Prepared in cooperation with the State of South Dakota,
West Dakota Water Development District, and the
U.S. Department of Agriculture (Forest Service)

Hydrologic Effects of the 1988 Galena Fire, Black Hills Area, South Dakota

Water-Resources Investigations Report 03-4323




U.S. Department of the Interior
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By Daniel G. Driscoll and Janet M. Carter, U.S. Geological Survey, and Donald O. Ohlen, SAIC, EROS Data Center, Sioux Falls, South Dakota

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Rapid City, South Dakota: 2004

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CONTENTS

FIGURES

FIGURES—Continued

TABLES

CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
acre	4,047	square meter
acre	0.4047	hectare
cubic foot per acre (ft^3/acre)	0.0700	cubic meters per hectare
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
cubic foot per second per square mile [(ft^3/s)/mi^2]	0.01093	cubic meter per second per square kilometer
cubic yard (yd^3)	0.7646	cubic meter
foot (ft)	0.3048	meter
inch (in.)	2.54	centimeter
inch (in.)	25.4	millimeter
inch per year (in/yr)	25.4	millimeter per year
mile (mi)	1.609	kilometer
square mile (mi^2)	259.0	hectare
square mile (mi^2)	2.590	square kilometer
tons per acre (tons/acre)	2.242	metric tons per hectare

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F = (1.8 \times °C) + 32$$

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$°C = (°F - 32) / 1.8$$

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29); horizontal coordinate information is referenced to the North American Datum of 1927 (NAD 27).

Water year (WY): Water year is the 12-month period, October 1 through September 30, and is designated by the calendar year in which it ends. Thus, the water year ending September 30, 1998, is called the “1998 water year.”

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ABSTRACT

The Galena Fire burned about 16,788 acres of primarily ponderosa pine forest during July 5-8, 1988, in the Black Hills area of South Dakota. The fire burned primarily within the Grace Coolidge Creek drainage basin and almost entirely within the boundaries of Custer State Park. A U.S. Geological Survey gaging station with streamflow records dating back to 1977 was located along Grace Coolidge Creek within the burned area. About one-half of the gaging station's 26.8-square-mile drainage area was burned. The drainage basin for Bear Gulch, which is tributary to Grace Coolidge Creek, was burned particularly severely, with complete deforestation occurring in nearly the entirety of the area upstream from a gaging station that was installed in 1989.

A study to evaluate effects of the Galena Fire on streamflow, geomorphology, and water quality was initiated in 1988. The geomorphologic and water-quality components of the study were completed by 1990 and are summarized in this report. A data-collection network consisting of streamflow- and precipitation-gaging stations was operated through water year 1998 for evaluation of effects on streamflow characteristics, including both annual-yield and peak-flow characteristics, which are the main focus of this report.

Moderately burned areas did not experience a substantial increase in the rate of surface erosion; however, severely burned areas underwent surficial erosion nearly twice that of the unburned areas. The sediment production rate of Bear Gulch estimated 8 to 14 months after the fire was 870 ft^3/acre (44 tons/acre). Substantial degradation of stream channels within the severely burned headwater areas of Bear Gulch was documented. Farther downstream, channel aggradation resulted from deposition of sediments transported from the headwater areas.

The most notable water-quality effect was on concentrations of suspended sediment, which were orders of magnitude higher for Bear Gulch than for the unburned control area. Effects on several other water-quality constituents, such as organic carbon and nitrogen and phosphorus nutrient constituents, probably were influenced by the large concentrations of suspended matter that were documented in initial post-fire, storm-flow events. The first post-fire stormflow produced the highest measured concentrations of specific conductance, nitrogen, phosphorus, organic carbon, calcium, magnesium, potassium, manganese, and sulfate in the burned areas. For most constituents sampled, differences in concentrations between burned and unburned areas were no longer discernible within about 1 year following the Galena Fire.

The effects of the Galena Fire on annual-yield characteristics of Grace Coolidge Creek were evaluated primarily from comparisons with long-term streamflow records for Battle Creek, which is hydrogeologically similar and is located immediately to the north. Annual yield for Grace Coolidge Creek increased by about 20 percent as a result of the fire. This estimate was based on relations between annual yield for Grace Coolidge Creek and Battle Creek for pre- and post-burn periods. Many of the post-burn data points are well

beyond the range of the pre-burn data, which is a source of uncertainty for this estimate.

Substantial increases in peak-flow characteristics for severely burned drainages were visually apparent from numerous post-fire field observations. Various analyses of streamflow data indicated substantial increases in peak-flow response for burned drainage areas; however, quantification of effects was particularly difficult because peak-flow response diminished quickly and returned to a generally pre-burn condition by about 1991. Field observations of vegetation and analysis of remotely sensed data indicated that establishment of grasses and forbs occurred within a similar timeframe. Comparison of pre-fire peak flows to post-1991 peak flows indicates that these grasses and forbs were equally effective in suppressing peak flows as the predominantly ponderosa pine forest was prior to the Galena Fire.

Numerous peak-flow events with small recurrence intervals occurred within burned areas through 1990. Peak-flow events for Bear Gulch during this period were about one to two orders of magnitude larger than corresponding peaks for a small control drainage located along Grace Coolidge Creek upstream from the burn area. The small peaks do not provide quantitative information applicable to estimation of peak-flow magnitudes for larger events, however. Peak-flow events for Bear Gulch that occurred during 1991-98 were generally similar to those for the control drainage. A short-term increase in peak-flow potential also was documented for the longer-term gaging station located along Grace Coolidge Creek; however, peak-flow response was less pronounced than for Bear Gulch, which had nearly complete deforestation within a much smaller drainage area.

INTRODUCTION

On July 5, 1988, a forest fire was ignited by lightning along Galena Creek, which is a tributary to Grace Coolidge Creek, in the southern Black Hills of southwestern South Dakota. Firefighting efforts initially were largely unsuccessful because of the particularly dry conditions of the predominantly ponderosa pine forest; however, the Galena Fire was controlled the night of July 8 following approximately 0.75 in. of rain. The fire eventually burned about 16,788 acres, primarily within the Grace Coolidge Creek drainage basin and almost entirely within the boundaries of Custer State Park.

A U.S. Geological Survey (USGS) gaging station with streamflow records dating back to 1977 was located along Grace Coolidge Creek within the burned area. About one-half of the gaging station's 26.8-mi^2 drainage area was burned.

The existence of long-term, pre-burn streamflow data provided a unique opportunity to evaluate the hydrologic effects of forest fire, with potential to obtain additional insights regarding effects of timber harvest on streamflow in the Black Hills area. Numerous studies around the world have addressed the topic of hydrologic influences from silvicultural activities; however, information for the Black Hills area is sparse. In 1988, a study to evaluate effects of the Galena Fire on streamflow, geomorphology, and water quality was initiated by the USGS in cooperation with the South Dakota Department of Environment and Natural Resources and the South Dakota Department of Game, Fish and Parks. The geomorphologic (Whitesides, 1989) and water-quality (Gundarlahalli, 1990) components of the study were completed by 1990. A data-collection network consisting of streamflow- and precipitation-gaging stations was operated through water year 1998 for evaluation of effects on streamflow characteristics. Additional cooperators that have supported this continuing component of the study included the South Dakota Department of Agriculture (Forestry Division), West Dakota Water Development District, and U.S. Department of Agriculture (Forest Service).

Purpose and Scope

The purpose of this report is to describe the hydrologic effects of the 1988 Galena Fire. The main focus is to evaluate effects on streamflow characteristics, including both annual-yield and peak-flow characteristics. Results from the studies of geomorphology (Whitesides, 1989) and water quality (Gundarlahalli, 1990) also are summarized.

Acknowledgments

The authors acknowledge the various cooperators that have provided support throughout the extended duration of this study. Thanks are extended to

staff from the Custer State Park Division of the South Dakota Department of Game, Fish and Parks for assisting with data collection and providing various data sets included in this report. Special thanks are due to Custer State Park Resource Program Manager Ron Walker for continued assistance throughout the duration of this study, including assistance with preparation of this report. The authors also thank Paul Horsted (Dakota Photographic LLC), Rollie Larson (retired Rapid City Central High School ecology teacher), and the Rapid City Journal for providing photographs.

DESCRIPTION OF STUDY AREA

The study area (fig. 1) encompasses the area burned by the Galena Fire. The fire burned about one-half of the drainage area for gaging station 06404998, which is located along Grace Coolidge Creek and has pre-fire records dating back to 1977. The study area also includes French Creek, which is generally south of the burn area, and Battle Creek, which is north of the burn area. Available streamflow records for both of these drainages pre-date the Galena Fire and are used for comparisons with records for station 06404998. Following the Galena Fire, station 06404800 was installed along Grace Coolidge Creek just upstream from the burn area. This station is used for comparisons with station 06405800, which also was installed after the Galena Fire and provides streamflow records for the extensively burned Bear Gulch drainage. Drainages considered for comparisons have general similarities in climate, hydrogeology, and land use, as described in the following sections.

Climate

The climate of southwestern South Dakota is continental, with generally low precipitation amounts, hot summers, cold winters, and extreme variations in both precipitation and temperatures (Johnson, 1933). Climatic conditions in the Black Hills area are influenced by orographic effects, with generally lower temperatures and higher precipitation at the higher altitudes.

Precipitation patterns are generally similar in all of the drainage basins considered. Mean annual precipitation for 1961-90 (fig. 2) ranges from about 17 in. in the southeastern part of the study area to more than 20 in. in the higher altitudes. The mean annual temperature is about 44°F at Custer and 45°F at Mt. Rushmore (National Oceanic and Atmospheric Administration, 1991). Annual evaporation potential generally exceeds annual precipitation throughout the study area. Mean pan evaporation for April through October for two stations located near the study area is about 30 in. at Pactola Reservoir (located north of the study area) and about 50 in. at Oral (located southeast of the study area) (National Oceanic and Atmospheric Administration, 1991).

Conditions in the study area prior to the Galena Fire on July 5, 1988, were hot and dry. Precipitation during May was 0.76 in. below normal at Custer and 0.37 in. below normal at Mt. Rushmore; June precipitation at these sites was 1.38 and 1.73 in. below normal, respectively (National Oceanic and Atmospheric Administration, 1988). Daily maximum air temperatures during late May and June prior to the Galena Fire generally were 10 to 20°F higher than normal for the Custer and Mt. Rushmore stations (fig. 3), and mean temperatures for June 1988 for these stations were the highest on record (South Dakota State University, 2003). These high temperatures coupled with scant precipitation created extreme fire potential.

Hydrogeology

Hydrology within the Black Hills area is greatly influenced by geology (Driscoll and Carter, 2001), which is highly complex. The Black Hills uplift is a northwest-trending, asymmetric, elongate dome, or doubly plunging anticline. Uplift began about 62 million years ago during the Laramide orogeny and probably continued in the Eocene period (Redden and Lisenbee, 1996). The oldest rocks in the study area are the igneous and metamorphic rocks of Precambrian age (fig. 4), which are exposed in the "crystalline core" of the central Black Hills (fig. 5). A sequence of younger sedimentary rocks is exposed around the periphery of the Black Hills area and includes outcrops of the Cambrian- and Ordovician-age Deadwood Formation, the Mississippian-age Madison Limestone (also locally known as the Pahasapa Limestone), and the Pennsylvanian- and Permian-age Minnelusa Formation. This layered sequence has been erosionally removed from the crystalline core area. The bedrock sedimentary formations typically dip away from the uplifted Black Hills at angles that can approach or exceed 15 to 20 degrees near the outcrops (Carter and others, 2002).

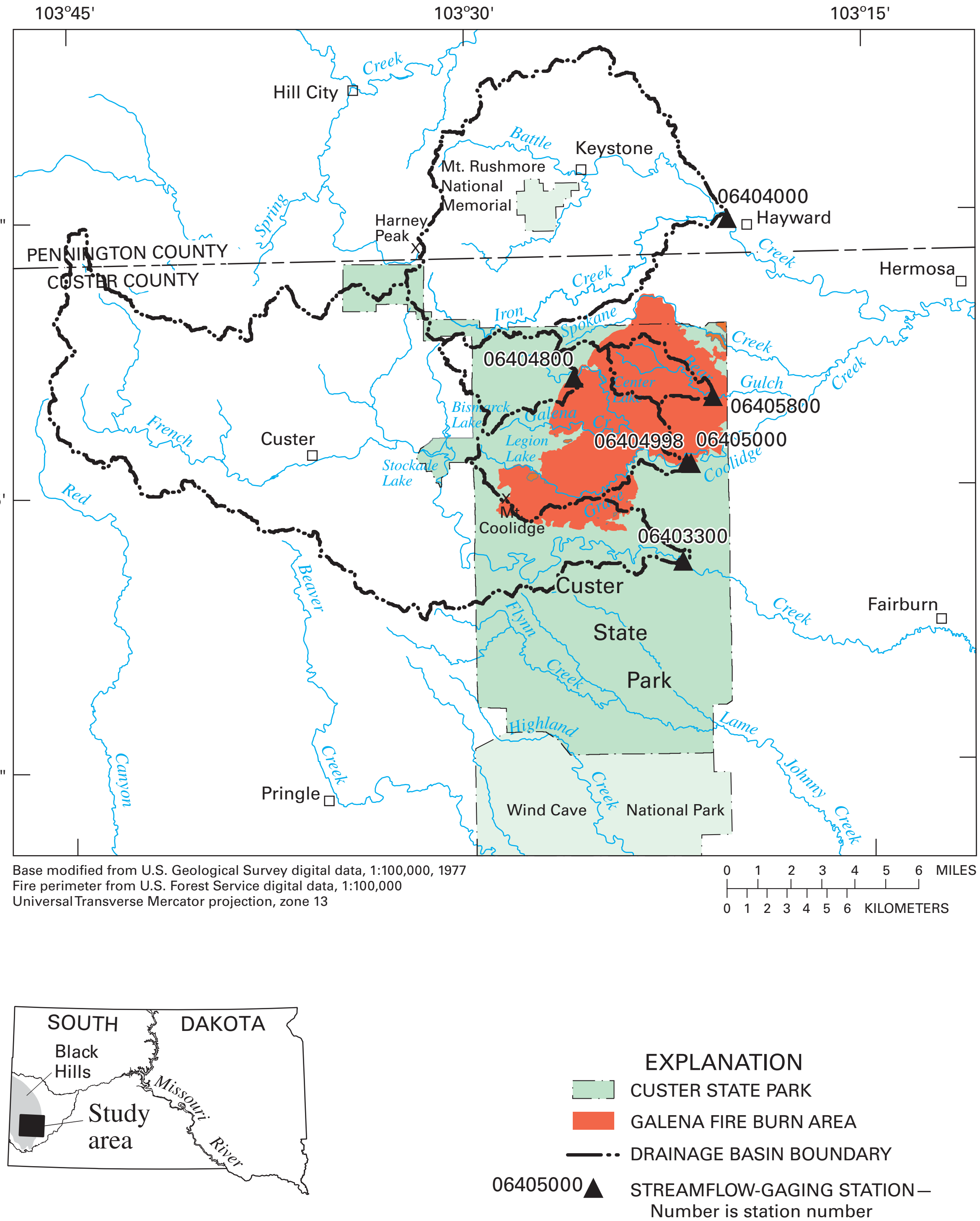


Figure 1. Location of study area. Locations of streamflow-gaging stations within the study area also are shown.

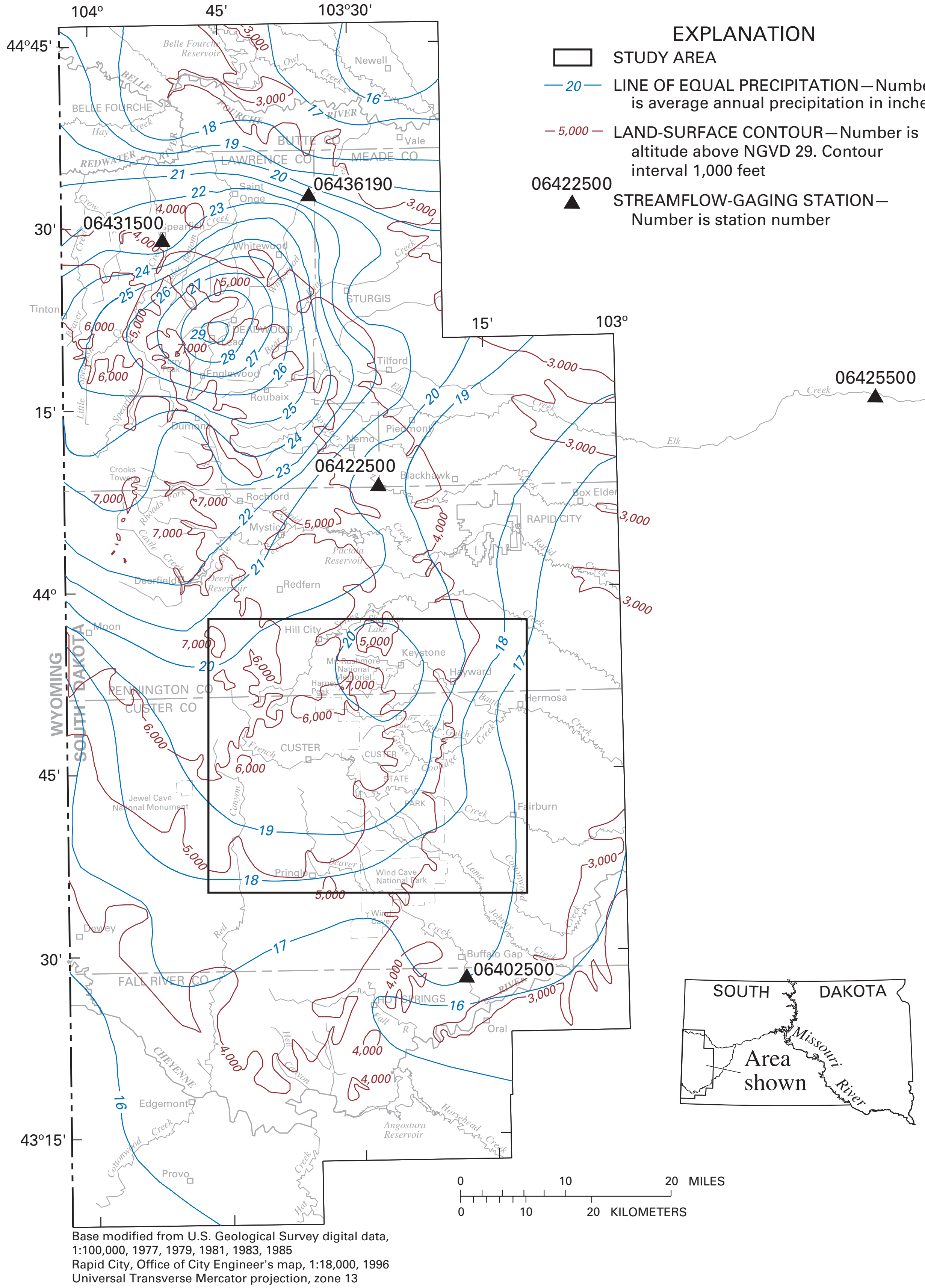


Figure 2. Isohyetal map showing distribution of average annual precipitation for the Black Hills area, water years 1961-90 (from Driscoll and others, 2000). Locations of streamflow-gaging stations outside the study area also are shown.

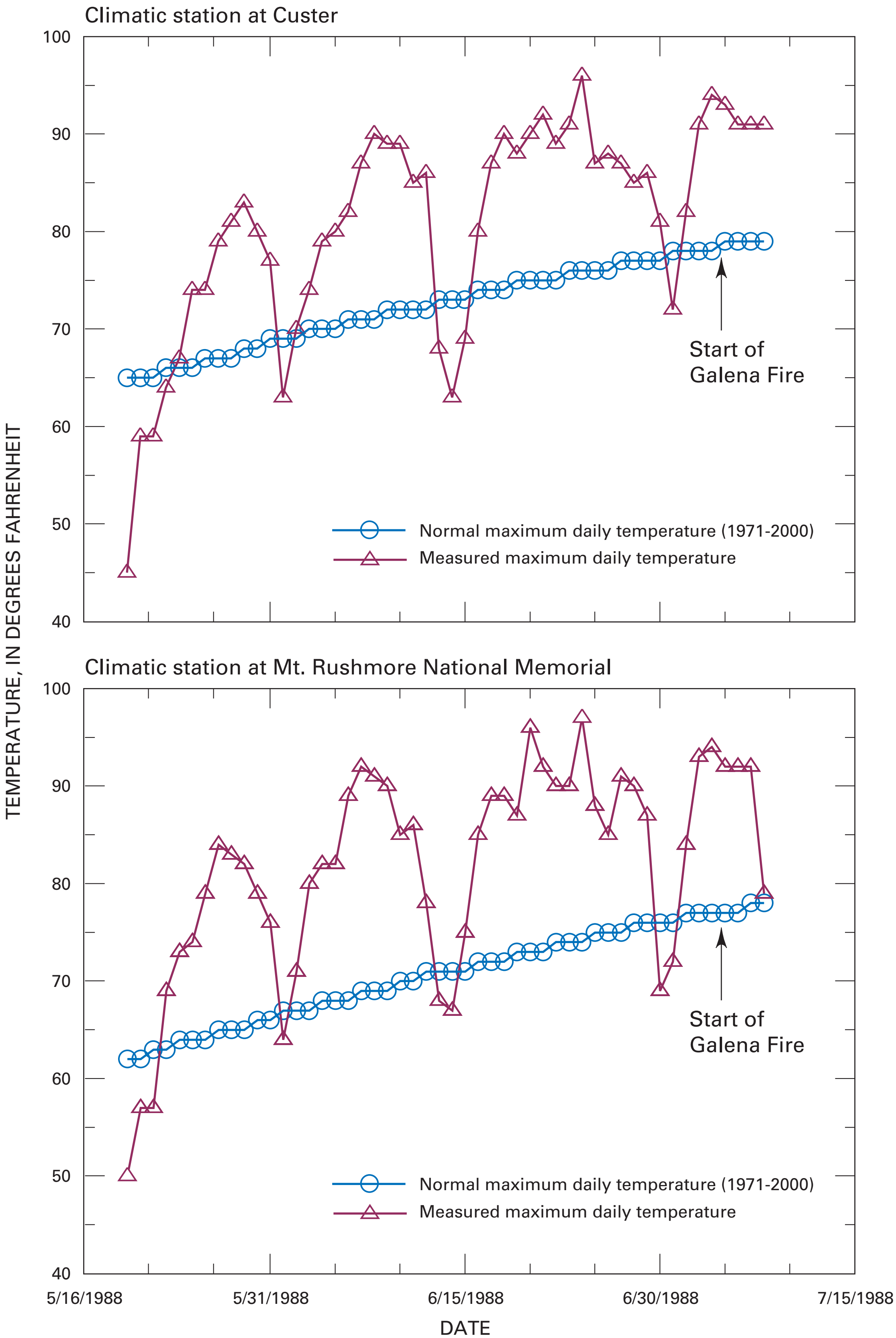


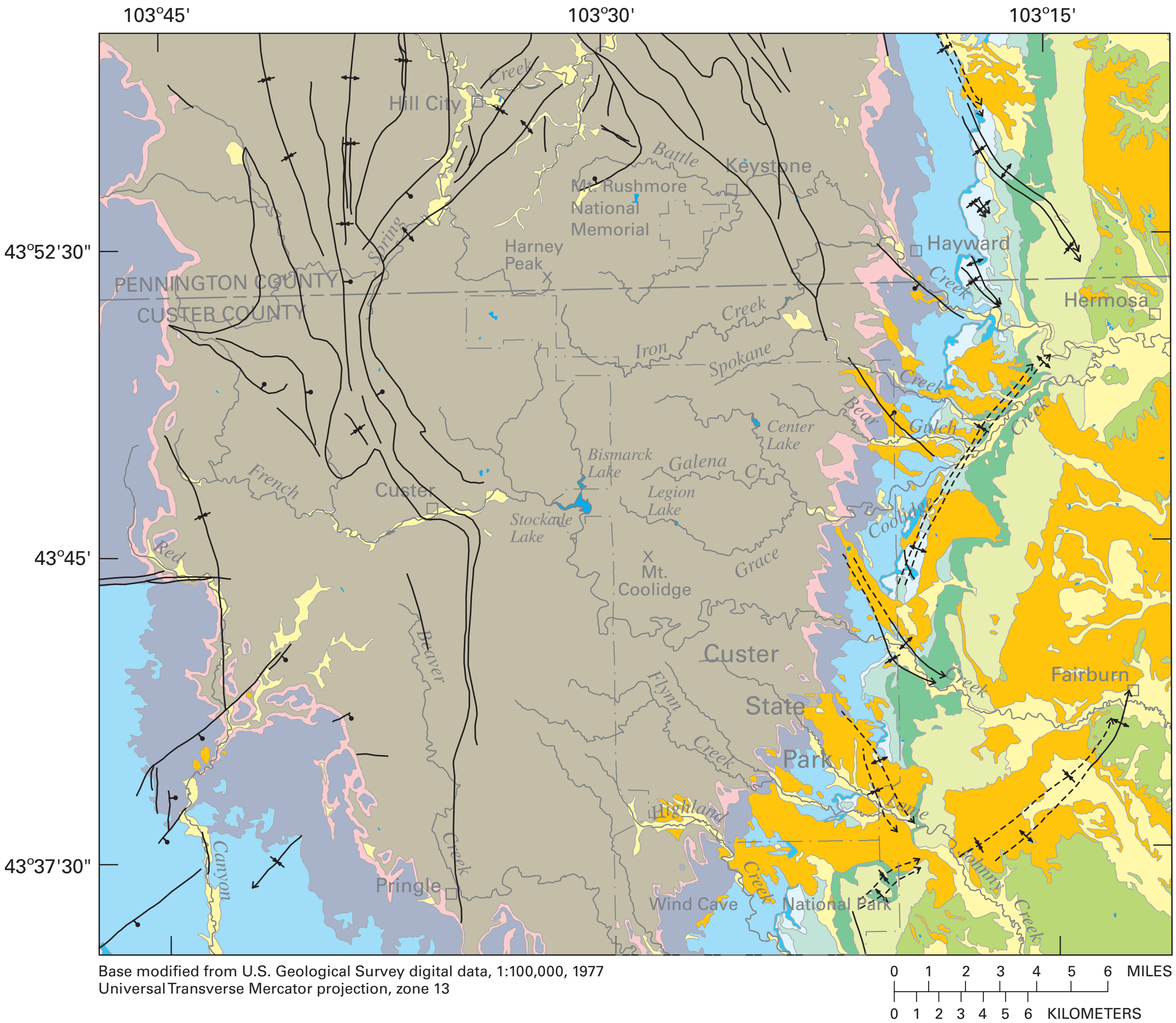
Figure 3. Air temperatures at Custer and Mt. Rushmore climatic stations prior to and during the Galena Fire. Data from South Dakota State University (2003) and National Oceanic and Atmospheric Association (1988).

ERATHEM	SYSTEM	ABBREVIATION FOR STRATIGRAPHIC INTERVAL	GEOLOGIC UNIT	THICKNESS IN FEET	DESCRIPTION
CENOZOIC	QUATERNARY & TERTIARY (?)	QTac	UNDIFFERENTIATED ALLUVIUM AND COLLUVIUM	0-50	Sand, gravel, boulder, and clay.
		Tw	WHITE RIVER GROUP	0-300	Light colored clays with sandstone channel fillings and local limestone lenses.
	TERTIARY	Tui	INTRUSIVE IGNEOUS ROCKS	--	Includes rhyolite, latite, trachyte, and phonolite.
MESOZOIC	CRETACEOUS	Kps	PIERRE SHALE	1,200-2,700	Principal horizon of limestone lenses forming teepee buttes. Dark-gray shale containing scattered concretions. Widely scattered limestone masses, forming small teepee buttes. Black fissile shale with concretions.
			NIOBRARA FORMATION	[1]80-300	Impure chalk and calcareous shale.
			CARLILE SHALE — Turner Sandy Member; Wall Creek Member	[1]350-750	Light-gray shale with numerous large concretions and sandy layers. Dark-gray shale
			GREENHORN FORMATION	225-380	Impure slabby limestone. Weathers buff. Dark-gray calcareous shale, with thin Orman Lake limestone at base.
			GRANEROS GROUP — BELLE FOURCHE SHALE	150-850	Gray shale with scattered limestone concretions. Clay spur bentonite at base.
			GRANEROS GROUP — MOWRY SHALE	125-230	Light-gray siliceous shale. Fish scales and thin layers of bentonite.
			GRANEROS GROUP — MUDDY SANDSTONE; NEWCASTLE SANDSTONE	0-150	Brown to light-yellow and white sandstone.
			GRANEROS GROUP — SKULL CREEK SHALE	150-270	Dark-gray to black siliceous shale.
		Kik	INYAN KARA GROUP — FALL RIVER FORMATION	10-200	Massive to thin-bedded, brown to reddish-brown sandstone.
			INYAN KARA GROUP — LAKOTA FM — Fuson Shale Minnewaste Limestone Chilson Member	10-190 0-25 25-485	Yellow, brown, and reddish brown massive to thinly bedded sandstone, pebble conglomerate, siltstone, and claystone. Local fine-grained limestone and coal.
	JURASSIC	Ju	MORRISON FORMATION	0-220	Green to maroon shale. Thin sandstone.
			UNKPAPA SS	0-225	Massive fine-grained sandstone.
			SUNDANCE FORMATION — Redwater Member Lak Member Hulett Member Stockade Beaver Mem. Canyon Spr Member	250-450	Greenish-gray shale, thin limestone lenses. Glauconitic sandstone; red sandstone near middle.
			GYPSUM SPRING FORMATION	0-45	Red siltstone, gypsum, and limestone.
	TRIASSIC	TRPs	SPEARFISH FORMATION — Goose Egg Equivalent	375-800	Red silty shale, soft red sandstone and siltstone with gypsum and thin limestone layers. Gypsum locally near the base.
PALEOZOIC	PERMIAN	Pmk	MINNEKAHTA LIMESTONE	[1]25-65	Thin to medium-bedded, fine-grained, purplish gray laminated limestone.
		Po	OPECHE SHALE	[1]25-150	Red shale and sandstone.
	PERMIAN / PENNSYLVANIAN	PIPm	MINNELUSA FORMATION	[1]375-1,175	Yellow to red cross-bedded sandstone, limestone, and anhydrite locally at top. Interbedded sandstone, limestone, dolomite, shale, and anhydrite. Red shale with interbedded limestone and sandstone at base.
	MISSISSIPPIAN	MDme	MADISON (PAHASAPA) LIMESTONE	[1]<200-1,000	Massive light-colored limestone. Dolomite in part. Cavernous in upper part.
	DEVONIAN		ENGLEWOOD FORMATION	30-60	Pink to buff limestone. Shale locally at base.
	ORDOVICIAN	Ou	WHITEWOOD (RED RIVER) FORMATION	[1]0-235	Buff dolomite and limestone.
			WINNIPEG FORMATION	[1]0-150	Green shale with siltstone.
	ORDOVICIAN / CAMBRIAN	O€d	DEADWOOD FORMATION	[1]0-500	Massive to thin-bedded buff to purple sandstone. Greenish glauconitic shale, flaggy dolomite, and flat-pebble limestone conglomerate. Sandstone, with conglomerate locally at the base.
PRECAMBRIAN		p€u	UNDIFFERENTIATED IGNEOUS AND METAMORPHIC ROCKS		Schist, slate, quartzite, and arkosic grit. Intruded by diorite, metamorphosed to amphibolite, and by granite and pegmatite.

[1]Modified based on drill-hole data

Modified from information furnished by the Department of Geology and Geological Engineering South Dakota School of Mines and Technology (written commun., January 1994)

Figure 4. Stratigraphic section for the Black Hills area.



EXPLANATION

GEOLOGIC UNITS

- QTac — Alluvium and colluvium, undifferentiated
- Tw — White River Group
- Kps — Pierre Shale to Skull Creek Shale, undifferentiated
- Kik — Inyan Kara Group
- Ju — Morrison Formation to Sundance Formation, undifferentiated
- TRPs — Spearfish Formation
- Pmk — Minnekahta Limestone
- Po — Opeche Shale
- PIPm — Minnelusa Formation
- MDme — Madison (Pahasapa) Limestone and Englewood Formation
- O€d — Deadwood Formation
- p€u — Undifferentiated igneous and metamorphic rocks

FAULT—Bar and ball on downthrown side

ANTICLINE—Showing trace of axial plane and direction of plunge. Dashed where approximated

SYNCLINE—Showing trace of axial plane and direction of plunge. Dashed where approximated

MONOCLINE—Showing trace of axial plane. Dashed where approximated

Figure 5. Geology of the study area (modified from Strobel and others, 1999).

The study area is underlain primarily by Precambrian igneous and metamorphic rocks that consist mostly of the Harney Peak granite and quartzite, with lesser amounts of granitic pegmatite and schist (DeWitt and others, 1989; Strobel and others, 1999). The Deadwood, Madison, and Minnelusa Formations underlie a much smaller portion of the burned area than the Precambrian rocks.

Although geology within the study area is complex (fig. 5), streamflow records for analyses of annual-yield characteristics for this study are considered only for drainage areas upstream from outcrops of the Madison Limestone. These drainages are dominated by outcrops of Precambrian igneous and metamorphic rocks and are within the “crystalline core” hydrogeologic setting identified by Driscoll and Carter (2001). Streamflow characteristics for this setting are typified by relatively small base flow and strong correlations between annual streamflow and precipitation.

Most streams, including Grace Coolidge Creek, generally lose all or part of their flow as they cross the outcrop of the Madison Limestone (Rahn and Gries, 1973; Hortness and Driscoll, 1998). Large streamflow losses also occur in many locations within the outcrop of the Minnelusa Formation, and limited losses probably also occur within the outcrop of the Minnekahta Limestone (Hortness and Driscoll, 1998).

The Precambrian basement rocks generally have low permeability and form the lower confining unit for the series of aquifers in sedimentary rocks in the Black Hills area. Driscoll and others (2002) assumed negligible regional ground-water outflow for Precambrian rocks; however, localized aquifers within Precambrian rocks occur in many locations in the crystalline core of the Black Hills, where enhanced secondary permeability results from weathering and fracturing. Ground-water discharge from Precambrian rocks provides base flow for streams in the study area, especially at higher altitudes where moisture surpluses result from increased precipitation and reduced evapotranspiration. Base flow can diminish very quickly during particularly dry periods.

Within the Paleozoic rock interval, aquifers in the Deadwood Formation, Madison Limestone, Minnelusa Formation, and the Permian-age Minnekahta Limestone are used extensively and are considered to be major aquifers in the Black Hills area. These aquifers receive recharge from infiltration of precipitation on outcrops, and the Madison and Minnelusa aquifers also receive significant recharge from streamflow losses. These aquifers are collectively confined by the underlying Precambrian rocks and the overlying Spearfish Formation, where present (fig. 5). Individually, these aquifers are separated by minor confining units or by relatively impermeable layers within the individual units. In general, ground-water flow in these aquifers is radially outward from the crystalline core of the Black Hills.

Land Use

Although a wide variety of land ownership exists within the study area (fig. 6), hydrologic differences resulting from differing land uses within the drainages considered probably are relatively minor. Most of the burn area is within Custer State Park (fig. 1). Drainage basins used for comparisons consist of various combinations of land ownership; however, the U.S. Forest Service (USFS) is the majority landholder in all of the comparison basins. Private landholdings, which are excluded from the Black Hills National Forest, are common within parts of the comparison basins. The Battle Creek drainage includes Mt. Rushmore National Memorial, which is administered by the National Park Service.

Land use and vegetation patterns generally are similar throughout the study area, regardless of land ownership. The predominant tree species throughout the study area is ponderosa pine. Historically, ponderosa pine has been the primary species utilized by a timber industry that has existed since the earliest European settlement of the area, which began soon after the Custer Expedition of 1874 when gold was discovered in French Creek. White spruce, which are locally known as Black Hills spruce, occasionally are intermixed with ponderosa pine stands, most commonly in locations that are particularly damp or well shaded. Various deciduous species exist throughout the study area, most commonly in bottom areas. Bur oak and ironwood typically are found at lower altitudes and give way to aspen and paper birch at higher altitudes (Ron Walker, Custer State Park, oral commun., 1989).

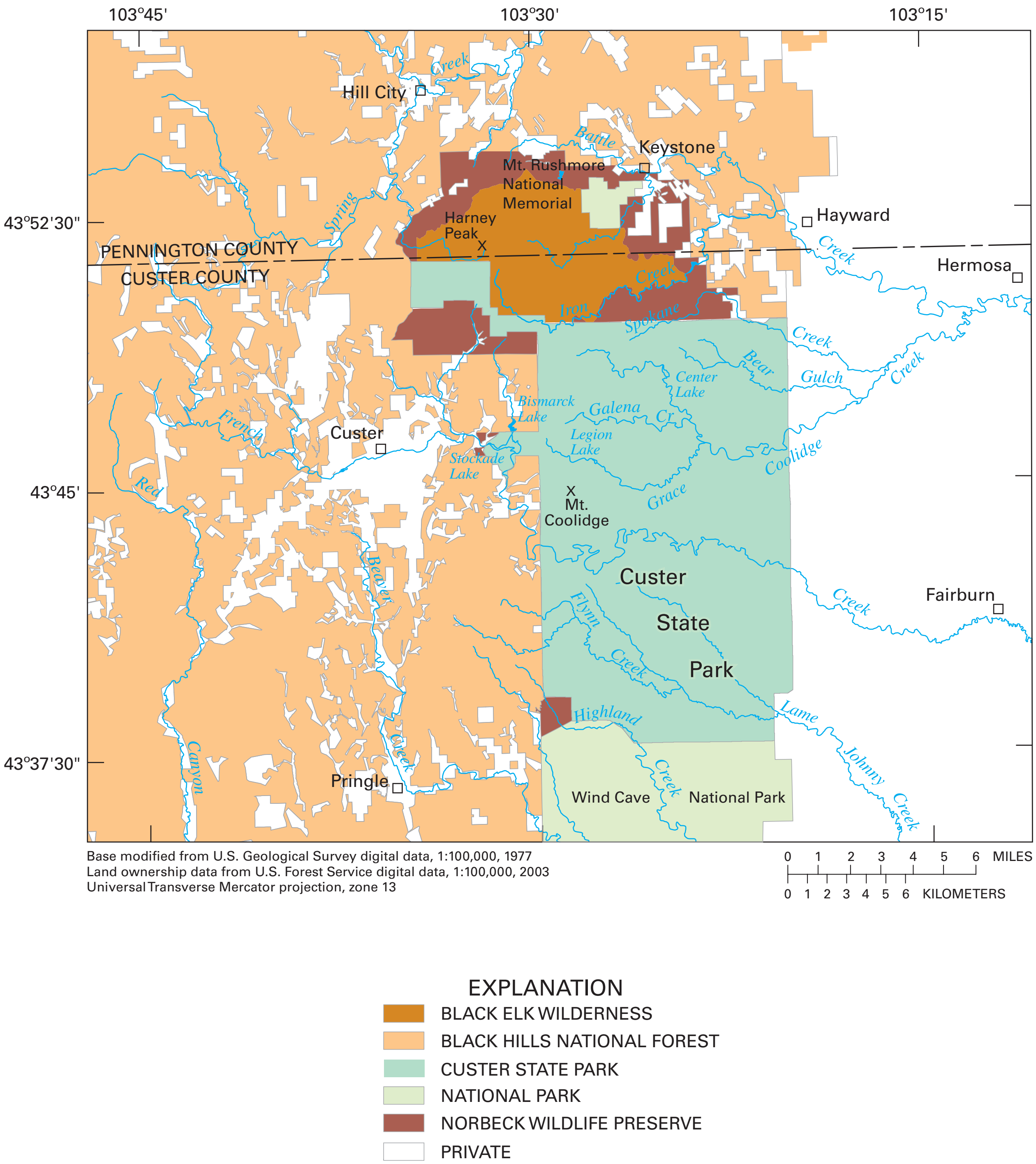


Figure 6. Land ownership in study area.

Land use within the study area historically has been dominated by timber harvesting and cattle grazing. One or both of these land uses have occurred to at least some extent throughout most of the study area since shortly after the Custer Expedition, in support of the mining industry. Grazing typically has been concentrated in the more heavily grassed bottom areas, many of which are in private ownership. Grassed understories within timber stands frequently are utilized during summer months, and private grazing permits are issued for many allotments within the Black Hills National Forest. An important focus of land management within Custer State Park is production of grasses for grazing by buffalo and a variety of big game.

Numerous other land uses have existed within the study area. Initial settlement of the area was during the gold rush, so in addition to mining, other support industries such as railroads and agriculture were common. Current mining activity is minimal, but most private lands exist on former mining claims or along relatively open bottom areas where agricultural activities (including grazing) were feasible. At the higher altitudes, cultivated cropland is uncommon and agricultural activities generally are limited to animal husbandry and hay production. Tourism has been a stable industry in the area since soon after the horseless carriage was invented. Outdoor recreation, including bicycling, fishing, hiking, and hunting, have become increasingly popular throughout the Black Hills area. During recent years, suburban growth has been increasing around the small communities in the study area. Although there are no urban areas within Custer State Park, tourist accommodations and facilities for Park staff are similar to many suburban areas throughout the study area.

Timber Management and Burn Characteristics

Most studies that have addressed the effects of timber harvest on water yield have utilized various indices of timber stand condition or density. Numerous records undoubtedly exist for various tracts of USFS land within the study area; however, documenting changes in timber stand conditions for numerous tracts of private land in the study area would not be practical. It is useful, however, to provide a general overview of the history of timber management in the area.

Streamflow records considered for this study could potentially be influenced by timber management dating back many decades. Various photographs taken during the 1874 Custer Expedition have been used to document long-term increases in ponderosa pine density (Progulske, 1974; Grafe and Horsted, 2002), and an example photograph pair is shown in figure 7. Increased density has resulted primarily from implementation of fire suppression since the arrival of European settlers in the area. Many parts of the French Creek drainage upstream from Stockade Lake have particularly large open areas that may result from a combination of fire effects before 1874 and subsequent human maintenance of open areas. In general, fire suppression can substantially reduce both the general percentages of open areas and ratios of mature to immature pines in typical stands. Fire suppression also causes reduced species diversity with increased dominance of ponderosa pine (Brown and Sieg, 1996).

Most studies of hydrologic effects of timber harvest have been conducted in small watersheds under highly controlled conditions. Hydrologic effects of timber management may be difficult to discern in large watersheds because timber stand conditions can be quite dynamic. Reduced timber stand density resulting from harvest or widespread mortality in a large watershed can be offset by ongoing timber growth in other parts of the watershed.

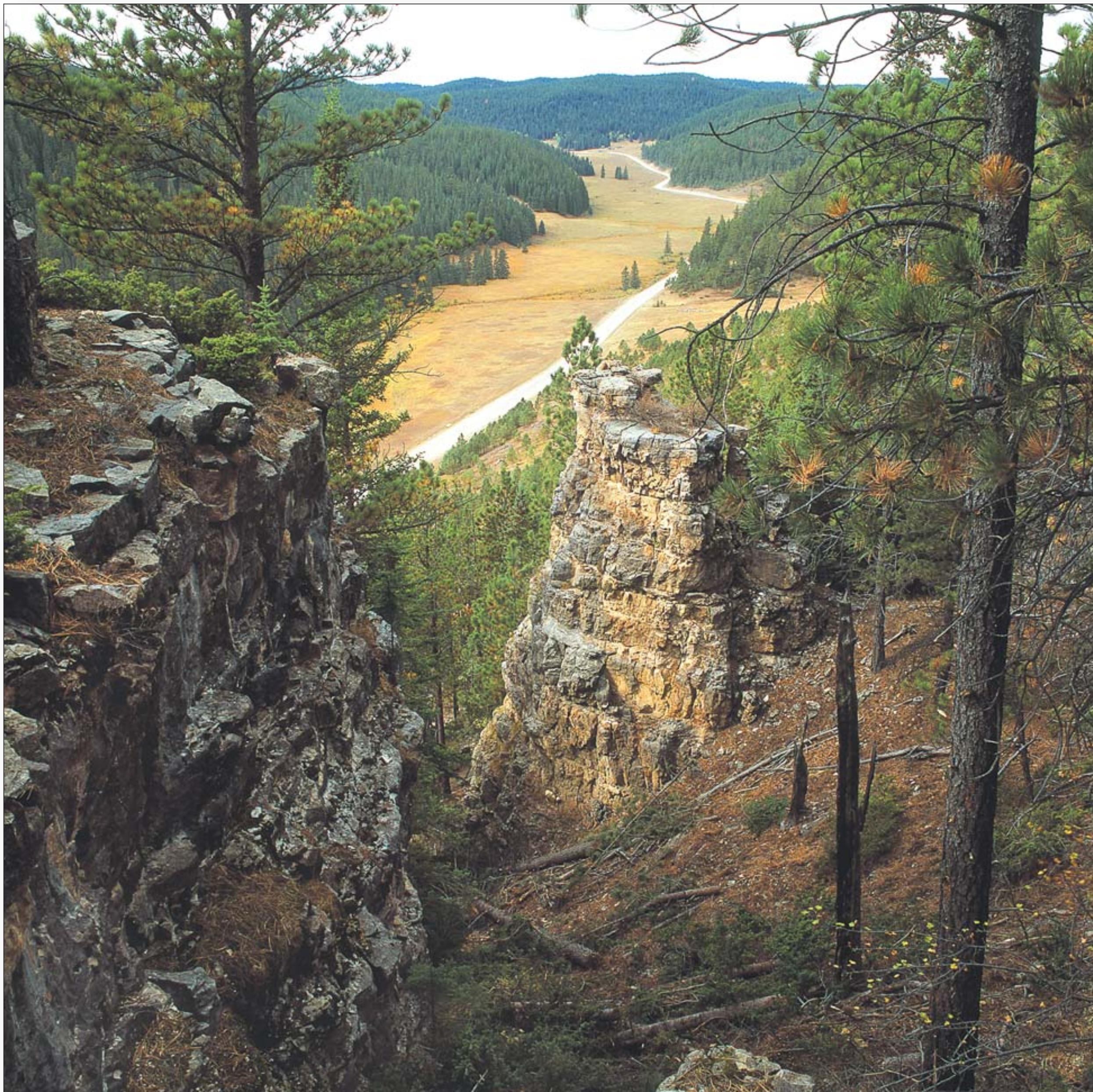
Timber Management

In spite of the wide variety in land ownership, timber management practices throughout the study area historically have been similar. Most parts of the study area with merchantable timber stands have been subject to selective-cut harvest practices during the last century and repeated rotational harvests have occurred in many locations. Logging methods in the study area have been largely independent of land ownership and over time have evolved from hand saws and animal-drawn equipment to complete mechanization, in many cases. Logging practices have evolved from high grading of the most desirable and accessible saw timber to highly controlled timber sales that can include pre-commercial thinning of non-merchantable timber throughout large areas. Large-scale clear cuts have been uncommon in the Black Hills area because of various factors including the particularly prolific germination characteristics of ponderosa pine in the area and propensity towards multi-story stands.

Wagon train passing through Castle Creek Valley, July 26, 1874

Figure 7. Photographs showing increase in pine forest between 1874 and 2000 in the Black Hills. (Photo pair is from the book, Exploring with Custer: The 1874 Black Hills Expedition, by Ernest Grafe and Paul Horsted. Published by Golden Valley Press, Custer, South Dakota. Information at www.custertrail.com. Used with permission.)

July 2000



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