATE MATTER DATA

COLLECTED IN THE VICINITY OF

THE CROW RESERVATION[a]

Station	Year	Average	Max	No. of Samples
Colstrip	73	3.4	-	-
Forsyth	73	6.3	-	-
Miles City	73	8.4	-	-
Hardin	72	3.4	-	-
Lame Deer	72	3.8	-	-
Lame Deer	72-73	2.9	5.6	13
Lodge Grass	72-73	5.7	10.0	10
Decker	72-73	2.5	8.0	12
McRae	73-74	1.0	2.4	10
Antenna Hill	73-74	1.0	2.4	10
Sarpy Creek	75-76	12.6	55.2	13
Youngs Creek	78	-	10.0	-

[a] Measured as gram/meter^2.

TABLE 4.1.1-3[illegible]

MEMBRANE FILTERS (TRACE ELEMENT ANALYSIS)AVERAGE VALUES,

OPERATIONAL PERIOD: 11/73-6/74

(ug/m^3)

Element	BN Site	McRae Site
Antimony	0.002	0.002
Tin	0.02	0.02
Vanadium	0.005	0.005
Beryllium	0.0001	0.0001
Chromium	0.001	0.001
Lead	0.0156	0.127
Cadmium	0.00004	0.00006
Strontium	0.00045	0.00033
Silver	0.001	0.001
Manganese	0.0042	0.0039
Zinc	0.0402	0.0493
Copper	0.008	0.008
Iron	0.151	0.123
Mercury	0.0002	0.0002
Calcium	0.212	0.115
Magnesium	0.047	0.047
Lithium	None detected	None detected
Sodium	0.064	0.064
Potassium	0.049	0.040
Selenium	0.001	0.001
Average no. samples	41	41

Source: Bureau of Indian Affairs, 1979a.

Particulate Chemistry and Size Distribution. Trace constituent measurements have been made pursuant to proposed developments at Colstrip, Sarpy Creek, and Youngs Creek. At Colstrip, trace element analysis was performed using membrane filters. The results for November 1973 to June 1974 are shown in Table 4.1.1-30. (Reference 5).

At Youngs Creek, dust fall samples were analyzed to determine trace constituents for organic fraction and metals for the the annual period of October 1975 through September 1976. The results indicate that the organic fraction ranged from 0 to 11 percent with an average of 3 percent (CIRCL, 1976). For trace elemental analysis, sulfate, beryllium, lead, calcium, vanadium, iron, zinc, strontium, arsenic, and mercury were determined. With the exception of iron and calcium all elements were found to be near or below maximum instrument detection limits. It was determined at Youngs Creek that:

> Analyses of TSP samples collected in the Youngs Creek area indicated trace element concentrations were well below the federal standards or criteria pollutants and below EPA Prevention of Significant Deterioration (PSD) minimum levels for noncriteria pollutants. The elements found in the suspended particulates were sulfate, lead, cadmium, iron, zinc, calcium, strontium, arsenic, and mercury (U.S. Department of Interior, 1981). (References 13, 69).

Fluoride data were collected for the Colstrip project using different monitoring techniques. The data collected are not readily comparable to existing ambient air quality standards but indicate that fluoride concentrations in the area did not increase after Colstrip Units 1 and 2 were built. Table 4.1.1-31 summarizes fluoride data that have been collected. (Reference 5).

Particulate size distribution measurements have been reported for Colstrip and Young Creek. At the BN and McRae sites, both downwind of the Colstrip area, 39.1 percent and 43.3 percent respectively, of the total particulate load were found to be in the submicron range. At Youngs Creek, 65.9 percent were in the submicron range.

TABLE 4.1.1-31

FLUORIDES IN THE AIR (Na FORMATE PLATES)

PER 30 DAYS OPERATIONAL PERIOD, 11/73-8/75

(ug/cm^2)

Sampler Location	Average Value	Maximum Value	No. of Samples
Rosebud Co. BN Site	0.017	0.13	19
Rosebud Co. McRae Site	0.008	0.11	21
Rosebud Co. Halfway Site	0.014	0.11	18
Rosebud Co. Antenna Hill	0.004	0.05	20
	Fluorides in the air (Ca formate Papers) Operational period: 11/73-8/75		
Rosebud Co. BN Site	0.021	0.23	19
Rosebud Co. McRae Site	0.012	0.09	19

Source: Bureau of Indian Affairs, 1979a.

Gaseous Pollutants. Measurements of baseline gaseous air pollutants including sulfur dioxide, nitrogren oxides, carbon monoxide, and ozone have been made for the Colstrip, Sarpy Creek, and Youngs Creek areas. Also, the state of Montana has been monitoring the same gaseous components in and around Billings. All measurements made since 1979 outside of the Billings area indicate that gaseous air pollution levels in the area are well below standards. In fact, most measurements, with the exception of those taken next to the Colstrip power plant, are close to the minimum detectable limit of air quality monitoring equipment.

The highest gaseous concentrations in the region have been recorded in the Billings urban area. Table 4.1.1-32 illustrates that, for the SO_2 data collected in 1979 for two sites in Billings, no violations of the ambient air quality standards are noted.

However, the state of Montana is engaged in a more comprehensive SO_2 monitoring program to determine if ambient air quality standards are being violated in Billings as previously mentioned (Montana Air Quality Bureau, 1981). (Reference 39).

Particulate and gaseous ambient air quality is very good on the Crow Reservation. Data collected indicate that gaseous levels of the major criteria pollutants on the reservation are well below ambient air quality standards. Particulate data levels are probably closer to the standards, principally due to the arid nature of the climate and the abundance of naturally occurring dust.

Emission Inventory

No evidence indicates that any major air pollution sources are on the Crow Reservation. The major sources in the area are the Colstrip power plant and the town of Billings. Table 4.1.1-33 illustrates the estimated emissions for particulates of SO_2 and nitrogen oxides for the Colstrip complex. Table 4.1.1-34 illustrates the Table 4.1.1-32 estimated emissions for 1976 for the major urban areas of Montana including Billings. The emissions in Billings, for particulates and SO_2, are larger than those identified for the Colstrip power plant. (References 22, 68).

TABLE 4.1.1-32

SULFUR DIOXIDE CONCENTRATIONS, BILLINGS, 1979

Averaging Time	Maximum Concentrations (ppm)											
Central Park Site	J	F	M	A	M	J	J	A	S	O	N	D
1-hour	.110	.225	.005	.110	.065	.040	.245	.068	.100	-	-	.005
3-hour	.107	.173	.040	.058	.030	.030	.109	.058	.080	-	-	.040
24-hour	.048	.069	.025	.019	.010	.011	.042	.017	.029	-	-	.025
Lockwood Site												
1-hour	-	-	-	-	-	-	.245	.195	.245	.227	.182	.268
3-hour	-	-	-	-	-	-	.129	.107	.170	.171	.150	.210
24-hour	-	-	-	-	-	-	.041	.043	.076	.055	.057	.074

Source: Montana Air Quality Bureau, 1981.

TABLE 4.1.1-33

COLSTRIP EMISSIONS

	Particulates	SO_2	NO_x
Construction	2040	-[a]	-[a]
Area	3467	-[a]	-[a]
Point[b]	2394	13,801[c]	32,083
Total During Construction	5507	-[a]	-[a]
Total During Operation	5861	13,801	32,083

[a]Data not available
[b]Includes units 1-4
[c]Assumes 90 percent control on units 3 & 4.
Source: U.S. Department of Interior, 1979.

TABLE 4.1.1-34
ESTIMATED EMISSIONS, 1976
(tons/year)

Region	Sources	SO_2	Particulates
Billings, AQCR 140	Point	39,762	3,476
	area	2,007	152,412
Helena, AQCR 142	Point	401,561	17,537
	area	977	91,242
Miles City, AQCR 143	Point	6,232	643
	area	396	87,468
Missoula, AQCR 144	Point	4,681	4,427
	area	3,282	175,475
State of Montana	Point	454,926	26,268
	area	9,462	757,597
	Total	464,388	783,865

Note: Emissions of NO_x, ozone, and hydrocarbon are not available in published form.
Source: Gelhaus, 1977.

Noise

No noise measurements have been made at any of the sites. Noise levels on the reservation are expected to be normal for rural areas in the United States—about 30 decibels. Occurrences of vehicular traffic, aircraft traffic, aircraft activity, or intense weather phenomena would increase noise levels in the short term.

Odor

No odor monitoring has been performed at any of the sites. Odor levels on the reservation are expected to be similar to those associated with rural dry land farming areas in the United States. Certain minor odor occurrences related to agricultural activities may be present during harvest time.

4.1.2 Geology

The Crow Reservation is composed of an area of 3,567 square miles (2,228,764 acres) with mineral rights on an additional 1,100,000 acres within the ceded area to the north of the reservation. The reservation includes parts of the folded Middle Rocky Mountains represented by the Bighorn Mountains and Pryor Mountains, and the western margin of the large Powder River Basin which includes the bulk of the reservation.

Topographic evaluations vary from approximately 9,000 feet in the Bighorns to 2,900 feet at Hardin. Most of the reservation lies at approximately 4,000 feet MSL with the eastern ranges (Wolf and Rosebud) rising to elevations of about 5,500 feet. The high topography of the southwestern part of the reservation is due to the uplift and folding of the Bighorn Mountains and Pryor Mountains; whereas, the Wolf Mountains and Rosebud Mountains are the result of the eroded, upturned margins of the Powder River Basin strata, particularly the edges of the Cretaceous sandstone.

The sedimentary rocks of the Crow Reservation overlie approximately 11,000 feet, not including the Precambrian granitic basement rocks found in the eroded and uplifted core of the Bighorn Mountains. Every geologic system except the Silurian is represented within the reservation boundaries. Precambrian to Mississippian strata generally outcrop in the southwestern part of the reservation. Pennsylvanian and younger rocks are found in the north and eastern portions of the area.

The general stratigraphy of the reservation is summarized in Table 4.1.2-1 and Figure 4.1.2-1 for the formations which outcrop within the boundaries of the reservation. A more detailed discussion of the major geologic characteristics that are pertinent to the environmental assessment is presented for the two major proposed plant site areas; i.e., Site 1 located in the north-central region of the reservation and Site 23 located in the southwestern part of the reservation.

4.1.2.1 Environmental Geologic Characteristics, Site 1

The candidate Site 1 area is located in parts of Sections 16, 17, 20 and 21, T2S, R31E, as shown in Figure 4.1.2-2, a geologic and structure contour map of the Bighorn Canyon, Hardin, Montana, area. The general region encompassing the Site 1A area is shown in Figure 4.1.2-2, overlain by the Niobrara and Carlile members (KCnc on map) of the Cody Shale Formation of the Upper Cretaceous Series. (References 53, 58a).

The Cody Shale includes 2,600 feet of dark-gray, partly sandy shale which underlies much of the plains region in south-central Montana. The Cody Shale is conformable above the Frontier Formation and under the Parkman Sandstone and includes rocks of the Colorado and Montana groups. Several members of the Cody Shale are mapped by Thom as formations (Thom et al., 1935, p. 49-58). (Reference 58a).

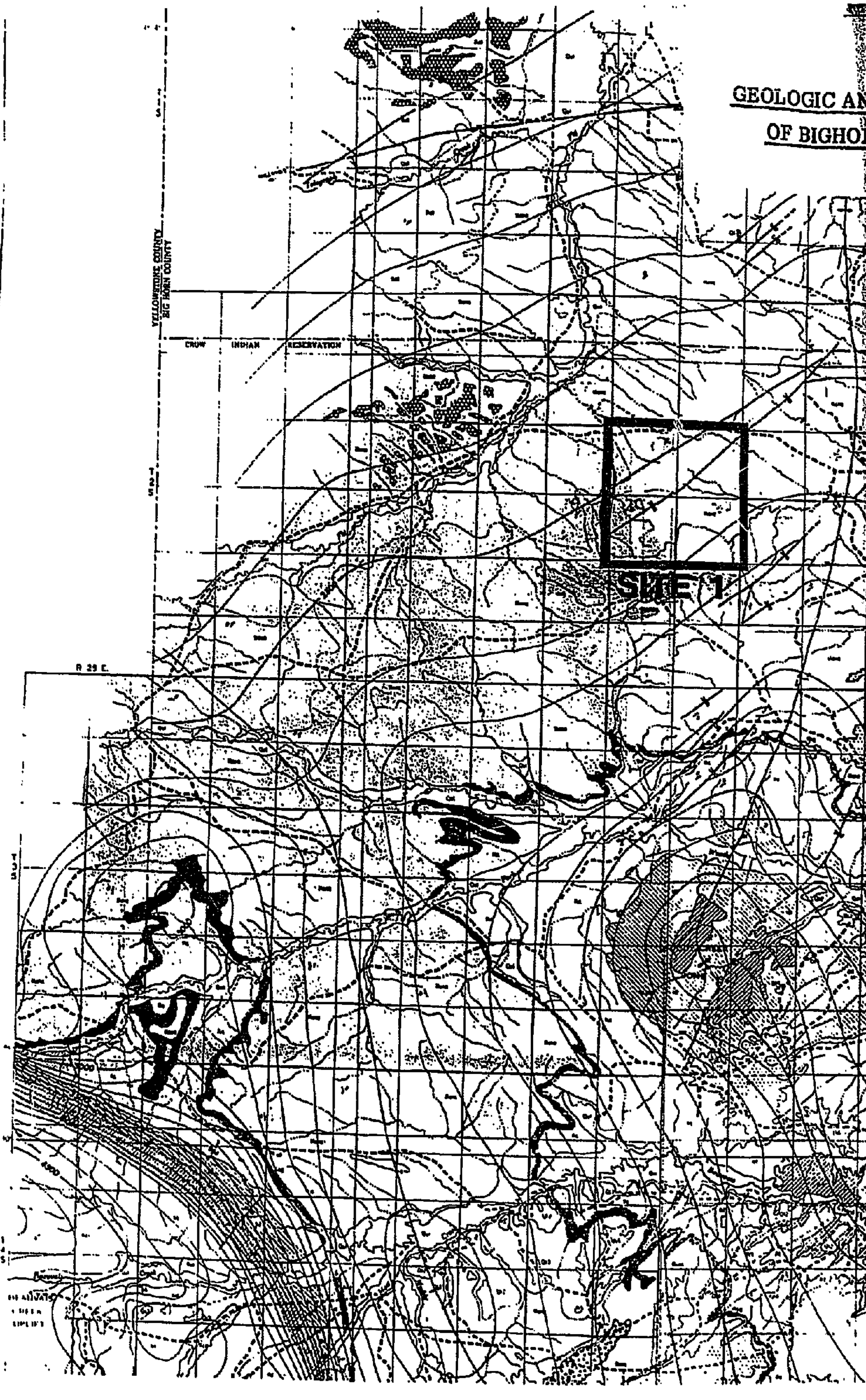
The Cody Shale is a thick, mappable formation composed of seven members. Although lithologic characteristics of the members enable the mapping of individual units in much of the area, the differences in lithology are commonly too little to make possible the distinction of individual members where the shale is not well exposed east of the Bighorn River. The lower members of the Cody Shale in the Colorado group are an unnamed basal member, the Greenhorn calcareous Member,

TABLE 4.1.2-1

GENERALIZED GEOLOGY OF THE CROW RESERVATION

System	Series	Group, formation, & Member		Thickness (feet)
Quaternary.				0-100±
Tertiary.	Pliocene(?) to Oligocene(?).			0-30
	Eocene	Wasatch formation.		350±
	Paleocene	Fort Union Formation	Tongue River member.	850-1,800
			Lebo shale member.	800-1,000
			Tullock member.	300±
Cretaceous.	Upper Cretaceous	Montana group	Hell Creek Formation.	600-650
			Bearpaw Shale.	300-600±
			Parkman sandstone.	280-350±
			Claggett shale.	425-650
			Eagle sandstone.	100-225
			Telegraph Creek Formation.	320±
		Colorado group	Niobrara shale.	400±
			Carlile shale.	425
			Frontier formation.	400±
			Mowry shale.	200-300
			Thermopolis shale.	525-600
	Lower Cretaceous	Cloverly formation.		320-425
		Morrison formation.		?-400
Jurassic	Upper Jurassic	Sundance formation.		400-480
		Unconformity		
Triassic and Carboniferous (Permian)(?).		Chugwater formation.		500-655
		Unconformity		
Carboniferous.	Pennsylvanian.	Tensleep sandstone.		45-75
		Amsden formation.		155-365
		Unconformity		
	Mississippian.	Madison limestone.		1,300±
		Unconformity		
Ordovician.	Upper Ordovician.	Bighorn dolomite		300±
		Unconformity		
Cambrian.	Upper Cambrian.	Deadwood formation.		900±
Pre-Cambrian.				(?)

SOURCE: U.S.D.I., Geological Survey, Bulletin 856



GEOLOGIC AN
OF BIGHO
YELLOWSTONE COUNTY
BIG HORN COUNTY
CROW INDIAN RESERVATION
SITE 1
R 29 E.

FIGURE 4.1.2-1

OLOGIC AND STRUCTURE CONTOUR MAP OF BIGHORN CANYON-HARDIN AREA

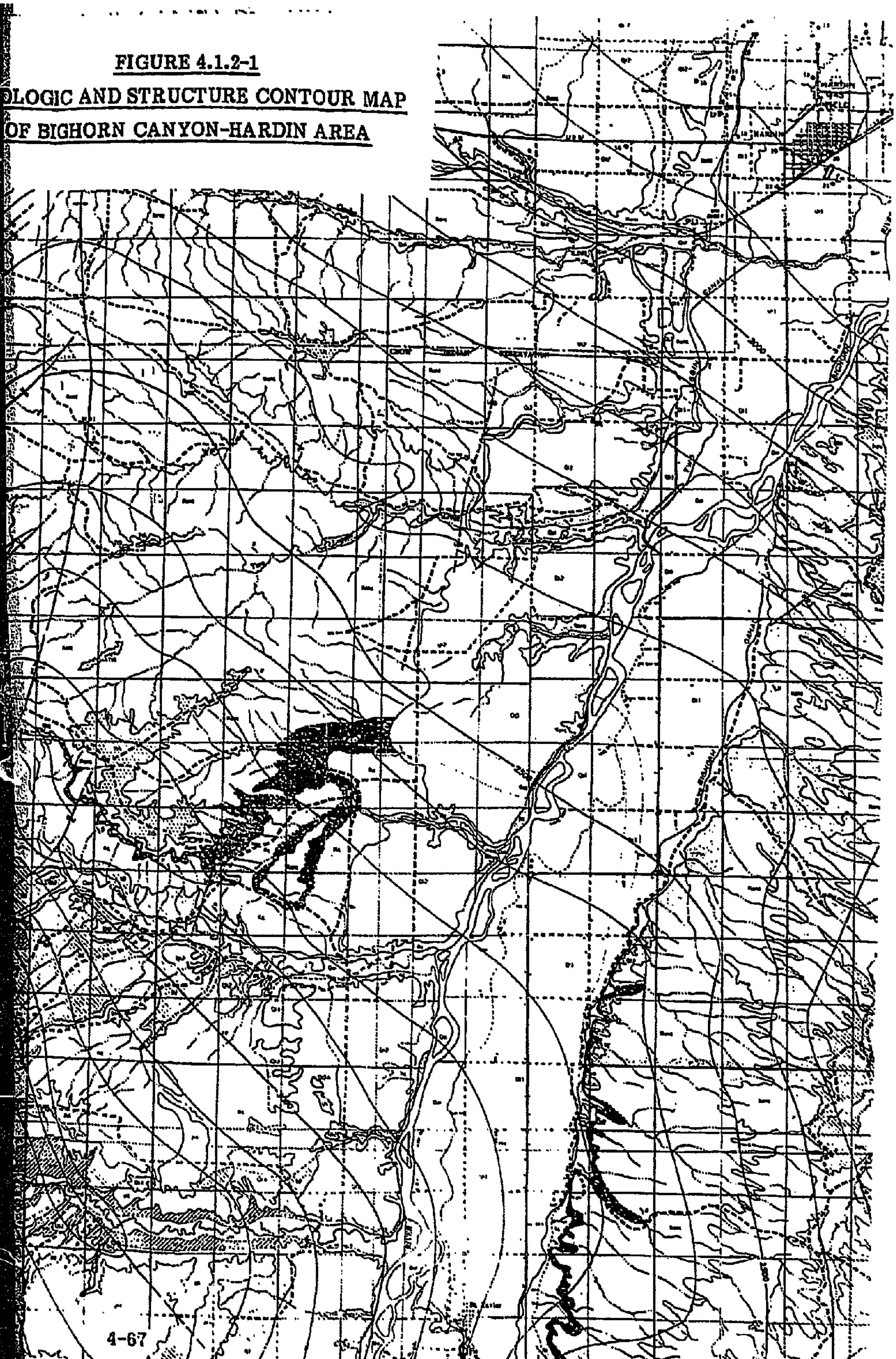


Figure 4.1.2-2

EXPLANATION

QUATERNARY — Recent

Qal

Alluvium
Unconsolidated silt, sand, and gravel; also includes the lowest terrace deposits (Qt1) along tributary streams of the Bighorn River

Landslide material

Undifferentiated surficial deposits on erosional surfaces
Mostly pediments, some of which are covered with reworked terrace gravels

QUATERNARY — Pleistocene; TERTIARY — Pliocene (?)

Stream terrace deposits
Terraces along Bighorn River and its tributaries covered by about 25 feet of unconsolidated silt, sand, and gravel. Qt1 is lowest and youngest surface, Tt8 is highest and oldest surface. A + or − indicates an intermediate level. Qt and Tt are uncorrelated surfaces away from the Bighorn River

CRETACEOUS — Upper Cretaceous

Khc

Hell Creek formation
Sandstone which supports growth of pine trees; lower few feet exposed only in northeast corner of area

Bearpaw shale
Dark-gray shale with numerous bentonite beds

Parkman sandstone
Upper part mostly massive yellowish-brown sandstone; lower part gray sandy shale

Cody shale
Dark-gray shale, in part bentonitic and in part sandy; Kcc, Claggett shale member—dark-gray bentonitic shale; Kcs, shale member equivalent to Eagle sandstone—dark-gray shale with many ironstone concretions; thin sandy zone indicated by "ss"; Kct, Telegraph Creek member—sandy shale, weathers to buff soil; Kcnc, Niobrara and Carlile shale members—dark-gray bentonitic shale; thin zone of calcareous shale, indicated on map by "z"; Kcg, Greenhorn calcareous member—dark-gray calcareous shale; Kc, lower shale member; Kcu, upper part of Cody shale undifferentiated in area south of Little Bighorn River, east of Bighorn River, and along Rotten Grass Creek

Frontier formation
Dark-gray sandy shale

CRETACEOUS — Lower Cretaceous

Mowry shale
Gray partly siliceous shale, siltstone, and sandstone

Thermopolis shale
Dark-gray bentonitic shale

CRETACEOUS / JURASSIC — Upper Jurassic

KJu

Cloverly and Morrison formations
Cloverly formation (Kcl): upper zone of shale and siltstone with rusty beds, middle zone of variegated shale, and lower basal lenticular conglomeratic sandstone—Pryor conglomerate member. Morrison formation (Jm) mostly green sandstone and siltstone with variegated shale locally. In areas where there is no Pryor conglomerate member, the two formations are undifferentiated (KJu)

JURASSIC — Upper Jurassic and Middle Jurassic — Ellis group

Swift and Rierdon formations, undifferentiated
Swift formation green and brown glauconitic fossiliferous sandstone, siltstone, and shale; Rierdon formation brownish calcareous shale with fine-grained ledge-forming sandstone and sandy limestone at top

Piper formation
Red shale and sandstone and gray limestone above basal gypsum beds

UNCONFORMITY (?)

PERMIAN AND TRIASSIC

Chugwater formation
Red sandstone and siltstone; north of Porcupine Creek, gypsum and thin beds of limestone in lower part indicated by "a", equivalent to Embar formation; a 5-foot bed of limestone 100 feet below top may be Alcova limestone

PERMIAN

Pe

Embar formation
Red siltstone and sandstone and light-gray dolomite and limestone. Mapped only in area from Crooked Creek to Porcupine Creek

UNCONFORMITY

PENNSYLVANIAN

Pt

Tensleep sandstone
Gray to buff sandstone and a few thin beds of dolomite

PENNSYLVANIAN / MISSISSIPPIAN

Pa

Amsden formation
Interbedded red shale and sandstone and thin beds of limestone, dolomite, and chert; basal 50 feet red shale and siltstone

UNCONFORMITY

MISSISSIPPIAN

Mm

Madison limestone
Light-gray to light-brown dense and finely crystalline limestone with some dolomitic limestone

UNCONFORMITY

DEVONIAN — Upper Devonian

Three Forks shale and Jefferson limestone, undifferentiated
Greenish and brownish shaly limestone and dolomite, upper part contains well-rounded frosted sand grains

UNCONFORMITY

ORDOVICIAN — Upper Ordovician

Ob

Bighorn dolomite
Massive cliff-forming dolomitic limestone overlain by thin-bedded dolomite

UNCONFORMITY (?)

CAMBRIAN — Middle and Upper Cambrian

Gallatin limestone and Gros Ventre formation, undifferentiated
Formation crops out only in Bighorn Canyon where the base is not exposed and most of the strata are concealed; contains thin-bedded limestone, shale, and sandstone at top and intraformational limestone, conglomerate, and shale below

Contact
Dashed where approximately located, dotted where concealed

U
D
Fault
Dashed where approximately located, dotted where concealed. U, upthrown side; D, downthrown side

Strike and dip of beds

4500
Structure contour
Drawn on top of the Mowry shale; interval, 100 feet; datum, mean sea level. Structure contours in area stratigraphically lower than the Mowry shale were extrapolated from the Madison limestone

Axis of anticline
Dashed where approximately located

Axis of syncline
Dashed where approximately located

Irrigation canal

53
Oil well

38
Shut-in oil well

18
Gas well

W 32
Dry hole
W, where used as water well

Well numbers referred to in table 4

U. S. Coast and Geodetic Survey benchmark
Elevation in feet

Dam

and the combined Carlile and Niobrara Shale Members, the total thickness being about 1,000 feet. Members of the Cody Shale which belong to the Montana group are the Telegraph Creek Member, a shale unit equivalent to the Eagle Sandstone, and the Claggett Shale Member. Rocks in the Montana Group part of the Cody Shale are about 1,600 feet thick.

Inasmuch as the dark-gray shale of the Cody Shale is relatively homogeneous in composition and uniform in its resistance to erosion, low, rounded hills are typical of Cody outcrops in the Hardin area. Some high topographic relief has resulted in the plains, however, where terrace gravels in high-elevation remnants have preserved the underlying shale from erosion. Very little vegetation grows on the Cody Shale except where silt has been deposited on it by streams or wind.

The Cody Shale in this region was measured and fossils were collected and identified by W. A. Cobban (Richards, 1955). Several members, including the Niobrara and Carlile, were characterized by Richards (1955). They are summarized as follows:

Lower Member of the Cody shale. The lower member of the Cody Shale consists of concretionary dark-gray shale and has several thin, lenticular beds of sandstone in its lower part. The member is about 200 feet thick in the southern part of the area and is somewhat thicker in Woody Creek valley. On the east side of Soap Creek Dome, an 8-foot bed of bentonite occurs about 60 feet above the base of the formation, but in Woody Creek valley the interval between the Soap Creek bentonite bed at the top of the Frontier Formation and the next higher bentonite layer is only 30 feet. The concretions found throughout the Cody Shale commonly are septarian, calcareous, and brown to gray in color. The member and the underlying Frontier Formation are equivalent to the Belle Fourche Shale in the Black Hills region of South Dakota.

Greenhorn Calcareous Member. The calcareous Greenhorn Member of the Cody Shale ranges in thickness from about 60 feet on the north side of Woody Creek Valley to nearly 100 feet on the east flank of Soap Creek Dome. It is composed of dark-gray, very calcareous shale which weathers to nearly white soil that is conspicuous on dry, sunny days. Its base is marked by a bed of gray limonitic bentonite and its top by a change from calcareous chunky shale in the Greenhorn Member to noncalcareous fissile shale in the Carlile Shale Member.

Thom collected several forms of the ammonite genus Vascoceras from concretions 40 feet above the base of the Greenhorn east of Soap Creek Dome (Thom et al., 1935, p. 49-51). Reeside identified them as the only specimens of the genus found in North America outside the state of Coahuila, Mexico (References 8, 9).

Carlile Shale Member. The Carlile Shale Member is about 280 feet thick and consists chiefly of dark-gray shale, which is sandy in the lower part. Two zones of concretions, one about 75 to 100 feet above the base, and one about 90 feet below the top, crop out widely within the area. Concretions of the lower zone occur in thin beds in a stratigraphic interval of about 25 feet. They are thin, very hard, gray on fresh surfaces, red to brown on weathered surfaces, and soluble in hot hydrochloric acid. This zone is an easily recognized stratigraphic horizon because the "rusty" concretions are the only ones of their kind below the Telegraph Creek Member and they are conspicuous on the shale surfaces.

The upper concretionary zone contains light-brown to grayish-orange septarian concretions and is well exposed near the top of the hill in the SW 1/4 Sec. 36, T6S, R32E. Elsewhere in the area, the zone forms small ledges. This horizon was mapped by Thom as the base of the Niobrara Shale (Thom et al., 1935, p. 52), but Cobban, after examining the fauna he collected, placed the contact nearly 100 feet above the zone of concretions. (References 8, 9).

Niobrara Shale Member. The Niobrara Shale Member, which is a little more than 400 feet thick where measured by Cobban on the east side of the Bighorn River south of Hardin, crops out along the northern and eastern edge of the area. It consists of dark-gray shale, many thin beds of bentonite, and several beds of septarian concretions. A 10-foot bed of calcareous shale about 90 feet above the base of the member weathers to form a band of yellowish-colored soil extending along the east side of the Bighorn valley from near Two Leggin Bridge southward past St. Xavier into the Rotten Grass Creek valley. This same bed forms a thin band of white soil south of Beauvais Creek and east of the airplane beacon in Sec. 30, T4S, R31E, where it looks very much like the calcareous Greenhorn Member. As the zone can be traced throughout most of the area, it was mapped wherever possible.

Unless exposures are good, the Carlile and Niobrara Shale Members are difficult to distinguish, so the two members were mapped together. The contact of the Niobrara Shale Member with the overlying Telegraph Creek Member is gradational between shale in the Niobrara and sandy shale in the Telegraph Creek Member. The contact is concealed in much of the area but can be mapped because the sandy shale of the Telegraph Creek Member forms yellow soil, whereas the Niobrara Shale Member forms gray soil.

Telegraph Creek Member. The Telegraph Creek Member crops out along the northern and eastern edges of the area. It was first named the Telegraph Creek Formation by Thom, who stated that the formation consists of 320 feet of light-colored sandy shales that crop out in T2S, R28-29E between the top of the Niobrara Shale and the base of the Virgelle Sandstone Member of the Eagle Sandstone. The writer and members of his party measured a total thickness of 785 feet of what is considered to be an equivalent unit, as follows: the upper 440 feet in Sec. 6, T2S, R29E, the middle 140 feet along the drainage divide in Sec. 17, T2S, R29E, and the lower 205 feet in the east-central part of T1S, R30E. The Telegraph Creek Member is 850 feet thick where measured by Cobban east of Little Bighorn River in T2D, R34E (References 8, 9).

Throughout the vicinity of Hardin, the Telegraph Creek Member is sandy shale that contains a few thin beds of sandstone and calcareous concretions. Most of the sand occurs in laminae and thin stringers in the shale; some of it is calcareous. Weathered surfaces on the Telegraph Creek Member are yellowish-gray, and they contrast moderately with the weathered gray shale of the Niobrara. However, the contact of the two members in the shale bluffs along the Bighorn River east of Hardin is not discernible from a distance, because the basal part of the Telegraph Creek is neither sufficiently sandy nor sufficiently weathered to have a color different from the color of the underlying shale.

The Telegraph Creek Member was described by Reeside as containing a mixed Eagle and Niobrara fauna (Thom et al., 1935, p. 54); nevertheless the Telegraph Creek Member is considered to be the basal part of the Montana Group. Cephalopods from the Telegraph Creek Member have been described and figured by Reeside (1927).

Shale Member Equivalent to the Eagle Sandstone. The Eagle Sandstone forms prominent ledges and cliffs north of U.S. Highway 87 in T1S, R29E, but it grades eastward into shale and becomes inconspicuous east of the Bighorn River in T1N, R33E. A unit of shale at a corresponding stratigraphic horizon north of the Little Bighorn River and east of the Bighorn River contains fossils considered by Cobban to be typical of the Eagle fauna. This unit has been mapped as a distinct member of the Cody Shale north of the Little Bighorn River, but it could not be mapped separately south of the Little Bighorn River.

The shale member is 375 feet thick where measured by Cobban in Sec. 13, T1N, R34E. It consists of three units: (1) 50 feet of dark-gray shale at the base with several beds of ironstone concretions generally similar in appearance to those in the Carlile Shale member: (2) 215 feet of yellowish-gray, weathering, silty shale with many ironstone concretions in the middle; and 90 feet of dark-gray shale which weathers brownish-gray and contains some septarian and ironstone concretions. A 20-foot zone of bentonite and bentonitic shale at the top of the middle unit forms a gray band across the surface. A thin, sandy zone, which makes small ledges about 160 feet above the base, is a good horizon marker in the area north of the Little Bighorn River and has been shown on the geologic map (Figure 4.1.2-2).

Claggett Shale Member. The Claggett, the topmost member of the Cody Shale, is about 350 feet thick north of the Little Bighorn River in the only part of the Bighorn Canyon-Hardin area in which it was mapped as a separate unit. It also crops out south of the Little Bighorn River, but there much of it is concealed and it cannot be separated from the underlying shale. The Claggett consists of dark-gray shale that is bentonitic in the lower part and concretionary throughout. Two beds of grayish-yellow bentonite at the base are overlain by nearly 70 feet of shale which weathers to a lighter color than the underlying shale and which contains several thin beds of bentonite. The shale above the bentonite zone contains a number of calcareous septarian concretions.

Large forms of Baculites and Inoceramus occur in reddish-brown septarian concretions near the top of the member at some localities. The contact between the Claggett Shale Member and the overlying Parkman Sandstone is the base of sandy shales in the Parkman.

A series of test holes were recently drilled by Woodward-Clyde Consultants in Secs. 9, 16, and 17, T2S, R31E, slightly north of the candidate Site 1 area (1980). The results of this preliminary test drilling showed stiff to very stiff clays over hard to very hard bedrock, presumably the Niobrara and Carlile Members of the Cody Shale formation, at depths of 3 to 7 feet. The upper 5 feet of bedrock had weathered in one of the test holes. Additionally, the clays were silty, sandy, calcareous, and occasionally porous. The claystone bedrock was slightly sandy to sandy and contained scattered bentonitic clay lenses.

Anticlines and Domes

Soap Creek Anticline. The Soap Creek Anticline extends from Rotten Grass Creek in the southern part of T7S, R33E northwestward to the Bighorn River in Sec. 25, T5S, R31E, north of which the anticline is concealed by extensive deposits of terrace gravel. Rotten Grass dome is near the south end of the anticline and Soap Creek Dome near the middle.

Soap Creek Dome. Soap Creek Dome, which is the only oil-producing structure in the area, was first described by Thom and Moulton (1921). The dome is elongate and the axis trends northward across Sec. 34, T6S, R32E. The Morrison Formation is exposed along Soap Creek at the highest structural point on the dome, which has more than 500 feet of structural closure at the surface. Formations above the Morrison are well exposed on the steeply dipping east flank of the dome, but they are concealed beneath terrace deposits on the gently dipping west flank.

Rotten Grass Dome. Rotten Grass Dome, in the SE1/4 Sec. 29, T7S, R33E, has a structural closure at the surface of less than 200 feet. Rocks exposed in and around the dome range from the top of the Mowry Shale to the Greenhorn calcareous Member of the Cody Shale. The asymmetry of the dome is opposite to that of Soap Creek Dome, and beds exist which dip less than 5 degrees on the east side of the dome dip as much as 25 degrees on the west side. The Western States Oil and Land Company's well No. 1, in the SW1/4 SW1/4 Sec. 28, T7S, R33E, was drilled in 1921 to the Morrison Formation and abandoned as a dry hole. It encountered water in the Cloverly Formation.

Reed Dome. Reed Dome is in the SW1/4 Sec. 35, T7S, R32E and the NW1/4 Sec. 2, T8S, R32E. It is west of Rotten Grass Dome and is at the eastern edge of the Bighorn Mountains. Rocks from the Chugwater Formation to the Morrison Formation are exposed in the uplift and, although the dip of beds on the flanks is steep, the structural closure is less than 200 feet at the surface. A well described only as being in Sec. 2, T7S, R32E, was drilled to a depth of 100 feet and abandoned as a dry hole.

Woody Creek Dome. Woody Creek Dome is centered in the N1/2 Sec. 33, T°S, R31E, south of Woody Creek. The dome is cut by a northeast-trending fault and has about 200 feet of closure on the southeast side and a little more than 100 feet of closure on the northwest side of the fault. Mowry Shale is exposed along the fault, and the Frontier Formation and the lower part of the Cody Shale cropout around the dome. The axis of the anticline on which the dome is located continues southeastward and disappears under extensive terraces near the Bighorn River. This axis, however, is not in line with that of the Soap Creek Anticline, the north end of which is also concealed beneath the terraces. A northward continuation of the axis from the Woody Creek dome forms the Two Leggin Uplift.

Beauvais Creek Uplift. The Beauvais Creek Uplift, which is north of Grapevine Dome, represents the northernmost recognized structural feature of the northward-plunging Bighorn Mountain Anticline. It is traversed by the eastward-flowing Beauvais Creek and outlined on the northern and eastern sides by Mowry Shale hogbacks. Reversals of the general northward dip in the area have made several small domes. Of these, Point Creek Dome, in NW1/4 Sec. 29, T4S, R30E, has structural closure of less than 100 feet. Another small dome, south of Point Creek, also has less than 100 feet of surface closure. Several wells drilled in T4S, R29-30E, encountered water in the Tensleep Sandstone and were abandoned as dry holes.

Hardin Gas Field. The Hardin gas field, in and around the town of Hardin, yields dry gas from sandy shale at an average depth of about 725 feet in what has been called the Frontier Formation. The sandy shale, however, probably is somewhat higher stratigraphically than the top of the Frontier Formation as mapped in this report. Elevations on the top of the producing zone in the wells indicate a low northward dip, similar to dips observed in shale outcrops east and west of Hardin. The surface formation, the Cody Shale, is concealed by terrace gravels at most places other than in river bluffs, but no faults that might have caused a trap for the gas were found in or near Hardin. The reservoir probably is a stratigraphic trap caused by sandy shale changing to shale or pinching out in the updip, southerly direction.

Ninemile and Hardin Areas. The Ninemile area lies along Dry Creek and Ninemile Coulee north of the Little Bighorn River and east of the Bighorn River. The steeply dipping, faulted Parkman Sandstone extends from the Little Bighorn River northward along the eastern edge of Sec. 12, T1S, R34E to Sec. 35, T1N, R34E and thence westward to the Bighorn River in Sec. 23, T1N, R33E; it marks in general the northern and eastern boundary of the Ninemile area. The Ninemile area lies mainly on a poorly defined anticlinal nose that plunges northward east of Hardin. North of the Little Bighorn River there are no anticlines with surface closure of 100 feet or more.

The Hardin gas field is centered in the town of Hardin, about 6 miles south of the mouth of Ninemile Coulee. The area surrounding Hardin, including the gas field, is called loosely the Hardin area, and no well-defined border is located between the Ninemile and Hardin areas. The Marcus Snyder Field was named upon the discovery of oil during 1952 in the G. J. Greer No. 2 Kendrick well just east of the Parkman Sandstone in the NE1/4 NW1/4 NW1/4 Sec. 6, T1S, R35E. No distinct boundary separates this field from the Ninemile and Hardin areas. An area of about 6 to 7 square miles within the 1,800-foot structure contour lies about 5 miles southeast of Hardin and along the Little Bighorn River. This small anticlinal structure is on the broad anticlinal nose that strikes northward from the Little Bighorn River in the south-central part of T1S, R34E through the Ninemile area, and southwestward from the Little Bighorn River toward Soap Creek Anticline.

The Parkman Sandstone around the northern and eastern flanks of the Ninemile area dips locally as much as 20 degrees northward and eastward. Steeper dips are common along faults. These steep dips persist along the outcrop of the Parkman sandstone just east of the mapped area. Westward dips in the Cody Shale are low along the western flank of the anticlinal nose that plunges northward through the Hardin and Ninemile areas, commonly less than 3 degrees. There are no closed anticlines in the Ninemile area and only one small, closed anticline in the Hardin area along the Little Bighorn River. Northward thinning of the Chugwater Formation may increase the closure on the top of the Tensleep Sandstone or Madison Limestone in the Little Bighorn River area. This thinning is at a rate of about 10 feet per mile from the latitude of Bighorn Canyon northward to the H. L. Hunt No. 1 Kendrick Cattle Co. well in the SE1/4 SE1/4 Sec. 24, T1N, R34E, Big Horn County, Montana.

Faults

The faults in the Bighorn Canyon-Hardin area are simple and have small displacement except for two fault zones: the Lake Basin-Huntley zone northeast of Hardin and the Sykes Spring zone at the south end of the Pryor Mountains. In the plains area north and northeast of the Bighorn Mountains, isolated small faults were found only because they are visible on aerial photos.

Sykes Spring Fault Zone. The Sykes Spring fault zone, named by Blackstone for the springs which rise along the faults (1940, p. 603), extends southward from East Pryor Mountain, through Secs. 27 and 34, T9S, R28E, Carbon County, Montana, and Secs. 23 and 26, T58N, R95W, Big Horn County, Wyoming, to Sykes Mountain south of Crooked Creek. The zone is about 5 miles long and not over 1/4 mile wide and consists of two or three northward-striking faults with associated shorter en echelon faults. The Sykes Spring faults transect rocks from the Madison Limestone in East Pryor Mountain to the Cloverly formation in Sykes Mountain.

Blackstone described the Sykes Spring faults as being controlled by a zone of structural weakness in the basement rocks that is common to the Sykes Spring faults and the Dry Head fault which lies along the east flank of East Pryor Mountain and north of the Sykes Spring fault zone (1940, p.612). The Sykes Spring faults formed as part of the Pryor Mountain structures, but their origin seems to have been associated with, or is in part a result of, the forming of Porcupine Creek Anticline which is an unfaulted northwestward-plunging extension of the western flank of the Bighorn Mountains. The Porcupine Creek Anticline abuts the Pryor Mountains opposite the mouth of Porcupine Creek.

Bighorn Canyon Area. A near-vertical fault at least 6 miles long strikes eastward across Bighorn Canyon through T8S, R28-29E. The fault has a downthrow of about 225 feet on the south where it crosses Bighorn Canyon. This is the only fault that was observed to cross Bighorn Canyon. Bedding plane faults may occur in steeply dipping beds of the west flank of Bighorn Canyon along the eastern edge of T7S, R29E.

Grapevine Creek Area. An easterly trending fault, in Secs. 24 and 25, T5S, R29E and Secs. 20 and 30, T5S, R30E, cuts the north and northeast sides of Grapevine Dome. Chugwater strata that dip about 30 degrees eastward are offset 1,100 feet to the east on the south side of the fault, and the Chugwater Formation is thinned considerably on the north side of the dome. A short fault trends northward across the outcrop of the basal sandstone of the Cloverly Formation in the southeastern part of Sec. 6 to the basal part of the Chugwater Formation in Sec. 7, T6S, R31E, a short distance north of the mouth of Bighorn Canyon. Both of these faults in the Grapevine Creek area are near lines of change in strike and dip of the strata on the edge of the Bighorn Mountains, and they undoubtedly were formed during the deformation that created the mountain structure.

Woody Creek Dome. A near-vertical fault crosses Woody Creek Dome, trending from Sec. 33, T3S, R31E into Sec. 11. This fault dies out in a very short distance in the Cody Shale south of the dome and has a maximum vertical displacement of about 100 feet. A similar fault in Secs. 3 and 9, west of the anticlinal axis extending northward from Woody Creek dome, has prominent surface expression as, on the north side of Woody Creek valley, it displaces the white-weathering Greenhorn calcareous Shale Member of the Cody Shale nearly 100 feet. Several other smaller faults on the north side of the valley are en echelon to the Woody Creek Dome fault, and they occur in a belt parallel to the axis of the northward-plunging Two Leggin uplift. Structural closure along the faults is less than 100 feet. One of these faults, approximately 5 miles in length, nearly bisects the proposed Site 1 area as shown in Figure 4.1.2-1.

Ninemile Area. Ten faults ranging from 1/2 mile to 2-1/2 miles in length cross the Parkman Sandstone in Secs. 23, 24, and 25, T1N, R33E and the southwestern part of T1N, R34E. These faults generally trend perpendicular to the strike of the Parkman sandstone, and the faults die out shortly after entering the shales that overlie and underlie the sandstone. The maximum horizontal displacement of the Parkman sandstone is about 3,000 feet. These faults are at the eastern end of the Lake Basin-Huntley fault zone, a narrow belt of northeastward-trending faults extending for about 100 miles northwestward through the town of Huntley and north of Billings to the Lake Basin area in Golden Valley County (Hancock, 1918, 1920). (Reference 53).

As the trend of most of the faults in the Ninemile area is perpendicular to, rather than parallel to, the strike of the formations, there is little or no structural closure along the faults. There seems to be a definite association of these faults with the Parkman Sandstone, and it seems probable that the faults follow the Parkman sandstone downdip and continue to die out in the shale above and below the Sandstone. If the deforming forces broke the sandstone beds and deformed the shale plastically, other sandstones—such as the Pennsylvanian Tensleep sandstone—which are stratigraphically lower than the Parkman may be cut by an entirely different set of faults that is seen in the surface formations.